FINAL REPORT

TRAVEL SURVEY RECOMMENDATIONS

RSG
the science of insight

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PREPARED FOR:
HOUSTON-GALVESTON AREA COUNCIL

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List of Abbreviations

AB	activity-based
ABS	address-based sampling
ACS	American Community Survey
APC	automatic passenger counting
ASU	Arizona State University
ATRI	American Transportation Research Institute
BMI	body mass index
CATI	computer-assisted telephone interviewing
CAV	Connected and autonomous vehicles
CBD	central business district
CBG	Census Block Group
CPO	cellphone-only
CVS	commercial vehicle survey
DAP	daily activity pattern
DMV	department of motor vehicles
DTA	dynamic traffic assignment
ETC	electronic toll collection
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HBO	home-based other
HBS	home-based school
HBW	home-based work
HH	household
H2H	home to home
HTS	household travel survey
IPF	iterative proportional fitting
LBS	location-based service
LEHD	Longitudinal Employment Household Dynamics
LPC	license plate capture
LSE	least squares error
MPO	metropolitan planning organization
NHB	non-home-based
NHTS	National Household Travel Survey
OD	origin-destination
ODME	origin-destination matrix estimation
ODOT	Ohio Department of Transportation

PA	productions and attractions
PDX	Portland International Airport
PSRC	Puget Sound Regional Council
PUMA	Public Use Microdata Areas
RDD	random digit dialing
RP	revealed preference
RTA	Regional Transportation Authority
SANDAG	San Diego Association of Governments
SP	stated preference
STOPS	Simplified Trips-on-Project Software
TAZ	transportation analysis zones
TDM	travel demand management
TMC	Texas Medical Center
TMIP	Travel Model Improvement Program
TNC	transportation network company
TOD	time of day
TTI	Texas Transportation Institute
UO	University of Oregon
VDOT	Virginia Department of Transportation
VOT	value of time

EXECUTIVE SUMMARY

The Houston-Galveston Area Council (H-GAC) engaged the RSG team to create a Travel Survey Data Collection Plan for the region to prepare for upcoming model enhancements and data collection needs. Observed data on travel and travel behavior are essential to regional travel forecasting processes. These data help maintain travel models. The data needs and data collection to support travel models is a complex subject, so this project assessed the pros and cons of different approaches, both from a modeling perspective and from a data collection perspective. This Executive Summary summarizes the project's conclusions and recommendations, originally provided as in a series of technical memoranda, and later compiled into a final project report.

H-GAC SURVEY RECOMMENDATIONS

The RSG team developed the following travel survey plan recommendations to support H-GAC's envisioned model updates and improvements.

HOUSEHOLD TRAVEL SURVEYS

H-GAC should commission a household travel survey as soon as is feasible, to provide data to update the TourCast model and to provide background data for regional planning. RSG recommends the following methodology:

- Use **smartphone-based GPS data collection**, for up to 7 days per household, with a 1-day, diary-based survey option for individuals without smartphones.
- Use random, **address-based sampling (ABS)** with **targeted geographic oversampling** for key market segments.

Smartphone-based GPS travel data collection provides the same data items as a more traditional diary-based survey, but the trip-end information (location and stop times) is recorded automatically via the smartphone app. This greatly increases accuracy, reduces response bias, lowers respondent burden, and makes it feasible to collect multiple days of travel data from each household. Most households who complete one day are willing to complete at least five days via the smartphone app.

Address-based sampling (ABS) is becoming more challenging over time from a response rate perspective. However, ABS is still the most effective method that provides a representative sample of the population, and it also allows targeting of rare trip types, hard-to-reach populations, and areas of particular regional or local interest. Addresses can be randomly selected by commercial address providers and divided geographically into different sampling strata. Offering monetary incentives for completing the survey can increase response rates and lower the overall cost of recruitment. Different regions and population groups respond differently to incentives, so it is helpful to test different levels during the survey pilot to gauge response rates.

The household travel survey sample size should be approximately 10,000 households (0.4% of the region's 2,500,000 households). Surveys should occur every four to five years in conjunction with the MPO requirements for long-range plan development. This is more frequent than previous surveys conducted roughly once every ten years, but it will help capture the effects of the growth of alternative mobility options. Further, sample size requirements may decline by combining more frequent surveys with a multi-day smartphone-based GPS data collection approach.

Weighting and expansion should follow a two-stage approach. First, start with an initial expansion based on the sampling strata and the number of households living within each. Second, use iterative proportional fitting to more closely match external targets based on the Census American Community Survey (ACS) data.

Survey cost is often a determining factor in deciding on collection methods, survey frequency, and sample sizes. Household travel survey costs range from $200 to $300 per household depending on collection methods, number of languages offered, and level of incentives provided.

POSSIBLE SUPPLEMENTAL SURVEYS

The following supplemental surveys are often conducted in conjunction with a household survey to provide supplemental data on unique populations or often underreported markets:

- University student survey.
- Toll road user survey.
- Bicycle user survey.
- Ride-hailing/car-sharing user survey.
- Connected and autonomous vehicle attitudes/stated preference survey.

H-GAC should consider conducting these supplemental surveys during the next household travel survey to gain more detail on the travel related to these specific travel markets. With cooperation from the universities, it can be very cost-effective to recruit students via college e-mail systems, and smartphone-based survey methods used for students can be essentially the same as those used for households. The other types of supplemental surveys can require different recruitment methods and survey instruments, so the costs can vary considerably. The most cost-effective approach for such surveys is often to send targeted follow-up questionnaires to those who recently participated in a household travel survey (and have agreed to participate in further surveys).

TRANSIT ON-BOARD SURVEYS

H-GAC conducted an on-board transit survey in 2017., so it is not necessary to conduct another one for another three to seven years. Things that can trigger the need for a new transit on-board survey are major new transit projects and/or pursuit of FTA New Starts/Small Starts funding opportunities. On-board surveys use tablet-based intercept surveys and on-to-off surveys at stations/stops. Typical costs are $1 million or more for approximately 40,000 on-board survey responses.

AIRPORT SURVEYS

Airport trips comprise much regional travel, especially for the H-GAC region with its two large commercial airports. Airport passenger surveys provide insight about ground access travel to/from the airports and visitor travel to the region. For international visitors who arrive via air travel, an airport survey is the only way to get information on their travel behavior within the region. Ideally, airport surveys should be conducted every two to three years to better understand mode choice and factors affecting mode shift over time; although the feasibility and frequency on airport partner interest and cooperation. Costs range from $200,000 to $500,000 depending on the extent of the survey and the methodology employed.

COMMERCIAL VEHICLE SURVEYS

H-GAC is building a new commercial vehicle model based on aggregate passive data and should consider collecting disaggregate data every five to ten years to update it. Similar to the case for household surveys, a smartphone-based GPS data collection approach would deliver more complete and accurate data, and lower respondent burden. Recruitment and retention rates are also much higher, resulting in more drivers providing multiple days of travel with each response. The sample should include 600-800 establishments, varying across industries and geographic distinctions within the region. Oversampling should include industries likely to use service or delivery trucks, given their impact on the transportation system. Use of incentives is important for recruitment. Expansion of the data should derive from total regional establishment population and distinguish between establishments that use their own drivers and those that use delivery services.

USE OF PURCHASED PASSIVE DATA

Historically, household travel surveys include visitor, establishment, external, and special generator surveys to provide additional detail about these segments of regional travel. However, with the increasing availability of large-scale passive data sets for purchase, including cell tower-based data such as AirSage and location-based service (LBS) data such as Cuebiq and Streetlight, these types of surveys are no longer recommended , and purchased passive LBS data is recommended for use instead (with the exception of airport surveys, if those are feasible).

The activity-based (AB) regional model primarily predicts trips made by residents of the H-GAC region, with both the start and end of the trips internal to the region. These are called Internal-Internal (I-I) trips and are the focus of the household travel and transit on-board surveys. Other trips predicted by the H-GAC regional model are Internal-External (I-X), External-Internal (X-I) and External-External (X-X). Table 1 shows the different travel markets and types of trips that are covered by the H-GAC regional model and the recommended source for the data needed to update the models.

As shown in Table 1, disaggregate LBS data are recommended as the primary source for the I-X, X-I, and X-X trip information and for the visitor and commercial based I-I trips. Since LBS data are more precise than cellular data, these can also provide an important supplemental data source for the resident internal trip market and will assist with calibration/estimation of destination choice and special generator models. H-GAC should use passive data for the following elements of model development:

- Resident Travel Patterns (both origin-destination and time of day).
- Visitor Travel Patterns.
- External Travel Patterns.
- Trucking Patterns.
- Attraction Rate Estimation.

TABLE 1: DATA SOURCES RECOMMENDED FOR VARIOUS MARKETS AND TRIP TYPES

MARKET	INTERNAL – INTERNAL (I-I)	INTERNAL – EXTERNAL (I-X)	EXTERNAL – INTERNAL (X-I)	EXTERNAL – EXTERNAL (X-X)
Residents	• Household travel survey (HTS) • Transit on-board survey; Airport survey (APS); • Disaggregate LBS data	• Disaggregate LBS data • HTS*	• Disaggregate LBS data • HTS*	N/A
Visitors/ nonresidents	• Disaggregate LBS data • Airport survey (APS)	• Disaggregate LBS data • APS *	• Disaggregate LBS data • APS *	• Disaggregate LBS data
Commercial Vehicles	• Disaggregate LBS data • Commercial vehicle survey (CVS)	• Disaggregate LBS data • CVS *	• Disaggregate LBS data • CVS *	• Disaggregate LBS data

* Main purpose is to capture internal (I-I) trips, but also captures some I-X and X-I trips.

RECOMMENDATION RECAP

HOUSEHOLD TRAVEL SURVEY

- Use address-based sampling with geographic oversampling and incentives.
- Use smartphone-based GPS data collection for up to 7 days.
- Allow travel diary-based options as needed for non-smartphone users.
- Survey approximately 10,000 households.
- Survey university students via e-mail with university cooperation.

OTHER SURVEYS

Carry out….

- Airport passenger ground access survey, if feasible.
- Transit on-board intercept survey (after 3+ years).
- Disaggregate, smartphone-based commercial vehicle survey.
- Supplemental surveys of specific travel markets (i.e., toll users, bicycle users, TNC/carshare users).
- Attitude and preference surveys regarding autonomous vehicles, to set a benchmark for future changes in acceptance, preferences, and adoption.

PASSIVE DATA

- Purchase disaggregate location-based service (LBS) data for all relevant internal, external, and through trips. A well-designed purchase request (in terms of geographic coverage and duration), along with careful expansion and processing of the passive data, can provide comprehensive and accurate data for much less cost than carrying out new establishment surveys, external surveys, visitor surveys, and special generator surveys. .

CHAPTER 1. INTRODUCTION

The Houston-Galveston Area Council (H-GAC) engaged the RSG team to create a Travel Survey Data Collection Plan for the region to prepare for upcoming model enhancements and data collection needs. This report provides Travel Survey Recommendations for the Houston-Galveston Area Council (H-GAC) based on findings and conclusions originally provided in a series of technical memoranda for the various project tasks.

Chapter 2 recommends a data collection plan (if applicable) for each travel survey investigated through this scope of work:

- Household travel surveys.
- University surveys.
- Transit user OD surveys.
- Visitor surveys.
- Airport surveys.
- Other special generator surveys.
- Commercial vehicle travel surveys.
- Establishment surveys.
- External surveys.

For each of the surveys recommended, this report suggests data collection methods, sampling and expansion/weighting, and sample size and data collection frequency and includes associated cost estimates/ranges. For each of the surveys not recommended, this report provides the rationale behind the recommendations and, where applicable, alternative passive data that can be purchased from third-party sources.

Chapter 3 provides recommendations for use of purchased passive data. Given the increasing applicability and quality of third-party, passive data sources, this chapter includes recommendations for purchasing and applying third-party data in addition to the surveys listed in Chapter 2.

Chapter 4 summarizes the recommendations from the preceding chapters.

This report also includes four appendices:

- Appendix A is the memo produced for Tasks 2 and 3. This memo identifies the H-GAC regional model update needs and travel data/survey needs.
- Appendix B is the memo produced for Task 4, and reviews travel survey method practices.
- Appendix C reports on a comparison of attraction rates derived from purchased AirSage passive data versus establishment survey data.
- Appendix D contains comments made by TXDOT and TTI staff on the final survey recommendations, as well as the RSG team's responses to the comments.

CHAPTER 2. TRAVEL SURVEY RECOMMENDATIONS

2.1 | HOUSEHOLD TRAVEL SURVEYS

METHODOLOGY

Household travel survey data are used to update the H-GAC regional travel forecasting model—with the activity-based (AB) travel demand model being the main model system component to be updated. As described in the memo produced for Tasks 2 and 3 (Appendix A), survey data are important for accurate model estimation or calibration. Table 2 summarizes the most important desired data characteristics and recommendations for achieving them.

Deploy Smartphone-based GPS Data Collection to the Greatest Extent Possible

Approximately 77% of US adults own smartphones, and that percentage is growing. Most adults will readily download a smartphone app to record their travel instead of using more traditional travel diary-based methods. Adults who do not own a smartphone can still participate via the diary-based methods, either via the internet or via a computer-assisted telephone interviewing (CATI). (Recent RSG experience is that approximately 75% of travel diary respondents respond online.) Compared to more traditional diary-based methods, smartphone-based GPS data collection has many important advantages, all of which are mentioned in Table 2.

More accurate recording of trip end locations and times: Smartphone-based GPS travel surveys record all times and locations. These data are usually more accurate than what respondents self-report. (This is particularly true for times of day and travel times, which respondents tend to round to the nearest 5, 10, or 15 minutes.) For locations, software for diary-based methods, used together with smartphone-based methods, has improved via the familiar Google Maps interface, and most smartphone-based GPS travel survey apps use this same interface for respondents to help respondents to identify their trips and provide additional information. Respondents can also use the map interface to split trips, merge trips, and insert omitted trips where necessary. Smartphone-based GPS travel survey data also includes time and location traces en route *during* each trip. This allows additional analysis of route choices, imputation of mode changes, imputation of transit boarding locations, walk access times and wait times, and imputation of downtown parking locations and walk egress times.

More complete capture of all trips: Our analysis to date indicates that smartphone-based GPS travel survey data collection captures 15% to 20% more trips per person-day compared to diary-based methods. Some short trips and stops may be omitted by travel diary respondents—either because they forgot making them or did not consider them important, but such trips are captured by smartphone. Compared to diary-based data, smartphone-based data contain only half as many person-days for which the person did not report making any trips at all. Thus, in the diary-based data, it is likely that some such cases are "soft refusals," where some respondents avoid the burden of reporting their trips by simply reporting that they did not travel.

Smartphone-based GPS travel survey data collection also has a lower trip reporting burden since the smartphone automatically records locations and times. Smartphone-based GPS travel surveys' data can also be used in post-survey analysis to adjust trip rates for the minority of the sample who use the more traditional diary-based methods.

TABLE 2: KEY HOUSEHOLD TRAVEL SURVEY CHARACTERISTICS AND ASSOCIATED RECOMMENDATIONS

DESIRED DATA CHARACTERISTIC	ASSOCIATED RECOMMENDATION(S)
Accurate data on trip end locations and times of day	• Smartphone-based GPS data collection • Use of Google Maps interface in software
Complete travel data—few missing trips	• Smartphone-based GPS data collection • Additional prompting for missed trips
Complete and consistent data on household members' co-travel	• Intelligent software for asking about other household members and copying trips across co-travelers
Adequate overall sample size	• Sample size of at least 10,000 households • Collection of multiple travel days per household • Use of incentives
A representative sample with no major unknown nonresponse biases	• Random ABS • Use of incentives
Adequate coverage of small and hard-to-reach population segments (e.g., low-income, zero-vehicle, non-English-speaking households)	• Targeted geographic oversampling, using ACS block group data to identify areas with high concentrations • Targeted outreach
Adequate coverage of rarer but important types of behavior (e.g., bike trips, transit trips, TNC] trips)	• Targeted geographic oversampling using ACS block group data on commute mode choice, or other external information (e.g., from transit on-board surveys)
Adequate coverage of policy interest areas like smart growth areas or other growth centers	• Targeted geographic oversampling using local expertise or planning maps

Multiple travel days per household: Reduced respondent burden means respondents are willing to provide up to five or seven complete days of travel data. In recent RSG projects, households who have provided at least one complete travel day for all members provide an average of over four complete days, with over 50% completing seven days. These additional days of data raise the effective sample size at minimal cost.

Variability in day-to-day observed behavior: One question that RSG is often asked is: What is the relative value of collecting multiple survey days from the same households compared to getting more households to each do a 1-day survey. This can be analyzed by determining what percentage of trips collected on each day are unique compared to the same person's trips on previous days—in other words, how much new information is provided on each subsequent survey day?

Analyzing the smartphone-based GPS data collected for trips for up to 7 days from about 4,000 households in the recent San Diego Association of Governments (SANDAG) travel survey, a trip was designated as "unique" if the respondent made no other trip on previous survey days between the same two Census blocks by the same mode at roughly the same time of day (TOD) (within a 2-hour gap). Figure 1 shows that about 60% of HBW and HBS trips are unique on day 2, but by the 5th weekday (Mon), only about 30% of the HBW and HBS trips are still unique—meaning that an (almost) identical trip has not already been observed on previous days. For other trip purposes (home-based other=HBO, non-home-based work=NHBW and non-home-based other=NHBO), and for total trips, between 70% and 90% of trips are still unique by the 5th weekday. (The percentage of unique trips is even higher on weekends, but most agencies do not use weekend days for modeling, so those are analyzed after the 5 weekdays and accordingly located at the right side of Figure 1.)

Figure 2 is based on the same information as Figure 1, but is presented in terms of how many "unique" trips there are as a multiple of day 1 trips. For HBW and HBS, 5 weekdays of data provide about 2.5 times as many unique trips as 1 day. For the other purposes, 5 weekdays of data provide more than 4 times as many unique trips as 1 day. This evidence strongly supports the value of collecting multiple days of smartphone data, particularly given each additional day of data costs only a fraction of the cost that would be required to recruit another household into the survey.

Of course, the household and person characteristics within a household do not change during a week, so analyzing more unique trips from the same set of households does not provide exactly as much statistical information as it would if those trips were made from a larger sample of households. Given that the total sample size and distribution is adequate, however, there will already be a wide spectrum of household and person types making each type of trip, so adding more households to the sample would not considerably increase the variety of choice behavior observed.

FIGURE 1: PERCENTAGE OF UNIQUE TRIPS RELATIVE TO PREVIOUS DAYS COLLECTED IN SANDAG SMARTPHONE-BASED GPS TRAVEL SURVEY DATA

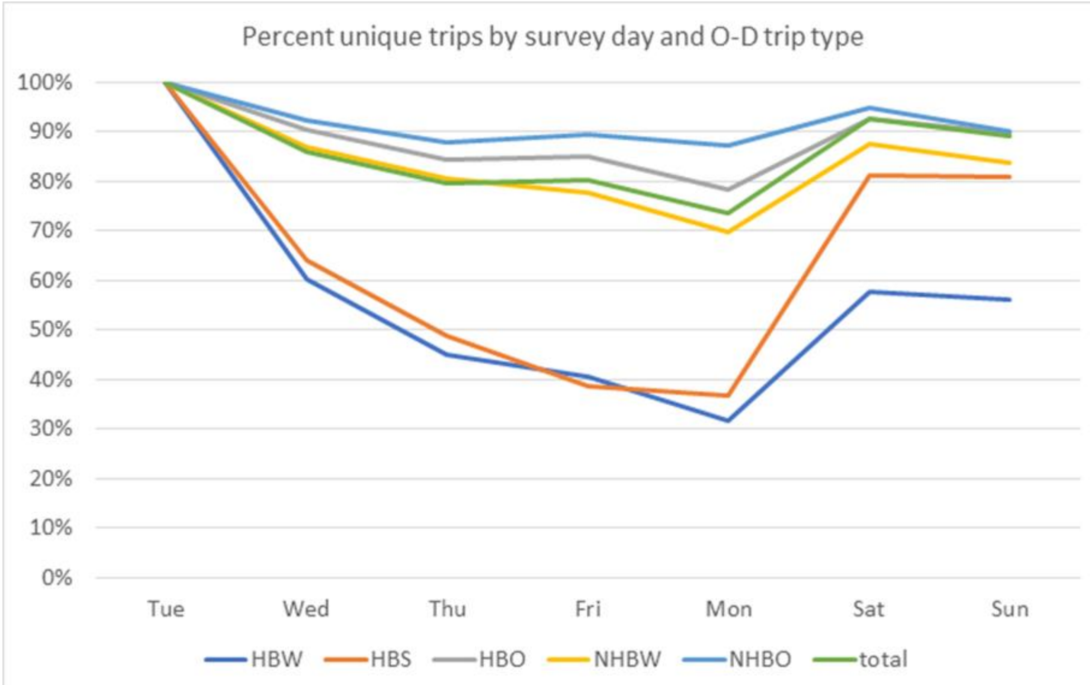
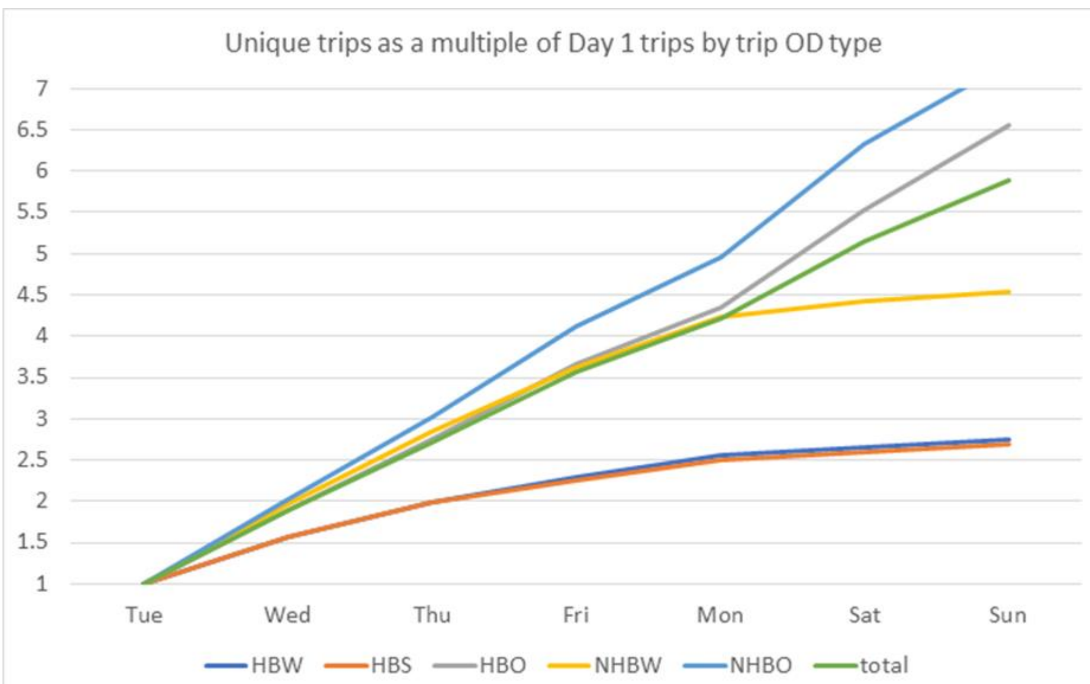


FIGURE 2: CUMULATIVE NUMBER OF UNIQUE TRIPS AS A MULTIPLE OF DAY 1 TRIPS, BASED ON SANDAG SMARTPHONE-BASED GPS TRAVEL SURVEY DATA



Options for reducing respondent burden: Respondents often find smartphone-based GPS travel surveys to be less burdensome, as evidenced by the following:

- Respondents are willing to provide multiple days of data.
- Respondents provide most trip details (e.g., mode, purpose, co-travelers) within two hours of completing the trip.
- Respondents have few missed trips or gaps in time with no location data, indicating that most people keep their smartphones charged and with them.

Smartphone-based GPS travel survey apps can also be programmed to identify and learn each respondent's travel habits to further reduce survey burden. This can include an app that prepopulates trip details based on past similar trips, which saves respondents time. Apps can also allow respondents to copy trips from one person to a co-traveler, as when a parent is traveling with a child and completing their survey for them (proxy trips). Proxy trip bias is also reduced because each adult's travel is recorded by his or her own smartphone.

Finally, RSG is currently testing and piloting a methodology in which the initial recruitment survey is also done in the smartphone app rather than in a separate online or CATI recruit survey. This "all -in-one-app" approach allows the travel period to start immediately upon recruitment and makes the entire process more seamless for respondents. Initial evidence is that this increases overall completion rates—particularly the percentage of initial recruits who go on to provide complete travel data.

TABLE 3: SUMMARY OF RECENT HOUSEHOLD TRAVEL SURVEY CHARACTERISTICS

REGION (CLIENT)	YEAR	HH IN REGION	HH IN SAMPLE	% OF HH IN SAMPLE	MAIN METHOD	CONTRACTOR	FREQUENCY/STRATEGY	SAMPLING/OVERSAMPLING/ ADDITIONAL SURVEYS
Minneapolis (Met Council)	Upcoming 2018	1,500,000	7,500	0.50%	Smartphone-based GPS	RSG	Every two years, 2,000-3,500 HH, smartphone-based	ABS; Geographic targeted.
Chicago (CMAP)	Upcoming 2018	3,000,000	12,000	0.40%	Smartphone-based GPS	Westat	TBD	ABS; Geographic targeted
Washington, DC (MWCOG)	2017/18	2,500,000	15,000	0.60%	Diary-based	RSG	TBD	ABS; Quota-based
San Diego (SANDAG)	2106/17	1,100,000	6,000	0.55%	Smartphone-based GPS	RSG	Combining with other major CA MPOs for cycling approach across four MPOs	ABS; Geographic targeted; military base oversample; bicycle intercept recruit
Columbus (ODOT)	2016/17	500,000	3,000	0.60%	Smartphone-based GPS	RSG	Combining with other Ohio regions for 10-year cycling approach	ABS; Geographic targeted
Phoenix (MAG)	2016/17	1,500,000	7,000	0.47%	Smartphone-based GPS	WestGroup, MMM	TBD	ABS; Geographic targeted
Research Triangle (ITRE)	2016	650,000	4,200	0.65%	Diary-based; smartphone pilot	RSG	Every two years, 1,000-2,000 HH; phasing in smartphone-based	ABS; Geographic targeted
Seattle (PSRC)	2014-15; 2017	1,500,000	6,300	0.42%	Diary-based; smartphone pilot	RSG	Every two years, 1,500-3,000 HH; phasing in smartphone-based GPS	ABS; Geographic targeted; designated growth areas, university survey

Summary on Data Collection Methodology

Smartphone-based GPS travel survey data collection is quickly becoming the standard method for household travel surveys. Table 3 provides a summary of recent surveys done by RSG and others (including one currently out for bid), and almost all of the examples from the last two years are smartphone-based GPS travel surveys. The competing smartphone apps for collecting travel data are maturing rapidly, adding new features and including further prompting and data processing to maximize data quality and completeness. With the maturing of the methods, the costs are also becoming comparable to those of diary-based collection. In fact, with the ability to collect multiple travel days, smartphone-based GPS data collection is already less expensive than diary-based collection on a per-travel day basis.

In most smartphone-based GPS travel surveys, adults who do not own smartphones provide their travel via diary-based methods (online or by CATI). In the Ohio Department of Transportation (ODOT) example, smartphones were loaned to most of the adults who did not own a smartphone but were willing to participate. A similar "loaner phone" approach is not recommended for H-GAC given its cost and respondent behavior. Loaner phones must be purchased, shipped, and retrieved, which increases costs and limits number of households that can be surveys within available budget. Loaner phone respondents also experience more missed trips and record more spurious "stay at home" days since respondents either are not accustomed to carrying a smartphone or have another, simpler phone they use. (These are the same drawbacks encountered in previous surveys that used GPS "black box" devices before the smartphone option was available.)

SAMPLING, EXPANSION, AND WEIGHTING

As described in the Task 4 memo (Appendix B), random ABS has been used for most major regional household travel surveys in the United States over the last 5 years or more, including all of the surveys listed in Table 3. Although response rates continue to decline for all types of surveys, ABS remains the most cost-effective way to potentially reach the entire household population while providing a sample that can be expanded and weighted in a statistically sound manner to obtain a representative and unbiased sample.

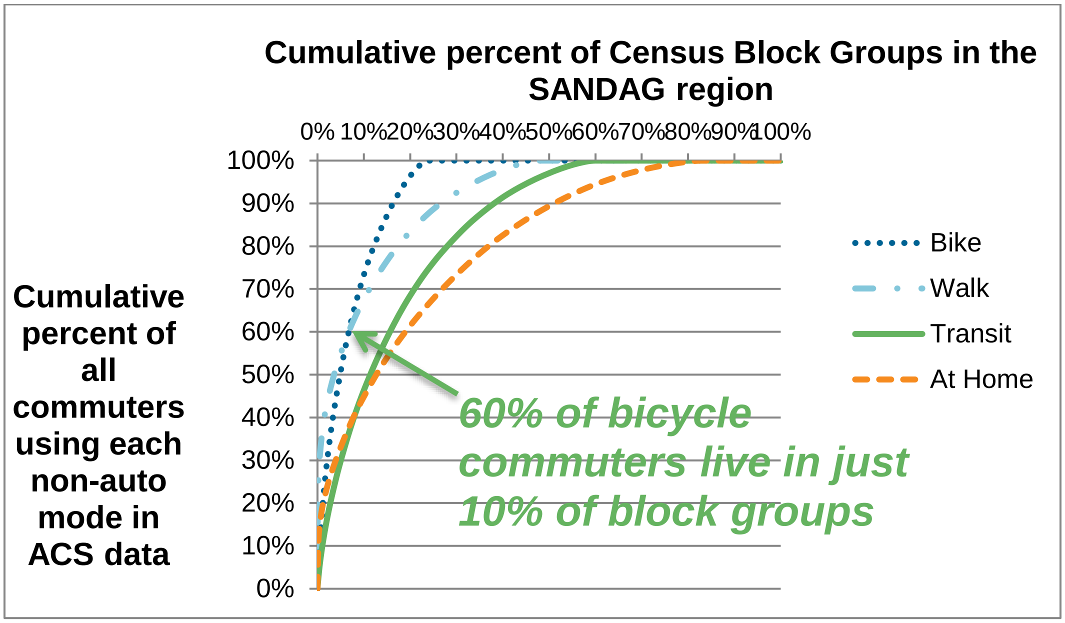
When a sample is described as "representative," that does not mean that it needs to have the same sociodemographic distributions as the population at large. It only means that any selectivity in sampling rates and response rates is known and can be adjusted for in expansion and weighting, so that the *weighted* sample will match the population across all important sociodemographic and geographic characteristics.

Targeted Oversampling

Some types of households—such as very low-income households, zero-vehicle households, and non-English-speaking households—comprise small fractions of the population but tend to be different in terms of travel behavior and are important to include for equity reasons. These households also tend to be hard to reach and exhibit lower response rates. These are all reasons to oversample such households—inviting a larger percent of such households in the region to participate in the survey to compensate for the lower response rates and provide a larger sample for analysis and modeling. Because one does not know exactly where each of these households lives in advance, the most effective method for oversampling is to use block group level published estimates from the most recent 5-year ACS data. By sending invitations to a higher percentage of addresses in the block groups with the highest concentrations of the targeted household types, more of them will be obtained in the sample. Nearly all the surveys listed in Table 3 used geographically targeted oversampling to some extent. If H-GAC wishes to both compensate for lower response rates and obtain a higher-than-proportional sample of these households for modeling and analysis, then it is important that the invitation rates for the selected block groups be at least two or three times as high as for the "regular" block groups that are not oversampled.

Another type of targeted oversampling that is typically recommended is to increase the number of observations for the rarer types of trips. This includes transit users and bicycle users, which are potentially important alternatives to auto travel that currently have quite small mode shares in most US regions. The ACS block group data on commute mode can be useful for identifying areas where bicycle commuters and other non-auto commuters live. As an example, Figure 3 shows that, according to ACS data, 60% of the bicycle commuters in the SANDAG region live in just 10% of the block groups. Walk commuting is also highly concentrated in denser downtown areas, while transit commuting and working from home is somewhat less spatially concentrated. Transit operators may also be useful in advising on which neighborhoods have the highest propensity to use transit—particularly for non-commuting, for which no ACS data are available.

FIGURE 3: EXAMPLE: SPATIAL CONCENTRATION OF ACS NON-AUTO COMMUTERS IN SAN DIEGO



As an alternative to using ACS block group data to identify households for oversampling, it is now possible to purchase data for individual household addresses with estimates of variables such as income, household size, and auto ownership based on each household's expenditures patterns via credit cards, supermarket cards, and gas cards, among other methods. RSG is assessing the accuracy of such data and their potential use for targeted oversampling, so this may also be an option for future surveys.

Another form of targeted oversampling is based completely on geography to capture larger samples for certain neighborhoods or municipalities. For example, both of these types of oversampling have been used in the recent Puget Sound Regional Council (PSRC) surveys in Seattle. Their "Regional Growth Centers" (areas designated for mixed-used, transit-oriented development) have all been included in the oversampled areas. In addition, the cities of Seattle, Bellevue, and Redmond have contributed extra funding to increase the sample size in specific parts of their cities. The latter type of oversampling provides an opportunity to increase total sample size by including city (or county) funding partners.

Incentives

As mentioned, response rates are declining for all types of surveys, including household travel surveys. One of the only effective means for boosting response rates is to offer incentives for completion. To give some indication of the effect, in states such as Florida where incentives are not allowed, response rates for travel surveys using ABS range from 1% to 2%, while in other regions where incentives have been offered, response rates range from 4% to 6%. It is typical to pay an incentive only once a household has provided complete data. It is convenient to offer incentives in the form of gift cards and offering a choice from among different gift cards (e.g., Starbucks, Amazon, Walmart) is less likely to bias the sample toward certain types of consumers. For a smartphone-based GPS travel survey, RSG typically offers an incentive in the range of $10 to $20 per adult in the household. (Setting an amount per person rather than per household helps to obtain more large households in the sample and compensates for the additional burden that larger households face to complete the survey.)

Spending more on incentives can reduce the overall recruiting cost through increased response rates, but it is useful to have some local, recent evidence on which to base such a decision. The pilot phase of a survey is typically used to establish response rates in representative parts of the region, and it can be useful to use a split-sample approach to test two or three different incentive levels during the pilot stage.

Expansion and Weighting

The Task 4 memo (Appendix B) provided detail on expansion and weighting approaches. For most recent surveys, RSG has been using the following approach:

- Perform the initial expansion based solely on the different sampling strata used in the sampling plan. For each geographic sampling stratum (defined as a set of block groups), set the initial expansion factor as the number of households living in the stratum block groups divided by the number of households in that stratum in the survey sample.
- Then, use iterative proportional fitting (IPF) to more closely match external ACS-based targets. The RSG team recommends using a list-based IPF approach that can use targets for both household-level variables (household size, number of workers, number of vehicles, age of head of household, presence of children, income group) and person-level variables (age group, gender, employment status—including part time vs. full time, university student status, race/ethnicity). Some data imputation may be required for data items such as income and race/ethnicity if a "do not wish to say" response is allowed for those questions.
- Use the most recent ACS 1-year microdata to set sampling targets at the Public Use Microdata Areas (PUMA) level. (PUMA is the finest geographic detail available on the individual ACS household and person data records.) If it is not possible to match some of the targets accurately at the PUMA level due to small sample sizes for particular PUMA/target variable combinations, then combining adjacent or similar PUMAs is a recommended approach to achieve a better match, although combining target categories may also be advisable. In general, the target categories should not be so detailed that they contain only a percent or two of the regional population. For example, it is advised to use 5+ as the highest target category for household size, rather than using separate targets for 5, 6, and 7+ person households.

FREQUENCY AND SAMPLE SIZE

A 10-year cycle for conducting household travel surveys was once typical in many regions. This cycle may have been appropriate at that time because supporting Census data was only available from the decennial Census short and long forms, and travel behavior and alternatives did not appear to be changing rapidly. Now, the situation is different. The Census long form has been replaced by the ACS, which is repeated every year. Also, with the rapidly growing use of TNCs (e.g., Uber and Lyft) and the "sharing economy," the growing dominance of online shopping, the apparently different travel patterns of the "Millennial" age cohort, and the approaching availability of connected and autonomous vehicles (CAVs), it seems that travel survey data will become obsolete for planning purposes before a 10-year cycle is completed.

The advantages and disadvantages of moving to more frequent household travel surveys were discussed in detail in the Task 4 memo. As shown in Table 3, some agencies such as those in Seattle, Minneapolis, and Research Triangle are moving to a 2-year survey cycle, each with a larger sample to start with and then smaller samples every 2 years. The preferences for those agencies are somewhat related to funding and planning cycles and also to the desire to have more frequent data for trend analysis.

For H-GAC, a 4-year or 5-year survey cycle seems appropriate, which is a similar frequency to the need to update the regional travel demand model for use in long-range planning. Unless H-GAC has any particular reasons for wishing to move to a more frequent cycle than every 4 or 5 years, the RSG team does not recommend doing so.

Table 3 shows the sample sizes for several recent household travel surveys and indicates the percentage relative to the number of households residing in the region. For the largest region—Chicago—the sample size is 0.4% of the regional population. For the smallest regions—Research Triangle and Columbus—the samples are around 0.6% of the population. All the regions are within the 0.4% to 0.65% range. For H-GAC, the RSG team recommends a minimum sample size of 0.4% of the region's 2,500,000 households, or 10,000 households. That sample size, along with multiple days of smartphone-based GPS data and oversampling for key hard-to-reach market segments, will ensure adequate sample sizes for updating all components of H-GAC's activity-based (TourCast) model system.

HOUSEHOLD TRAVEL SURVEY COST

Costs for household travel surveys require consideration of many factors. Here, some benchmarks are provided to allow further consideration. First, a suitable benchmark is knowing the cost per household for the National Household Travel Survey (NHTS). The 2008-2009 NHTS cost $175 per household. The 2016-2017 NHTS cost $225 per household. This cost is for a one-day household travel diary using ABS, and that does not include any GPS data (neither smartphone-based or device-based). For states or regions considering conducting a household travel survey, these are some factors that impact cost:

- Extent and depth of public outreach (e.g., minimal efforts vs. door-to-door efforts).
- Extent and number of foreign languages (e.g., conducting the project in one, two, or six languages).
- Duration of data collection (e.g., collecting data for 3 months, 6 months, 12 months).

- Mix of methodologies and technologies used, including whether smartphones are distributed to households without them (which RSG does not recommend).
- Number of days of data collection (e.g., 3, 7, 14) per household. The standard for smartphone studies is currently seven consecutive days.
- Number of agencies and stakeholders involved (e.g., one agency or a cohort of five agencies overseeing the project).
- Number of, if any, add-on sample segments or supplemental surveys.
- Complexity and extent of aggressive oversampling, and the study region's overall civic engagement. Both factors can impact response rates.
- Overall sample size as this can impact economies of scale for fixed expenses (e.g., unit price per invitation envelope decreases as sample volume increases).

Additionally, as discussed elsewhere, when conducting a smartphone-based GPS travel study there are also cost savings for conducting a predominately smartphone-based GPS sample approach. Given that smartphone-based GPS data collection has fixed costs such as code maintenance, updating the operating systems with new releases (e.g., in September 2017, Apple released iOS 11), it is more cost-effective per household to conduct a predominately smartphone-based GPS travel study (e.g., everyone who has a smartphone participates that way), than to collect only 5% or 10% of the sample as smartphone-based GPS sample.

Overall, in the near-term, the RSG team believe that predominately smartphone-based GPS travel studies will have a per unit cost of approximately $200 to $300; this cost will vary based on the factors listed above. Single-day diary-based surveys with no smartphone component may be marginally cheaper on a per-household basis, but these are more expensive on a per-travel-day basis.

POSSIBLE SUPPLEMENTAL SURVEYS

University Student Surveys

University students tend to be underrepresented in household travel surveys using ABS for the following reasons:

- On-campus housing is designated as "group quarters," and the addresses are not included in available databases for sampling.
- Even those living in off-campus housing tend to change addresses quite often, decreasing availability of their current, accurate addresses for sampling.
- Young, single adults tend to have lower response rates in ABS.

If, however, universities in the region are willing to cooperate, then it can be possible to recruit additional university students into the sample via university-administered e-mail lists. This approach was used by RSG in the Seattle region in 2015 and in other regions.

E-mail invitations can be sent out by the university or the university can provide a list of e-mail addresses that can be used for sampling. It is best if the e-mail addresses can be used to selectively invite students and not faculty or staff, but if that is not possible then it does not add much additional costs to invite faculty or staff.

In addition to the low cost of using e-mail-based recruitment compared to address-based recruitment, cost savings can also be achieved by asking all university students to respond as single-person households, without attempting to obtain travel data for the entire household. Most students who do not live with their parents tend to live alone or else live with unrelated roommates/housemates, so essentially behave as single-person households.

E-mail invitations can be used for either diary-based or smartphone-based GPS travel data collection. For H-GAC, the RSG team recommends that smartphone-based GPS travel data collection be used, as that would be compatible with the main household survey method, and smartphone ownership among university students is nearly universal. The survey instrument used for students can be the same as that used in the household survey, except that one may wish to add, subtract, or customize a few specific questions or answer categories. For example, questions about student status/year and housing type can be useful in expanding the sample to the student population using the universities' enrollment and housing data.

Toll User Survey

A toll user survey could serve various purposes. One option is to invite more toll users into the household travel survey by use of intercept or "convenience" sampling. Possible methods would be to hand out invitations at toll booths, have a toll authority send out or e-mail invitations to registered electronic toll collection (ETC) users, obtain an address or e-mail list of ETC users from the toll authority, or use video license plate capture (LPC) to identify toll facility users (and users of adjacent non-tolled facilities). These households would then participate in the same smartphone-based GPS or diary-based travel survey as other users, possibly with a set of additional custom questions added regarding toll road use.

Another option would be to identify toll road users from the household travel survey data, and to invite those who are willing to participate in an online (or CATI) follow-on survey. The follow-on survey could contain several attitudinal questions and stated preference scenarios customized around an actual trip that toll users (or non-toll-users in toll road corridors) reported during the main travel survey. This type of customized follow-on survey has been used in many studies by RSG and others to better estimate willingness to pay for time savings, or value of time (VOT).

Bicycle User Intercept Survey

Although there is a great deal of policy interest in bicycle use in many regions, the mode share for bicycle use remains quite low and it can be difficult to obtain enough bicycle trips in a household travel survey to effectively model bicycle travel choices and patterns. Passive data sources may also not be able to isolate bicycle trips from other modes. One method to learn more about bicyclist trip patterns is to locate interviewers along popular cyclist routes and conduct a targeted intercept survey among passing bicyclists. The questions asked are like those asked in a transit user intercept survey, asking trip purpose, origin and destination, and key demographics. The OD information, along with independently collected bicycle count data, provides valuable data for calibrating the bicycle trip demand predicted by the regional AB model.

If conducted in conjunction with a household travel survey, respondents who are interviewed in the intercept survey can also be invited to take part in the household travel survey, potentially increasing the number of bicycle users in that survey. This approach was recently used by RSG in the San Diego region, although the number of intercept survey respondents who also took part in the household travel survey was quite small.

Ride-hailing/Carshare User Survey

Because ride-hailing services such as Uber and Lyft, and carsharing services like Zipcar and car2go, are such a recent and fast-growing phenomenon, most MPOs have little or no survey data regarding the users or use patterns. To remedy this situation, some agencies are interested in conducting smartphone-based GPS travel surveys in which users are recruited at common Uber and Lyft pick-up/drop-off locations (or Zipcar parking spaces). Once recruited, they participate in the same type of smartphone-based GPS travel survey as used in full household travel surveys, but asking additional questions for ride-hailing or carshare trips

For H-GAC, it may not be necessary to conduct such a targeted survey if a major household travel survey can obtain a sufficient sample of such trips for mode choice modeling. In the recent 7-day smartphone-based GPS travel survey in San Diego, about 1,800 Uber or Lyft trips were recorded by the 6,000 households, plus another 250 or so conventional taxi trips. It may also be possible to geographically oversample in neighborhoods where ride-hailing or carsharing among the residents is most common.

In terms of representativeness of the sample, it is better to capture users via usual ABS plus geographic oversampling methods than to use intercept/convenience sampling. However, intercept/convenience sampling could be used to augment the number of such trips that will be captured in the survey, if desired for modeling purposes. In either case, it is important to identify the use of Uber, Lyft, or any other ride-hailing service as a separate mode option for each trip, and to identify the use of Zipcar, Car2Go, or any other carshare system as an option to describe the vehicle used for any auto trips. Additional survey questions specific to the use of those services can be added.

Autonomous Vehicle Attitude/Stated Preference Survey

CAV technology is still in preliminary stages of adoption in the existing vehicle fleet. New vehicles are gaining autonomous and semiautonomous features such as automatic emergency braking, adaptive cruise control, lane departure warning, and lane-keeping assist, and various levels of self-driving capabilities. Fully self-driving vehicles operating on most roads with no driver intervention are still several years away and the costs and features of these vehicles are not well known. As a result, the range of future autonomous scenarios is broad, and depends largely on the developing regulatory environment, technological progress, and consumer preferences.

The project team recommends developing and implementing a stated preference survey to evaluate how significantly cheaper and more widely accessible on-demand mobility services will affect the travel choices and behaviors of individuals and households. The stated preference survey could be most effectively carried out as a follow-up survey among people in the main travel survey sample who indicate that they are willing to participate in further surveys.

By focusing the stated preference questions on the demand for mobility services given increasing levels of autonomy, the research will allow estimates of price sensitivities as well as the propensity for travelers to use these services under a variety of distinct operating conditions and levels of vehicle autonomy. The survey will allow the research team and the H-GAC to have a first look at how these potentially disruptive technological changes within the space of mobility service providers can be expected to unfold as CAV technologies become more available and deployed in greater numbers across the region. The results could be used to derive a simple market share simulator that will allow the team a first look into how these technologies may be poised to change travel and consumer behavior.

The research could also be designed to ask respondents directly about CAV technologies and their perceived implications. Using past survey work for public and private sector clients as a guide, questions could be designed that touch on a variety of relevant areas such as; likelihood of adoption and level of interest in CAV technologies, potential effects on travel behavior, destination choices, trip generation and travel distances, complementary or contradictory effects on transit use, and employment and residential location choices.

The survey would be administered to a panel of respondents living in the greater Houston area. To participate, respondents would need to have used an on-demand mobility service and have made a recent a qualifying trip that could be used as a reference trip in the stated preference experiments. The survey would be broken up into several parts and could include the following sections:

- **Demographic questions:** Respondents would be asked basic personal information (e.g., gender, household arrangements, employment), their current level of use of ride-hailing, carsharing, bike-sharing or transit, automobile ownership, home and work location, and approximate weekly travel distances.
- **Current use of mobility service providers:** A following series of questions would ask respondents about how they currently use mobility service providers to make trips. Questions could include, the types of services used, frequency of use, the frequency and purpose of these trips, trip distances, cost of trips, and the reasons for choosing a mobility service provider.
- **Most recent trip:** Questions would establish a reference trip for use in the stated preference exercises. The questions would include the respondent's most recent trip that used a vehicle, TOD, travel time, mode used, occupancy, and individual trip costs.
- **Stated preference (SP) questions:** Respondents will be shown SP questions and asked to evaluate scenarios that trade off attributes of their most recent trip using the

same mode as described or make their trip using a semi or totally autonomous vehicle through a mobility service provider. Attributes might include, trip cost, length, wait times, level of vehicle autonomy, presence of a driver, and other trip-specific factors that might influence the use of a mobility service provider.

- **Attitudes and Perceptions:** A series of benchmarked questions from previous RSG studies to identify level or interest and concerns about CAV technologies.

The sampling plan should be designed to include sufficient representation from current users of mobility service platforms, based on information for questions asked in the main travel survey.

The SP data would be compiled into a dataset suitable for the estimation of aggregate and individual utilities using maximum likelihood and Bayesian techniques. Potential model segments may include current users and nonusers of mobility services or urban and suburban residents; segments may also include trip types, departure times, or trip distances.

SUPPLEMENTAL SURVEY COSTS

Many supplemental samples or surveys are conducted at the person level (rather than the household-level). For example, a college special generator travel diary is typically conducted for persons living on campus. Similarly, many other options such a military special generator survey, a survey of TNC users, and a survey of recreational bicyclists can also be conducted at the person level. Person-level surveys tend to cost less than household-level surveys because of the lower burden on the participants and higher response rates. Similarly, when these surveys are conducted in conjunction with or immediately following the core household travel diary, other costs can be saved on sample, design, or other factors. Some other factors include the following.

Is It a Follow-on to a Previous Survey?

For example, inviting sample who recently completed a household travel diary to take a follow-on survey has lower costs because there is far less of a need to purchase/obtain sample. Indeed, if planned, a follow-on survey can be conducted immediately after the household travel diary to maximize response. An example is a transit SP survey to measure willingness to take transit into Indianapolis, which was conducted as a follow-on to the household travel survey.

What Is the Expected Response Rate?

The type of survey, how and in what manner the sample is contacted, and other factors can dramatically impact response rate. RSG has seen response rates vary from less than 10% to more than 70% based on the approach used. For example, a social media ad on an agency website has a far lower response rate than an e-mail to registered vanpoolers.

Is There a Direct Intercept Effort (or Not)?

Direct intercept efforts have costs associated with expenses such as staff to conduct intercept, posters/materials for intercept locations, and permission fees, among others. These costs then can impact the cost per respondent.

Other Factors

Other factors include those mentioned in the household travel diary section above (e.g., methodology, technology, duration of data collection). Depending on these factors, the cost per respondent is expected to range from $50 to $150 per person.

2.2 | TRANSIT USER INTERCEPT/OD SURVEYS

METHODOLOGY

H-GAC is currently conducting a transit user OD survey using the most up-to-date, best-practice methodology. This data collection methodology includes an on-board tablet-based intercept survey sampling 10% of all boardings and an on-to-off survey sampling 20% of all boardings.

SAMPLING AND EXPANSION

Generally, transit OD surveys are conducted for the following reasons:

1. For internal understanding of the transit system—to determine if the system serves riders and potential riders efficiently. (Houston is a great example, given their work to realign the bus system in recent years.)
2. For modeling and planning purposes—to serve as the core data to analyze and evaluate the effects of new or changed services.
3. For federal level planning and funding—to obtain Federal Transit Administration (FTA) funding for potential future projects and to comply with FTA before/after study requirements for OD data.

If boarding and alighting flows (i.e., rider markets) are known through an automated process (or through an on-to-off survey), then statistical rules can be applied to obtain a scientific sample for each market to obtain a desired confidence interval around results for each market segment. These automated processes to obtain boarding and alighting flows do not exist for most systems but may happen within the next 10 years. Most studies without rider market data, or where the timing is such that an on-to-off is not ready prior to the OD survey, apply the 10%/20% sampling rates.

FREQUENCY AND SAMPLE SIZE

H-GAC should sponsor a survey every 3 to 7 years depending on how many new projects are being considered and how much FTA New Starts funding regional transit agencies may be seeking. Ideally, transit agencies would have a strong and current understand of their riders' boarding and alighting patterns all the time (not just every 3 to 7 years). Then, if there is a desire to know more about route-specific or area-specific patterns, the transit agency would target and survey the riders making that boarding and alighting pattern and survey them to understand the reasons for such a pattern and to adjust service as necessary.

System-wide surveys tend not to happen often as it is expensive and time consuming. However, boarding and alighting data (on-to-off survey data equivalents) may be more automated in the future, decreasing cost and time. When this occurs, transit agencies will be able to conduct more targeted studies, which could improve their system more frequently. System-wide studies will also benefit from more automated on-to-off data, which can be a major component of the costs of those studies.

COST

Conducting a system-wide on-board OD survey with 10% of boardings sampled for large agencies can result in more than 40,000 survey responses and cost over $1 million, especially if both an on-board OD and an on-to-off survey are conducted.

2.3 | VISITOR SURVEYS

RECOMMENDATION TO USE PASSIVE DATA

RSG is not recommending conducting visitor surveys—other than as part of airport surveys covered in the following section—for the following reasons:

- Disaggregate visitor travel surveys tend to be expensive as they involve intercepting people at multiple likely visitor locations (e.g., hotels, convention centers, beach resorts) and asking them about their travel patterns while in the region. The best way to capture such travel is via a travel diary (or smartphone app) for one day or more, which is essentially the same methodology as used for a resident travel survey. Thus, the cost of conducting an effective and useful disaggregate visitor travel survey can approach the cost of doing a regional household travel survey for a similar sample size.
- Unless one wishes to create a detailed AB or tour-based model system of visitor travel in the region, purchased passive data can provide all the details necessary to support a simpler model to describe visitor trip patterns in the region. As described in Chapter 3, cell-based or location-based service (LBS) data can determine which trips within a region are made by nonresidents as opposed to residents. While these data may not be ideal for capturing short-distance walk trips made by visitors, they can capture the longer trips, which are made predominantly by auto. While the passive data do not indicate trip purpose, purpose can be inferred from the trip end locations (e.g., financial district versus convention district versus medical centers versus Gulf shore).
- Even if one did wish to create a more detailed tour-based model of visitor travel in the region, it is possible that disaggregate LBS data that tracks individual's travel in the region would be adequate for such a model.

- As is true for other uses of passive data, these data will provide more complete coverage of possible OD pairs in the region than even a more expensive disaggregate travel survey can.

In sum, the RSG team recommends that H-GAC purchase a passive dataset (most likely LBS) that will support modeling of nonresident travel patterns and resident travel patterns. H-GAC should gain experience using such data before determining whether a more expensive disaggregate visitor travel survey would be worth the cost and effort.

2.4 | AIRPORT SURVEYS

METHODOLOGY

Airport surveys typically target either air travelers' ground access to the airport or air travelers' satisfaction regarding certain aspects of their air travel trip. The project team recommends ground access airport surveys at George Bush Intercontinental Airport and the William P. Hobby Airport to meet H-GAC's planning needs. Since airports are unique and major generators of traffic, ground access surveys are helpful for understanding and modeling the significant travel to and from airports. The ground access survey will collect information on the number of people traveling to and from the airport, travel mode, and other characteristics about their travel.

The methodology recommended for ground access surveys involves sampling a representative number of flights and then—according to those flights—intercepting passengers at the gate. Travel to and from airports is stressful. The reason to sample at the gate is that air travelers are most relaxed and willing to take a survey at that time of their trip, versus at other parts in their trip when they need to go through security or pick up their baggage.

Airport ground access surveys can be paper-based if the information desired is minimal (i.e., if the survey only asks the mode(s) used and characteristics of the travel to/from the airport). For more complex surveys, such as SP surveys that include questions on potential mode choice in addition to the questions related to the respondent's travel at the time of the survey, the questionnaires can be administered via tablet computers by dispersing them among air travelers waiting at the gate.

Mode choice to airports has become much more dynamic, primarily due to the ability to use TNCs, which are considerably cheaper than taxis, cover a wider area, and are convenient to hail via smart phone. The convenience and low cost of TNCs has made the need to park or rent a car at an airport less compelling than in the recent past. Thus, trends are indicating fewer drive-and-park trips and fewer car rentals, which affects airport revenues significantly. For example, recently airports in the US have experienced significant decreases in the revenue from parking. Therefore, the project team recommends that H-GAC include the SP aspect of the survey to learn more about ground access preferences and understand potential impacts of these preferences on the airport transportation system and its revenues.

Finally, employees of airports are an important market segment for these studies, as airports have many employees that need a reasonably fast and affordable way to get to work. Airports, fortunately, tend to be some of the most accessible places in a region by transit, which many employees utilize. The project team recommends that H-GAC consider including employees in future ground access surveys as this population comprises a significant ground access market.

An additional possible use of airport survey data is to obtain data for nonresident visitors as they wait for flights to depart the region. In addition to standard questions such as the origin and mode and party size for their trip to the airport, these visitors can provide additional information like purpose(s) of visit, length of stay, variety of places visited, etc. This is not a complete sample of visitors as it excludes those who arrived by car. It is, however, a (nearly) complete sample of *international* visitors to the region, and those visitors may be more difficult to identify in passive datasets.

SAMPLING AND EXPANSION

The project team recommends sampling using OAG Aviation Worldwide Limited data (OAG.com) to help understand future flight schedules, including types of flights and number of seats on these flights. It is important to screen out connecting passengers for a ground access survey and to focus on trips originating for the airport under study.

Expansion and weighting for air traveler data should use Federal Aviation Administration (FAA) Airline Origin and Destination Survey (DB1B) data (a 10% sample of airline tickets from reporting carriers) or T-100 Segment data (domestic market air carrier statistics). These data sources provide robust information on domestic flight patterns, but these sources are not fully comprehensive. For example, the DB1B data do not include international travel. On the other hand, T-100 Segment data includes some international data but lacks TOD information (which can be obtained through OAG data). Therefore, supplementary data sources from the airport, OAG, or other available sources will need to be combined with these federally available sources to fully understand the international markets and expand the data accordingly.

Expansion and weighting for airport employees is more difficult, as there are myriad employers and employees at an airport. H-GAC will need to coordinate with each airport to obtain counts of employees where possible. If employee estimates are not available, then counts can be utilized in certain employee-only access areas to attempt estimates of the total number of employees at an airport. Employee parking spaces, employee shuttles, and visual observations on-board transit also might be counted and used to estimate employee populations.

FREQUENCY AND SAMPLE SIZE

Different agencies conduct studies at different rates. For example, over the past 20 years, Massport (Logan International Airport) has conducted comprehensive ground access surveys biennially. Other airports conduct these surveys on an ad hoc basis. Given that ground access markets are highly dynamic, more frequent studies are ideal. Thus, the project team recommends that H-GAC conducts ground access surveys every 2 to 3 years to maintain a longitudinal understanding of mode choice and the factors that affect mode choice. These surveys will aid in both planning and operations for the two major airports in Houston.

COST

The cost to conduct a major airport's ground access survey is in the range of $200,000 to $500,000, depending on several factors, including the following:

- Do tablets need to be rented for conducting the survey?
- Does the survey include airport employees?
- Does the survey use SP to model future demand?
- How good is the employee/passenger count data from the airport?
- How costly is the security vetting and badging process to survey at gates?
- Are there special substudies (e.g., understanding boarding and alighting behavior on airport people mover/transit systems)?

It is helpful to consider that often the airport, airlines, and other transportation-related agencies may also be interested in ground access data and funding for such surveys can potentially be spread across multiple agencies.

2.5 | OTHER SPECIAL GENERATOR SURVEYS

RECOMMENDATION TO USE PASSIVE DATA

Apart from the airports, which are covered in the preceding section, important special generators for the Houston region include the following:

- Major medical centers.
- Large shopping malls.
- Stadiums/sport complexes.
- Tourist resorts.
- Universities.

As the purpose for visiting each of these types of locations is self-evident, the data required for planning help better quantify the OD and TOD patterns for trips to and from these generators because their effects on local traffic patterns are large. As discussed in the Task 4 memo (Appendix B) and Chapter 3, passive data can provide much more comprehensive data on OD patterns and TOD patterns than more expensive disaggregate intercept surveys.

Visitors to tourist resorts are mainly nonresidents of the region. The visitors to medical centers, shopping malls, and stadiums are mostly regional residents but may include nonresidents. An advantage of using passive data is that the same data source will include both residents and nonresidents and their patterns can be analyzed separately.

As discussed in Chapter 3, an important consideration in purchasing passive data to study special generators is that the zone system for aggregating the data be specified so that the special generators are isolated as their own zones. It is also important that the passive data be accurate enough to identify which trips go to/from those zones. In the latter sense, LBS data are more accurate and suitable than cell-based data.

Although a disaggregate survey of university students is recommended as an “add-on” to the household travel survey in Section 2.1, passive OD data for universities as special generators may also be useful for model calibration, particularly for the longer commuter and visitor trips that universities generate.

2.6 | COMMERCIAL VEHICLE TRAVEL SURVEYS

METHODOLOGY

Given the various types of CVSs, the RSG team recommends that H-GAC considers the following types for collecting regional data on commercial vehicles:

- **Establishment Surveys:** Collecting data on the characteristics of commercial establishments and their approach to moving goods and providing services. Data collected typically include employer characteristics; number and type of employees and vehicles; and aggregate mode, shipment size, and transfer facility data.
- **Truck Trip Diary Surveys:** Collecting data on commercial trip origins, destinations, start times, stop times, routes, distances, vehicle types, commodity types, and stop characteristics.
- **Roadside Intercept Surveys:** Collecting data on profiles of commercial vehicle trips using a specific roadway segment. Data collected typically include origin and destination data, trip start times, trip end times, vehicle types, and commodities carried (weight and value).

The combination of these three types of surveys into a comprehensive data collection program allows H-GAC to collect necessary data on establishments and truck movements by using roadside intercept as the primary means of recruiting drivers to complete the truck diary and establishment survey questions. Recruiting remains one of the larger challenges in CVSs. Typically, this has been done by contacting the establishment to answer questions about the establishment and then subsequently contacting drivers within the establishment to complete the truck diary survey.

Typical establishment surveys (as described above) involve an approach that includes the following steps:

1. Defining geographic boundary of concern.
2. Adopting industry/commodity classification scheme.
3. Identifying the universe of companies to survey.
4. Determining the sample size.
5. Establishing data elements.
6. Designing a survey questionnaire.

7. Conducting the survey.
8. Assembling the database.
9. Expanding the data.
10. Validating the accuracy of the data.

The following information (including, but not limited to) are generally collected using an establishment survey:

- General facility information (e.g., name and location).
- Nature of business (North American Industrial Classification System—NAICS).
- Types of goods/commodities shipped or services provided.
- Quantity of goods/commodities shipped.
- Value of goods/commodities shipped.
- Number and types of vehicles.
- Establishment size and number of employees.
- Specific shipments and their origin, destination, mode, and time of travel.
- Frequency, size, and weight of shipments.
- Truck stops, locations, and durations to pick up and deliver goods.
- Travel time and cost of travel.

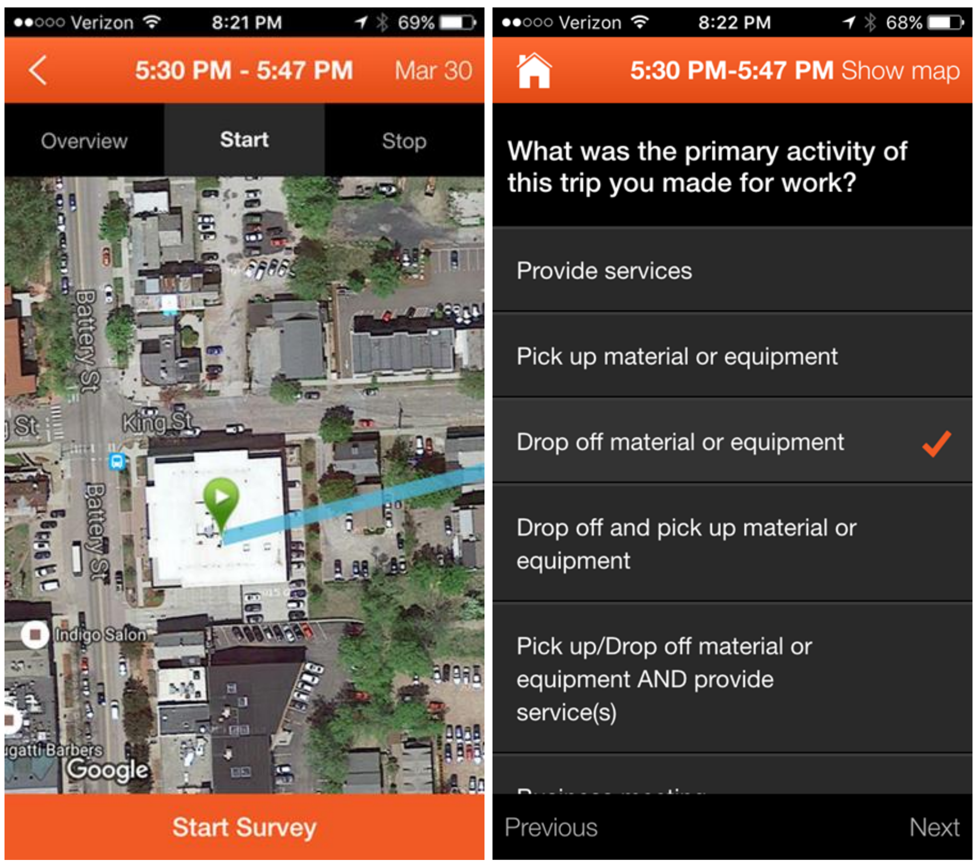
The CVSs should take advantage of an innovative approach to data collection to increase participation rates, reduce respondent burden, and improve the accuracy and quantity of establishment and vehicle tour data collected: a GPS-enabled smartphone application to collect the driver's travel information and characteristics of the establishment. RSG has developed a smartphone application (called rMove™), offering a robust and cost-effective alternative to the traditional pencil and paper options and online recall survey instruments (Figure 1). The project team recommends the use of a smartphone application to collect the CVS data. This would have several advantages:

- Respondents generally find the app less burdensome, making recruitment and retention easier. Most commercial vehicle operators today use smartphones, and the app can be downloaded from the Apple App Store for iPhones and from the Google Play Store for Android-based devices.
- Automated recording of travel stops, routes, and TOD using GPS-enabled technology leads to a significantly higher rate of survey completion and accuracy, and fewer instances of missed or underreported trips.
- The app automatically prompts respondents to review their travel patterns on a built-in map and indicate stop purposes, vehicle types, and goods descriptors, and report discrepancies during the same day as the actual trip-making events, which improves recall. The screenshots from the app shown in Figure 4 illustrate the main travel report screen where the driver can select a trip to view when prompted, the map view where respondents can zoom in and view trip end points to confirm accuracy, and a question on trip purpose.

- For little additional cost, the app can collect multiple days of travel for each respondent (e.g., up to one week). A multiday sample provides more observed driver-days per recruit and the opportunity to analyze driver and travel pattern variability and system reliability.
- The mobile app provides the opportunity to collect GPS data on commercial vehicle drivers without requiring a separate survey.

Drivers without access to a smartphone, or those who have concerns about downloading and installing the mobile application, should be given an option to participate using an online travel diary. After data collection, the online travel diary database can be seamlessly merged with the smartphone application database to provide a single dataset that includes all respondent trip information.

FIGURE 4: SAMPLE SCREENSHOTS FROM CVS MOBILE APPLICATION



SAMPLING AND EXPANSION

The sampling plan for the establishment and commercial vehicle travel diary surveys should consider key geographic distinctions within the H-GAC region, establishment size, and industry, with some oversampling of industries likely to have service or delivery vehicles (with data weighting to adjust for oversampling and driver incidence). To support model development, the targeted sample size should be between 600 and 800 establishments and 2,400 and 3,200 drivers. Of this total, our recommendation is that 60% to 70% of the sample would comprise a cross-section of establishments in a variety of industries in the study region, and 30% to 40% of the sample would comprise establishments in the truck transportation and freight industry (i.e., NAICS code 484).

It is important to distinguish between establishments that employ their own drivers and those that are simply consumers of transportation or services and account for both types of establishments. This helps accurately estimate total demand when the sample is expanded to represent the population of establishments in the region. The survey-sampling frame should cover as much of the commercial vehicle generating activity in the region as possible, including multiple representative industries and public sector establishments. Various options exist for the sampling frame, including a commercial vehicle registration database from the State of Texas or databases of business establishments in the study region.

Stratified sampling should occur by industry classification to obtain responses from different market segments, including the following:

- Manufacturing, Agriculture, and Extractive Industries (e.g., heavy and light manufacturing, farm production, nurseries, timber, gravel and mining).
- Wholesale and Distribution (e.g., food and beverage distributors, suppliers of various types, and warehousing for retail).
- Retail and Restaurants (e.g., point of sale establishments with dedicated drivers for pick-up or delivery).
- Government, Education, Hospitals, and Utilities (e.g., city/county/state services, inspectors, maintenance, cable providers, gas and electric, colleges and universities, hospitals).
- General Services (e.g., landscapers, tree trimmers, HVAC, plumbers, building contractors, general construction, home healthcare and diagnostic labs, insurance claims adjustors).
- Transport Handling (e.g., for-hire trucking, including drayage, moving companies, couriers).

A challenge facing a commercial vehicle data collection project is a trade-off between comprehensiveness and cost effectiveness. For example, light-duty vehicles comprise most commercial vehicles used for service-related stops in urbanized regions. This includes such diverse services as heating, ventilation, and air conditioning; plumbers; electricians; health care and social services; construction; municipal services; and landscapers. Moreover, within urbanized areas, service-related trips are more numerous than purely freight-related trips. Thus, it is important for a commercial vehicle model to capture the service portion of the market and that the establishment survey sample a representative portion of firms engaged in those service activities. The importance of collecting robust data on this segment is magnified by the lack of other data describing their travel. For example, traffic count data for validation of light-duty vehicle movements are limited because automated traffic counting devices do not distinguish commercial from noncommercial uses. Many commercially available datasets of truck GPS traces include few service-related truck movements as they are biased toward heavy truck movements used for hauling freight, mostly over long distances.

The use of monetary incentives for survey completion can improve response rates and reduce nonresponse bias. This, in-turn, can improve data quality and reduce overall survey costs. The use of monetary incentives is well known and has been employed by researchers for several survey types. It is recommended as a part of best practices by survey research organizations. Monetary incentives are particularly important for CVSs as commercial vehicle respondents are more difficult to reach and less likely to cooperate with data collection efforts.

FREQUENCY AND SAMPLE SIZE

CVSs are a large undertaking and provide comprehensive data to understand commercial vehicle movements in a region. As commercial vehicles affect the economy and mobility in a region, these should be conducted every 5 to 10 years. The Texas Department of Transportation has conducted commercial vehicles for metropolitan planning organizations (MPOs) across the state that could be used instead of each region conducting their own survey. This combines resources to achieve larger sample sizes overall and provides a consistent approach to collecting data on commercial vehicles.

COST

An establishment survey can provide valuable and detailed information on shipments and an establishment's specifications; however, this is an expensive method to collect freight movement data. Establishment surveys that collect either OD data or full driver diary data can be nearly as resource-intensive as household surveys—primarily because of recruitment costs. The survey costs vary widely ($350k for Portland[1] to $1.5 million for Phoenix[2]) and the data collection methods are undergoing tremendous changes due to new survey technologies (such as smartphones) to reduce burden, increase response rates, and improve accuracy.

2.7 | ESTABLISHMENT SURVEYS

RECOMMENDATION TO USE OTHER DATA SOURCES

The main reason for using establishment surveys has been to calibrate trip attraction rates for the H-GAC model. For several reasons, the RSG team recommends that H-GAC not conduct another establishment survey until it has tried using other data sources instead, including the following:

- **Household travel survey data:** The H-GAC TourCast model uses destination choice models that are designed to use disaggregate observations of tour and trip destinations rather than aggregate attraction rates. The use of multiday smartphone-

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[1] Portland Metro Establishment Survey, 2016 (collected data on ~28,800 trucks and ~723,000 trips)
[2] MAG Commercial Establishment Survey, 2016 (to collect data at 416 establishments in the MAG region)

based GPS household travel data will provide more data and more accurate data for estimating those models.
- **Passive data:** As described in Chapter 3, purchased passive data can provide a much less expensive data source on trip attractions with greater OD coverage. The RSG team recommends using passive data to calibrate the TourCast destination choice models, and Chapter 3 describes several methods.

Given the low cost of purchased passive data and the several other purposes that it can be used for (identified elsewhere in this chapter), the RSG team recommends that H-GAC perform the next AB model update without conducting establishment surveys. Based on the success of that work, H-GAC can determine whether establishment surveys might be worthwhile for further model updates. RSG has compared attraction rates from the most current establishment survey to those that can be derived from recent AirSage data. This information is included in Appendix C.

2.8 | EXTERNAL SURVEYS

RECOMMENDATION TO USE PASSIVE DATA

Obtaining estimates of external travel, including external-external (XX), internal-external (IX) and external-internal (XI) trips is currently the most common use of purchased passive data, and the RSG team recommends that H-GAC purchase passive data for this purpose for the following reasons:

- Roadside intercept OD surveys are often prohibited, and are cost-prohibitive in any case.
- Alternative methods such as using LPC or Bluetooth capture are also expensive and do not capture all vehicles. Also, they are mainly designed to identify XX trip flows, but cannot identify the internal zone for IX and XI trips.
- Aggregate passive data provide better OD coverage, and the same date request to identify OD patterns for external (XX, IX, XI) trips can also provide data to identify OD patterns for internal (II) trips to calibrate the main AB modules of the TourCast model.
- In addition, the data request could be designed to provide some information about trip origin/destinations beyond the external stations. For example, if it was desired to know what percentage of trips entering each external station was made by residents of specific counties or states, then that data could be requested. (Such information might be useful in integrating the H-GAC model with a statewide model for estimating external trips.)

CHAPTER 3. METHODS TO USE PASSIVE DATA

While surveys have traditionally been the primary source of information on both travel behavior and travel patterns used for developing travel forecasting models, passively collected OD data are now widely available and increasingly being used to support model development. Passive data differs in several important ways from survey data:

- **Traveler Characteristics:** Since passive data are anonymous by nature and for reasons of privacy concerns, these data cannot support behavior choice modeling when traveler characteristics—such as income—are key determinants of behavior. Surveys remain a critical source of information for the development of travel models.
- **Spatial Distribution:** Because of the large samples of data that can be collected passively, these datasets can provide information that surveys cannot—especially information on spatial distribution. Consider, for example, the data needed for the recent development of an AB model for a smaller MPO. The household travel survey dataset included data from over 1,500 households (~1% sample) on over 15,370 trips. This dataset provided observations on the relative frequency of trips for 8,350 cells, or 2.0% of the over 400,000-cell OD matrix. In contrast, cell phone-based passive OD data provided information on the relative frequency of trips for roughly 183,000 OD pairs, or 34.5% of the cells in the OD matrix.
- **Cost:** For certain types of travel, data can be collected cost-effectively through passive methods, while surveys of the same would be extremely expensive.

Thus, while both surveys and passive data can provide some of the same information (e.g., aggregate trip rates, lengths), they complement rather than substitute. Ideal modeling strategies will leverage both survey and passive datasets—using each for aspects they represent best. In formulating the data recommendations to support model development for H-GAC, the project team identified the best data source(s) for each data need described in both the recommendations regarding survey data collection in the previous chapter and the recommendations in this chapter regarding passive OD data.

This chapter is separated into three subsections:

- The first subsection outlines the recommendations for the use of passive data in H-GAC's modeling efforts.
- The second subsection provides an overview and recommendations regarding the types of passive data to be acquired.
- The third and final subsection on passive data includes an overview and recommendations regarding methods of expanding passive data for modeling. Since passive data represent a convenience sample and not a controlled random sample, these data are not generally representative of all travel or all travelers. Various systematic biases have been observed and documented in the literature. These must be corrected using appropriate expansion methods to produce representative datasets from passively collected data. Failure to correctly account for the under- or

overrepresentation of certain groups of travelers, areas of origins and destinations, or types of trips could lead to faulty analyses and models.

3.1 | RECOMMENDED USES

The project team recommends passive OD data for five uses in H-GAC's travel model development, a sixth recommendation suggests research on the fusion of survey and passive data:

- External Travel Patterns.
- Visitor Travel Patterns.
- Trucking Patterns.
- Attraction Rate Estimation.
- Constant Rich Destination Choice Models.
- Data Fusion with Household Survey Data.

While in most cases these applications of passive data serve as a substitute for various types of survey data, there are also new data-driven methods (e.g., constant rich destination choice models) that passive data can support but traditional data cannot.

EXTERNAL TRAVEL PATTERNS

Passive OD data are recommended for use in determining external travel patterns for the H-GAC region and the development of the H-GAC travel model's external travel modules. H-GAC's current external travel models are based on travel patterns from an intercept survey conducted in 1995 (and simply factored up to more recent counts). Since these data are now over 20 years old, acquiring new data on external OD patterns should be an important priority for the model update.

In recent years, fully passive data collection methods (discussed in Section 3.2) no longer require fielding equipment and instead rely on processing datasets collected/produced for other reasons (e.g., from mobile devices or in-vehicle devices). Compared to older methods like traditional surveys and semi-passive methods (e.g., LPC surveys and Bluetooth), these newer methods are more cost-effective. Moreover, unlike semi-passive methods, fully passive methods provide observations not only on external-external trips passing through the region, but also on the internal origins and destinations of inbound and outbound trips.

The development of external travel modules is one of the most widespread uses of passive OD data in travel modeling and has become commonplace. Additionally, expanding passive external OD data is often a simpler process than other OD data. This is because IPF (i.e., frataring) to traffic counts at external stations is often (but not always) sufficient to properly expand the data.

To support the full range of external travel modeling required and of interest to H-GAC, it is recommended that the passive data source(s) be segmented by vehicle class (at least light vehicles and trucks), TOD, residence (within or outside the region), and purpose (work and nonwork). This may require purchasing two datasets: 1) a GPS OD dataset specific to commercial vehicles; and 2) a cellular or LBS dataset, which can provide segmentation based on residency and purpose.

VISITOR TRAVEL PATTERNS

Passive OD data are recommended for use in determining visitor travel patterns for the H-GAC region and the development of the H-GAC visitor-related parameters, whether for adjustments or modules in H-GAC's travel models. According to the Greater Houston Convention & Visitors Bureau, Houston has more than 80,000 hotel rooms and hosted more than 20 million visitors in 2016, continuing a trend of growing tourism. Galveston Island, for example, is a major tourist attraction.

Visitor travel is significant in the region and must be accounted for to properly represent travel patterns and traffic. H-GAC, however, has not conducted a visitor survey or collected other data on visitor travel patterns. H-GAC should purchase a passive dataset that can provide OD data (and perhaps other information) specific to visitors to the region.

The use of passive OD data for visitor modeling is more recent, but quickly growing, with recent/ongoing studies in several states. Passive OD data for visitors to a region can be acquired at much less cost than a visitor survey can be conducted and can provide much (if not all) of the information needed for visitor modeling. Although it typically cannot provide party size or purpose, passive OD data can provide rich information including the entry/exit mode (auto vs. flight vs. cruise ship), duration of stay within the region (less than a day, overnight, multiple night), visitor trip/tour rates and attraction rates, trip/tour lengths, and general OD patterns to support either trip-based or basic tour-based simulation models of visitor travel.

Only passive datasets with significant device identifier persistence to allow residence location imputation can provide information specific to visitors. These datasets include LBS and cellular data. An aggregate passive dataset would be adequate to support trip-based visitor modeling. However, a disaggregate (i.e., trace-level) dataset could support tour-based modeling; this may be an option for LBS data, but it is not an option for cellular.

TRUCKING PATTERNS

Passive OD data are recommended for use in determining truck travel patterns for the H-GAC region and the development of the H-GAC travel model's truck travel modules. This recommendation is in conjunction with H-GAC's ongoing efforts to develop a new truck touring model using passive truck GPS data. Since it is likely that this new truck model, currently under development, will serve H-GAC for some time, it may not be necessary to purchase additional truck GPS data again for several years. However, it is important that the existing truck GPS dataset support both external and internal truck movements and that it can combine with a more general passive dataset to isolate light vehicle OD patterns. It is likely that the current GPS dataset may need to be reprocessed to support this functionality. It is possible, but unlikely, that a new purchase of commercial GPS OD data may be required; these data are relatively inexpensive.

Passive truck OD data are recommended in combination with a CVS to support future truck simulation modeling because these surveys can provide some valuable information such as payload, which passive data cannot. See Section 2.6 for further discussion.

ATTRACTION RATE ESTIMATION

Passive OD data are recommended for use in developing attraction rates for the H-GAC region. While attraction rates have traditionally been estimated from establishment surveys, both new multiday smartphone household surveys and passive OD data provide more cost-effective information for estimating attraction rates. While it is possible that multiday smartphone household survey data may be sufficient to support accurate attraction modeling, passive OD data should also be used in conjunction or sequence with an estimation framework. Passive data provides observations of far more attractions than establishment surveys or even multiday household surveys and is believed to be a superior data source for attraction estimation, provided it is properly expanded. However, estimation of attraction rates from passive data alone is generally limited to more aggregate categories of attractions by purpose than those typically used for AB modeling—hence, the value of household survey data in combination with passive data for this purpose. A simple, illustrative analysis of attraction rates using cellular data for the region is being conducted as a part of the project and will be summarized in an appendix to this document.

To support the estimation of attraction rates, it is necessary to use passive datasets with significant device identifier persistence to allow residence location imputation and some level of purpose imputation. Both cellular and LBS data have sufficient identifier persistence, but currently available GPS datasets for noncommercial vehicles do not.

CONSTANT RICH DESTINATION CHOICE MODELS

Passive OD data are recommended for use in the development of constant rich destination choice models in H-GAC's AB model and truck touring model. Constant rich or fixed-factor destination choice modeling is a data-driven modeling technique for simulation models that is in many ways analogous to OD pivoting in aggregate models. Both data-driven methods strive to address that the spatial distribution of trips is widely acknowledged in both practice and research (www.TFResource.org) as the largest source of error in travel forecasting. Although traditional destination choice models offer some important improvements over traditional gravity models, they still struggle to reproduce observed OD patterns. Given the even greater difficulty in representing intercity OD patterns with gravity and destination choice models than representing local patterns in urban models, data-driven approaches have become a common practice in statewide modeling (e.g., Michigan, Indiana, Tennessee, Florida). Data-driven modeling is also widespread for metropolitan modeling outside of the United States; in fact, this practice is required in the United Kingdom. Awareness of this in the United States has recently grown as a result of greater global interaction and communication. Data-driven forecasting methods are also now being applied in metropolitan modeling in the US (e.g., Chattanooga, Ann Arbor, Charleston) to leverage the full power of passive OD data.

Fixed-factor or constant rich approaches involve a deeper integration of passive OD data into a travel model than does aggregate OD pivoting. As such, they generally require more effort. However, they can also potentially yield greater benefits than pivot-point methods and are applicable to AB models, as well as more traditional aggregate trip-based models. However, the use of aggregate OD pivoting with AB models can produce inconsistencies between aggregate and disaggregate results, for example.

The fixed-factor approach works by incorporating a set of constants into the destination or activity location choice model components of a travel demand modeling system. These factors, which are alternative specific bias constants, are estimated in a statistically rigorous way to allow the model to reproduce expanded passive OD data with minimal error. Fixed factors or constants can be specific to individual or groups of origins or destinations or OD pairings.

Fixed-factor methods can be developed in two different ways. First, a sequential estimation approach in which the factors are estimated after and independently of other model parameters is like pivot-point methods in that it does not affect model sensitivities for good or ill, and it is easier to apply. This method usually involves estimating the constants as shadow prices and has been successfully applied in practice with encouraging results (Lee et al., 2016). Second, simultaneous estimation of fixed factors together with other model parameters requires more effort, but it also offers the potential for better results by addressing likely under-specification errors and potential model over-sensitivities. Over-specification errors are still possible, though this is less of an issue with Big Data. This approach, while theoretically appealing, remains untested in practice. For more details on these methods see the Federal Highway Administration's (FHWA) Travel Model Improvement Program (TMIP) guide, How-To: Develop Big Data Driven Demand for Traffic Forecasting.

Constant rich methods are notably different than traditional k factors sometimes used in gravity models. The constants discussed here are theoretically motivated, incorporated in a behavioral framework, and can be systematically statistically estimated from a sound support of passive OD data. In contrast, k factors were developed in an ad hoc fashion, with little or no theory, based on survey or traffic count data that often could not support them.

Constant rich approaches allow spatial choice models to incorporate passive OD data, better replicate observed OD patterns in the base case (Lee et al., 2016), and presumably better forecast future or alternative OD patterns. Moreover, constant rich methods can produce both agreement of aggregate OD patterns with observed data and consistency between the disaggregate and aggregate results of a simulation modeling system. In the context of simultaneous estimation of constants with other utility parameters, this approach should also theoretically lead to less biased, more realistic model sensitivities.

Any aggregate passive OD data could support some level of fixed factors in H-GAC's destination choice models. However, datasets that allow segmentation by imputed purpose (LBS or cellular) allow better segmentation of constants. Further, while aggregate passive OD data can be used to develop fixed factors—particularly using sequential estimation, fusing disaggregate (trace-level) passive data with household survey data may ultimately lead to the best methods of simultaneous estimation.

DATA FUSION WITH HOUSEHOLD SURVEY

Passive OD data are a rapidly evolving data source. The past few years have seen the entry of new vendors, entirely new technologies, and significant improvements in data quality. Modeling methodologies, generally developed with survey data in mind, are beginning to evolve in response to these new and increasingly powerful datasets. However, as noted in the introduction to this chapter, passive data and survey data are best viewed as complementary. Some of the most exciting opportunities for improving travel models involve efforts at data fusion of these complementary data sources. While efforts in this direction remain in the stage of early research, it seems increasingly likely that large-scale fusion of controlled random sample smartphone survey trace data with passively collected LBS trace data (and other commercially available data) may produce entirely new types of composite datasets in the next several years. These datasets may offer substantial advantages, combining the strengths of both traditional and passive data.

While next generation datasets may not be available to support near-term model development efforts for H-GAC, it may be worth additional exploration or investment. H-GAC should consider the possibility of this type of data fusion in the selection of passive data and purchase disaggregate trace data rather than aggregate OD data.

3.2 | TYPES OF PASSIVE OD DATA

The discussion below is focused on pertinent considerations for the selection of passive data sources for the uses recommended for H-GAC in Section 3.1. Chapter 2 of the Task 4 memorandum (Appendix B) contains a more detailed overview and discussion of the types of passive datasets.

CELL TOWER (AIRSAGE)

Cellular data could support H-GAC's basic passive data needs in combination with a truck GPS dataset. Cellular data could support external and visitor modeling, attraction rate estimation, and constant rich destination choice modeling. Cellular data from AirSage likely has the highest penetration rate of passive data sources in the H-GAC region and should be capable of expansion to represent all travel. It also has sufficient device identifier persistence to allow for the imputation of residence locations to segment resident and visitor travel as well some level of purpose imputation (although the purpose imputation still has significant limitation in accuracy and consistency with survey data).

However, the location precision of cellular data is limited, and locations are generally only known with a precision of more than 100 meters—and sometimes only within 1 to 2 kilometers or more in areas of limited tower coverage. Although precision tends to be better in urban areas with better tower coverage, this limited locational precision has implications both in the level of OD information that can be provided and the accuracy of short-distance trip patterns (important for walk trips). Further, cellular data are only available at the level of aggregate OD patterns. This limits its value for some potential applications. For instance, while cellular data could support trip-based visitor modeling, it would not support tour-based visitor modeling. It would also not support disaggregate data fusion with household survey data.

TRUCK NAVIGATIONAL GPS (AMERICAN TRANSPORTATION RESEARCH INSTITUTE; INRIX/STREETLIGHT)

H-GAC has already purchased a truck navigational GPS dataset for the development of its new truck touring model. This dataset has adequate sample penetration and—with appropriate data validation/cleaning—should be expanded to represent all truck travel. GPS offers the best possible locational precision, which supports even facility-level analyses. Truck GPS data can be processed in different ways to support various types of analysis, and it may be desirable or necessary to process the data in different ways for this variety of applications (e.g., the development of the truck touring model versus fusion with another passive dataset for all vehicles/person movements).

AUTO NAVIGATIONAL GPS (INRIX/STREETLIGHT; TOMTOM)

Although GPS offers superior locational precision and disaggregate trace-level data are often available, GPS datasets for noncommercial vehicles have two challenges that limit their usefulness to support model development. First, their sample penetration is so low that it is unclear whether there are expansion methods capable of rendering them representative of all traffic. Second, their device identifier persistence is limited, and it is generally not possible to impute residence location or purpose. For both these reasons, these data could not support important recommended elements of H-GAC's model development and is not included in the project team's recommendations.

LOCATION-BASED SERVICES (CUEBIQ; STREETLIGHT)

Although LBS data offers more variables and—on average—somewhat less precision than GPS data, it is far more precise than cellular data. Although it offers slightly lower sample penetration than cellular data, the difference is increasingly marginal, and it is equally capable of being expanded to represent all travel. Like cellular data, it also offers good device identifier persistence; however, unlike cellular data, it can be acquired at either the aggregate or disaggregate level. In these ways, LBS data offers a particularly attractive combination of attributes and may provide the best source of passive data for H-GAC's model development.

RECOMMENDATIONS ON SELECTION OF DATASETS

Given both the uses for passive data recommended in Section 3.1 and the qualities of the various available passive datasets presented in this (and the Task 4) memorandum, it is recommended that H-GAC use the truck GPS dataset it has already purchased in combination with an LBS dataset. The truck GPS data should be used to reduce the LBS dataset to represent only non-truck trips. As an alternative, and if the cost is reasonable, H-GAC might consider the purchase of a new disaggregate truck GPS dataset for the same time periods as the new LBS dataset to allow disaggregate deduplication. The LBS dataset should include or support segmentation by residence location. Disaggregate LBS trace data would be preferable for some purposes such as the development of visitor touring models or data fusion with the household survey, but aggregate LBS data may also be an acceptable option. The project team recommends LBS data to support H-GAC's model development, but cellular data could be an alternative capable of supporting H-GAC's basic analysis needs. Cellular data, however, would have some limitations (e.g., locational precision).

3.3 | PASSIVE DATA EXPANSION

All existing commercially available passively collected OD data are based on incomplete sample frames. These commercially available datasets exclude travelers without mobile devices while they travel, and these datasets include only a select portion of travelers with mobile devices. Moreover, short-distance trips or short-duration activities are often underrepresented in the data because they require more frequent observations of position that are not always available. Travel to and from locations with poor coverage can also go un- or under-detected. Failure to account for such biases can lead to erroneous representations and faulty predictions of trip rates, trip lengths, trip flows between origins and destinations, and present and future travel activity and traffic in general.

Evidence for these systemic biases with respect to demographics and trip/activity duration have both been presented at practice-oriented conferences and published in peer-reviewed journals (Bernardin et al., 2015; Zanjani et al., 2015; Bindra et al., 2015; Bernardin et al., 2017; McAtee, 2017). Demographic biases, although an important problem, are relatively more easily corrected. However, trip-length biases are particularly problematic because they can substantially distort the data, are difficult to measure and correct, and are not well understood by many practitioners.

OVERVIEW OF PASSIVE OD DATA EXPANSION METHODS

Various methods exist for expanding passively collected OD data. Expansion methods can be categorized in several ways. At the highest level, the methods can be divided in terms of what control data they use to ensure representativeness. Three types of control data can be used:

- **Geographic Penetration Methods:** Demographic/market penetration information for geographic areas can be and is commonly used, although it cannot address or correct all the important types systematic bias in passive data.
- **Traffic Count Methods:** Traffic counts are also commonly used, and there are a variety of techniques for using them to expand passive data. Although simplistic methods have important limitations, more robust methods can address all known systematic issues in passive data. The various methods that make use of traffic counts can be divided further based on whether they rely on a network assignment model. Methods that do use assignment models can be divided into those that use origin-destination matrix estimation (ODME) algorithms and those that do not (parametric scaling).

- **Disaggregate Expansion Methods:** A new type of control data is actively sampled GPS/LBS trace data with multiple levels of quality control—including the traveler and machine learning algorithms. These data can be used to audit disaggregate passive data; these new data may be the most powerful, direct, and accurate method for expanding passive data.

The expansion methods presented in this section include eight methods currently in use and one promising method, which is the topic of active research. These nine expansion methods are categorized based on the control data used and are highlighted in the list below **in bold**. Most well-conceived expansion schemes use the following methods in combination instead of single expansion method (most commonly simple scaling to traffic counts):

- Geographic Penetration Methods
  - Market Penetration
  - Trip Generation-Based
- Traffic Count Methods
  - Simple Scaling to Counts.
  - Multifactor Scaling:
    - Nonassignment-Based:
      - **IPF to Counts (Frataring).**
      - **Iterative Screenline Fitting/Matrix Partitioning.**
    - Network Assignment-Based:
      - Nonparametric (ODME):
        - **Direct ODME.**
        - **Indirect ODME.**
      - **Parametric Scaling to Counts.**
  - Disaggregate Expansion Methods:
    - Disaggregate Trace Auditing.

The matrix in Figure 5 compares these nine expansion methods across capabilities, including the ability to fix trip-length bias, fix coverage problems, or fix demographics bias. The matrix also compares methods based on other characteristics, including the independence of the network, the ease of application, the holdout count sample, and transparency.

FIGURE 5: COMPARISON OF EXPANSION METHODS

#	Method	Fix Trip Length Bias	Fix Coverage Problems	Fix Demographic Bias	Independent of Network	Ease of Application	Holdout Count Sample	Transparency
1	Market Penetatraion-based	✘	✓	✓✓	✓	✓	✓	-
2	Trip-Generation-based	✘	✓	✓✓	✓	-	✓	✓
3	Single-factor Scaling	✘	✘	✘	✓	✓	-	✓
4	Frataring	✘	✓	✘	✓	✓	✘	✓
5	Iterative Screenlines	✓	✓	✓	✓	-	✓	✓
6	Direct ODME	✓	✓	✓	✘	✓	-	✘
7	Indirect ODME	✓	✓	✓	✘	✘	-	-
8	Parametric Scaling	✓✓	✓	✓	✘	✘	-	-
9	Disaggregate Trace Auditing	✓✓	✓	✓✓	✓	✘	✓✓	✓

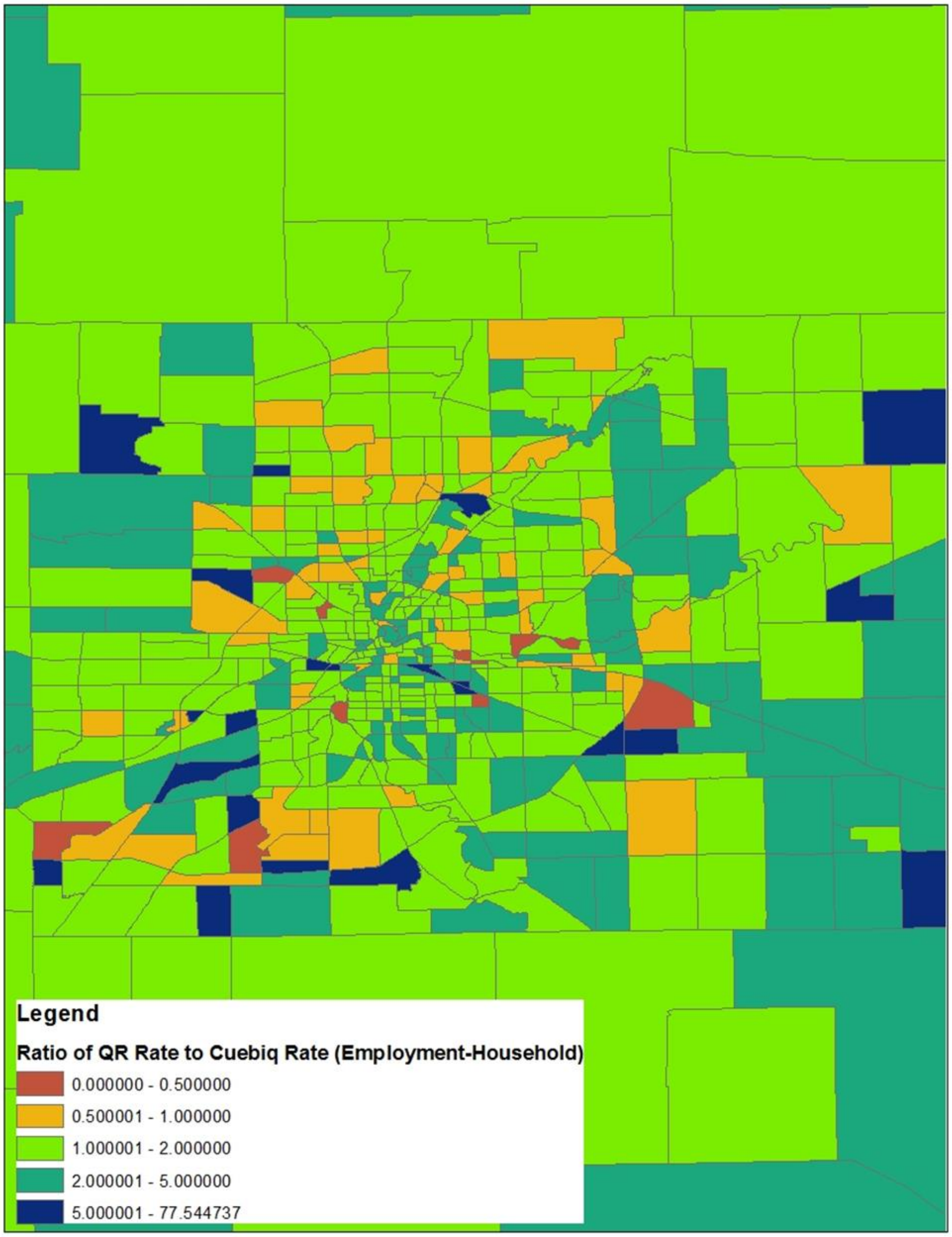
MARKET PENETRATION

Market Penetration methods require information on the portion of the population included in the sample. To be meaningful and effective, this information must be available at a relatively fine level of geographic resolution. AirSage, for example, uses data on cell carrier market penetration at the block group level to develop expansion factors for its data. Although valuable in correcting for demographic biases (e.g., biases related to income that have been demonstrated, for instance, in GPS data for the Detroit metropolitan area), they do not correct for biases related to trip detection (e.g., trip-length bias or coverage biases). This method is generally only applicable for noncommercial travel and for datasets with sufficient device identifier persistence to allow imputation of residence location (cellular/LBS)—and is therefore generally not an option for the currently available GPS datasets.

TRIP GENERATION-BASED

Trip Generation-Based methods develop expansion factors for passive data based on zonal level comparisons of observed trips in the passive data with estimated trips from trip generation models. While using these comparisons to generate expansion factors may help address coverage issues, it could also introduce biases from the trip generation model used. Based on the correlation of trip rates from multiple passive data sources for the same area, there is reason to believe that at least some of the trip rate variation observed in passive datasets may be real. Moreover, while this method can help address coverage issues, it cannot address systematic biases related to frequency of observations and trip length. Thus, comparisons with trip rates are sometimes used as a part of initial data validation and cleaning rather than as part of the actual expansion. In this context, this method is used to identify outlier locations that might require data cleaning or correction (of zonal socioeconomic data as frequently as the passive data). This approach does not require device identifier persistence, unlike market penetration methods.

FIGURE 6: RATIO OF QUICK-RESPONSE TRIP RATES TO OBSERVED TRIP RATES IN CUEBIQ LBS DATA IN NORTHEAST INDIANA USED FOR DATA VALIDATION



SIMPLE SCALING TO COUNTS

Simple Scaling of passive data to one or more traffic counts uses a single expansion factor for the whole passive dataset. In the cases where disaggregate data has sufficiently precise location information for map-matching, the method can be used directly based on a map-matching algorithm. In other cases, for less precise or aggregate data, the method is used with a network assignment model and algorithm. Simple scaling is often incorporated within or used in conjunction with the other expansion methods and is one of the most common expansion methods both used alone or in combination. The attractiveness of the method owes mainly to its simplicity, which lends itself well to explanations to nontechnical audiences and requires less effort than many other expansion methods. However, its simplicity also limits its usefulness. Since this method relies on a single expansion factor, it cannot correct for many issues including variations in coverage within a region or trip-length bias. Sometimes automobile occupancy is offered as an explanation for this scaling factor; however, this is only one of several factors that may be captured by and reflected in this type of scaling.

ITERATIVE PROPORTIONAL FITTING TO COUNTS (FRATARING)

IPF (or frataring) to traffic counts uses zonal expansion factors calculated by comparing the observed trips to/from a zone with counts of traffic entering/exiting the zone. Since it relies on counting traffic entering/exiting a zone, this method can only be used in special circumstances. It is most commonly used for external stations along a region's boundary, but it can also be used for airports and certain other special generators. This method is powerful and widely used method, when feasible. It may contribute to addressing issues such as trip-length bias but is not believed to fully correct for them.

ITERATIVE SCREENLINE FITTING/MATRIX PARTITIONING

Iterative Screenline Fitting or **Matrix Partitioning** is unique in that it uses traffic counts to produce expansion factors that may be able to correct for systematic biases—but without using a network assignment model. Avoiding the use of a network assignment model is an advantage since the use of any model can introduce error. Moreover, this approach typically can only make use of a subset of traffic counts in a region resulting in a holdout sample of counts, which can still be used to provide independent validation of the passive OD data.

The approach works by first identifying "screenlines" or "cutlines", which are commonly used to validate travel models. Each screenline should partition the study region into two subareas and align with the zone system used to define ODs, and traffic counts should be available or taken everywhere the roadway network crosses the screenline. (For this reason, it is helpful to choose screenlines that follow natural/physical barriers like rivers, freeways, and railroads—each which have limited roadway crossings.) The sum of the traffic counts along each screenline can then be compared to the number of trips in the OD matrix that cross the screenline. This comparison can be made without a network assignment model by partitioning or aggregating the OD matrix. Since each screenline partitions the region into two subareas, A and B, all origins and destinations can be identified as falling in either A or B. The OD matrix can then be aggregated into a matrix of four cells: 1) trips from A to A; 2) trips from A to B; 3) trips from B to B; and 4) trips from B to A. The two off-diagonal cells (trips from A to B and from B to A) cross the screenline while the others do not. In this way, groups of OD trips can be compared against screenline counts without a network assignment model, and a preliminary/component expansion factor is developed as the sum of the screenline counts divided by the sum of the off-diagonal elements of the aggregated matrix. The iterative screenline fitting process works by iterating or looping over the screenlines—factoring trips crossing each screenline to match the screenline counts.

Although this factoring guarantees that the OD trips match the sum of counts for the current screenline, each factor has the potential to introduce disagreement between the OD trips and previous screenlines given individual OD pairs may cross several screenlines and have several differing factors applied. For this reason, the iteration is needed so that the expansion factors for individual OD pairs can stabilize to values that minimize errors versus all the screenline counts. However, this does not guarantee perfect agreement of the OD data with any individual screenline count.

The effectiveness and value of this method is a function of the number of screenlines that can be constructed for use in the method. The method can shorten trip lengths and is believed to reduce trip-length bias when using a sufficient number of screenlines but likely does not fully correct for it—particularly for short trips. Further, the method may not achieve as good a fit to counts as alternative methods, but this stands to reason since it only uses the subset of the counts on screenlines. Thus, while the method is attractive in its independence from a network model, it may be best used in combination with other methods.

DIRECT ODME

Direct ODME is one of the most common approaches to expanding passive data in practice and is also widely documented in the literature. Several different ODME algorithms exist and each can produce significantly different results and have different properties. ODME methods that use OD data only as a "seed" or starting point and produce a final adjusted OD matrix by minimizing errors versus traffic counts are not appropriate for expanding passive OD data and can significantly distort the observed data. However, methods that attempt to find a solution and produce a final OD matrix (which minimizes errors versus counts and versus the original OD data or the original OD data with appropriate adjustment constraints) can be powerful and appropriate methods for data expansion. These methods are capable of correcting systematic biases related to trip lengths and coverage "holes" (provided there are at least some observations in the "holes" to expand).

A proper understanding of ODME is grounded in two facts. First, counts provide real-world information about underlying OD patterns. Second, counts alone cannot be used to identify OD patterns. Each of these facts can be proved mathematically. The truth of the former is demonstrated, for instance, in the method of iterative screenline fitting. The truth of the latter is evident from the number of "known" traffic counts, which is always substantially smaller than the number of "unknown" OD flows. Therefore, the problem is statistically under-determined, and there is not a unique set of OD flows that correspond to a set of traffic counts on a network.

On the one hand, from the first fact that counts provide information about the underlying OD patterns, ODME has real potential to improve or correct OD matrices produced using passive data. From the second fact that counts alone cannot identify OD patterns, ODME methods focused solely on count data are ill-conceived. A balanced ODME approach recognizes the value of both traffic count data and passive data and uses traffic counts as control data to improve the representativeness of OD data while being careful not to mangle or distort it. Mathematically, the OD data are more important than the count data in producing a usable final solution. This is because the OD solution space dwarfs the network solution space. If an ODME method is used consistent with this fact, then it can be an efficient and powerful tool for expanding passive OD data.

Direct ODME has several practical advantages as a method to expand passive OD data. Since software implementations of ODME algorithms are widely available, direct ODME is one of the quickest and easiest ways of expanding OD data to traffic counts and correcting for systematic trip-length biases. In fact, ODME can correct for several types of errors or biases in the OD data without requiring complex methods or in-depth analysis. However, this is not without its downsides. ODME can over-correct and distort OD patterns to over-fit count data if not used carefully and appropriately. This danger and the distrust that it inspires in some professionals is the main drawback of the method—together with its lack of transparency and the difficulty of understanding the underlying issues that the expansion adjustments address.

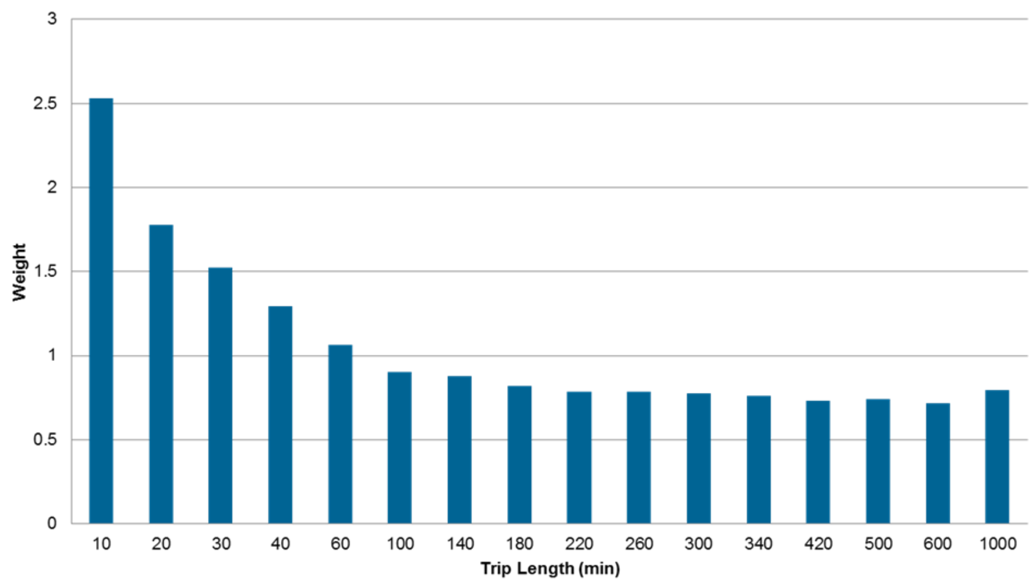
Using ODME in combination with and secondary to other expansion methods like iterative screenline fitting or parametric scaling can allow the imposition of tighter constraints on the ODME adjustments and greater confidence in the expansion while also allowing a tighter fit to traffic counts. If H-GAC desires a tighter fit to counts than is ultimately produced by other methods, then a final round of ODME expansion adjustments (within strict constraints) is recommended as a final, optional step in the expansion.

INDIRECT ODME

Indirect ODME involves analyzing the results of ODME to develop a simpler set of expansion factors. This approach can coincide with parametric scaling—but can also involve the development of nonparametric schemes of expansion factors based on trip length or districts. A more limited set of expansion factors can be more readily understood and interpreted than a multitude of direct ODME-based expansion factors and, in this way, inspire greater confidence in some cases. Moreover, this approach can help establish the amount of the ODME adjustments related to a specific phenomenon (e.g., trip length) and confirm that these adjustments (e.g., changes in average trip lengths) result in better agreement between the OD data and traffic counts independent of the details of the ODME adjustments. The chart in Figure 7 illustrates truck trip-length-based expansion factorings using this method in an example from Iowa.

This approach provides a relatively higher level of transparency and interpretability of final results compared to direct ODME, supports insights from ODME, and requires an intermediate level of effort from leveraging widely available ODME algorithms. The level of effort associated with the approach can vary depending on the complexity of the expansion factors developed. Basic schemes to address trip-length bias can be applied with only marginal additional effort compared to direct ODME, while complex schemes using multiple factors can require substantial effort. The additional increment of effort beyond direct ODME is one of the disadvantages of the approach—together with the inability of the method to produce as good of an agreement with counts as direct ODME or correct for errors in the data that are more difficult to understand or identify.

FIGURE 7: TRUCK TRIP-LENGTH-BASED EXPANSION FACTORS FROM INDIRECT ODME IN IOWA

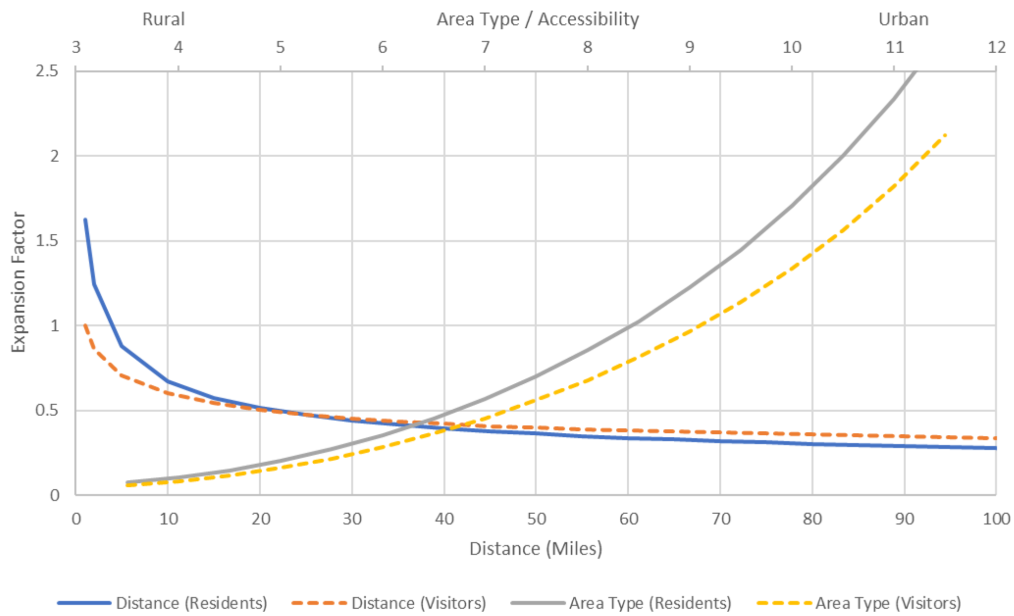


PARAMETRIC SCALING TO COUNTS

Parametric Scaling is perhaps the most theoretically straightforward way of addressing and correcting for systematic trip length and certain other biases in passive OD data, but this method can also be one of the more complex methods in practice. In theory, this method may be applied to datasets with sufficient locational precision for map-matching without the use of a network assignment model; however, this would require substantial data processing, and it has only been applied to date using a network assignment model. The approach is to estimate the parameters of a formula that produces expansion factors for trips as a function of their length or other attributes. The parameter estimation is challenging, and several methods have been used in search of a statistically and computationally efficient method. Direct least squares error (LSE) versus traffic counts has been conducted using a genetic algorithm; this method is statistically efficient but extremely computationally inefficient. Sequential LSE (and close analogs) are not statistically efficient, but much more practical. This approach is a form both of indirect ODME and parametric scaling in which regression is used taking the ODME expansion factors as the observed data. The chart in Figure 8 illustrates calibrated expansion factor curves from parametric scaling in an example from the Charlotte, North Carolina, region. Results have been mixed. Given a relatively simple specification of the expansion factor function, parameters can also be calibrated heuristically.

This approach has the advantage of producing relatively easily understood expansion factor formulas and avoiding or reducing the ambiguities of ODME-based approaches. Further, it can be firmly grounded in a robust statistical procedure; in practice, less rigorous methods may be more appropriate. However, the involvement of a network assignment model and complexities of the parameter estimation can be drawbacks and, in some cases, require more effort.

FIGURE 8: CALIBRATED EXPANSION FACTOR CURVES FROM PARAMETRIC SCALING FOR THE CHARLOTTE, NORTH CAROLINA, REGION



DISAGGREGATE TRACE AUDITING

Disaggregate trace auditing is a new method for expanding passive data being studied by FHWA's TMIP. This approach audits the trace data of a small subsample of individual travelers in the passive dataset by actively engaging them in a smartphone-based GPS travel survey. The smartphone survey application creates a high-quality assured trace of an individual's travel on a day or set of days. The device itself tracks the traveler using GPS or LBS and creates a preliminary trace. The travelers then review/verify their traces that day and add any missed trips, drop any false trips, and fix any inaccurate locations. The respondent-verified trace is then processed using machine learning algorithms trained to identify traces that may have problems. Analysts then review traces flagged by the algorithms as questionable. In this way, the survey application produces highly accurate travel traces that can be used as control data for expanding passive data. Comparison of a sufficiently large set of survey traces with the passive traces of the same individuals on the same days can support statistical inferences about the completeness and accuracy of the passive data and key parameters of an expansion factor function. The function can also include demographic parameters based on statistical comparisons of the demographics reported by the survey respondents and those of the population at large. In this way, disaggregate trace auditing may provide the most direct and powerful means of expanding passive data to represent all travel.

This new method can only be applied to disaggregate passive datasets with sufficient locational precision like GPS or some LBS, but it is not possible with cellular data. The method requires either additional data collection (survey data) or the inclusion of trace auditing as part of the sample design of a concurrent smartphone-based GPS household survey. For some regions, this approach may be cost prohibitive—but for other regions, such as H-GAC, that may be considering a smartphone-based GPS household survey, the marginal cost of the approach should be comparable to other expansion methods. Moreover, disaggregate trace auditing can serve the dual purpose of passive data expansion and being part of a larger, more ambitious scheme for passive and survey data fusion.

RECOMMENDATIONS FOR PASSIVE DATA EXPANSION

A multitiered approach to the expansion of passive data is generally advisable given the different limitations of various methods. If H-GAC were to acquire the recommended disaggregate LBS data in combinations with disaggregate truck GPS data, the following recommendations are offered regarding its expansion:

- Geographic penetration methods should be used first for data validation and cleaning. If this reveals demographic biases, then one of these methods should be used to develop preliminary, component expansion factors.
- IPF should be used for external stations, the airports, and other special generators as possible.
- If possible, both in terms of budget and the ability to construct the necessary screenlines, iterative screenline fitting should be conducted next.
- Then, at least one of the following methods should be applied. Multiple methods could be used in combination, if desired. Parametric scaling is likely to produce the best expansion factors among these methods, but the choice of method(s) should also consider level of effort and the desired level of agreement of assignment results to counts:
    - Parametric scaling.
    - Direct ODME.
    - Indirect ODME.
- H-GAC should also include disaggregate LBS trace auditing as a part of its sample design if it opts to conduct a smartphone household survey. H-GAC should also perform disaggregate trace auditing independently of the other methods above to validate the expansion factors produced by that process, if possible. Reliance on disaggregate trace auditing alone is not recommended due to the lack of proven applications.

CHAPTER 4. SUMMARY OF RECOMMENDATIONS

4.1 | INTRODUCTION

This chapter summarizes recommendations for H-GAC and includes the following sections:

- Household travel surveys.
- Possible supplemental surveys to the household travel survey.
- Transit user OD surveys.
- Airport surveys.
- Commercial vehicle travel surveys.
- Aggregate passive data.

4.2 | HOUSEHOLD TRAVEL SURVEYS

The RSG team recommends that H-GAC commission a household travel survey as soon as is feasible to provide data to update the TourCast model and for regional planning. RSG recommends the following methodology:

- Use **smartphone-based GPS data collection**, for up to 7 days per household, with a 1-day, diary-based survey option for individuals without smartphones.
- Use random, **ABS** with **targeted geographic oversampling** for key market segments.

SMARTPHONE-BASED GPS DATA COLLECTION

Smartphone-based GPS travel data collection provides the same data items as a more traditional diary-based survey. The crucial difference is that the trips ends (locations and times) are recorded automatically via a smartphone app, and then the respondent is prompted to provide details of each trip (e.g., purpose, mode, co-travelers) within that same app. This method has the following advantages:

- The GPS-based trip times and locations are usually **more accurate** than self-reported data.
- The number of trips captured tends to be 15-20% higher compared to diary-based methods. Analysis has shown this **reduction in nonresponse bias** to be significant, even after accounting for demographic differences between the smartphone-based GPS and diary-based samples.
- Respondents usually provide trip details within a few hours of completing the trip, **reducing the chance for recall error**, and providing evidence of the **lower respondent burden**.
- Most households provide **multiple days of useful travel data**. Analysis has shown that about 75% of households that complete 1 day go on to provide at least 5 complete days of travel data. Furthermore, each day's data **provides mostly unique trips** that were not captured on earlier days. For most trip purposes, five weekdays of data provide about four times as many unique trips as one day of data.

ADDRESS-BASED SAMPLING WITH GEOGRAPHICALLY TARGETED OVERSAMPLING

Addresses to send survey invitations to should be selected randomly by commercial address providers. The percentage of invited households should be determined geographically, with the Census Block Groups (CBGs) in the region apportioned into different sampling strata based on the following factors:

- **Rare trip types (e.g., transit, bicycle users):** ACS block group data on commute mode share is useful for identifying neighborhoods with a proportion of nonauto commuters. Transit agencies may also help to identify additional neighborhoods with high noncommute transit use.
- **Hard-to-reach populations:** Certain groups, such as very low-income households and non-English-speaking households, tend to exhibit lower response rates to travel surveys. ACS block group data are also useful to identify the areas with the highest concentrations of these groups, and the invitation rate can be increased to compensate for the lower expected response rates. Additional outreach efforts in such neighborhoods can also be worthwhile.
- **Areas of particular regional or local interest:** These may include designated "smart growth" areas such as transit-oriented or mixed-use development. In some cases, local city agencies may also be interested in contributing funding to collect a larger sample within their boundaries.

The RSG team recommends that the percentage of the households in the oversampled areas invited to participate in the survey be at least twice as high as in the non-oversampled areas. This is particularly true for low-income areas, where the oversampling is compensating for lower response rates *and* obtaining a larger-than-proportional sample of such households for modeling.

Incentives

H-GAC should offer incentives, which can increase overall ABS response rates anywhere from 1% to 6% and reduce overall recruiting costs. For smartphone-based GPS travel surveys, a typical incentive is in the range of $10 to $20 per adult in household, paid only to households that complete the entire survey. Incentives are often paid in the form of gift cards. If gift cards are used, offer a choice among different ones (Amazon, Starbucks, Walmart) to avoid biasing the sample toward any specific type of consumer. A pilot survey can help gauge response rates for different incentive levels.

Sample Size and Frequency

Recent regional household travel surveys include sample sizes that range from 0.4% to 0.65% of the households living in the region, with larger regions including between 0.4% to 0.5%. For H-GAC, the RSG team recommends a minimum sample size of 0.4% of the region's 2,500,000 households, which is 10,000 households. If 70% of the households participate via smartphone and provide an average of 4 days of data, this will produce 28,000 household-days of smartphone-based GPS data, plus 3,000 days of diary-based data.

With new travel alternatives like TNCs and CAVs, travel behavior is expected to change substantially over the coming years. The traditional 10-year cycle between household travel surveys may now be too slow. The RSG team recommends that H-GAC consider conducting a household travel survey every 4 or 5 years, matching the frequency of the long-range planning cycle for most MPOs. More frequent data collection cycles, growing smartphone use among the population, and the increasing availability of passive data to supplement disaggregate survey data also mean future surveys may require smaller sample sizes, especially if data collection occurs over multiple days.

SURVEY COST

A household travel survey currently costs between $200 to $300 per household, depending on several factors, including the following:

- The sampling and data collection methods.
- Economies of scale based on sample size.
- The number of languages offered and the extent of outreach effort.
- The level and effectiveness of incentives offered.

As an example, the 2016-17 NHTS, a diary-based survey using ABS, cost approximately $225 per household. Surveys using smartphone-based GPS data collection currently tend to be somewhat more expensive per household, but less expensive per household-day of data provided.

WEIGHTING AND EXPANSION

The RSG team recommends using a multi-stage approach to weighting and expansion:

- Perform initial expansion based on the different sampling strata used in the sampling plan, dividing the actual number of households living in each stratum by the sample households in the stratum.
- Use IPF to match external targets more closely based on ACS data. Use a list-based IPF approach that can accommodate targets at both the household-level (e.g., size, income, number of workers, number of vehicles, age of head of household, presence of children) and the person level (e.g., age, gender, worker status, student status, ethnicity). Use constraints on the weighting procedure to prevent weights on individual households from becoming too large or too small.
- Use the most recent ACS 1-year microdata to set sampling targets at the PUMA level and combine adjacent or similar PUMAs if it is not possible to match the targets at the PUMA level.

Table 2, presented already in Chapter 2, provides an overview of how the recommendations above serve to provide the desired data characteristics for AB modeling and other survey-based analyses.

4.3 | POSSIBLE SUPPLEMENTAL SURVEYS

Several supplemental surveys can be conducted in concert with a household travel survey.

UNIVERSITY STUDENT SURVEY

University students who live in on-campus housing ("group quarters") are excluded from ABS frames. Other university students also tend to exhibit low response rates for ABS due partly to a high frequency of address changes. One way of inviting university students to participate in a household travel survey is to obtain the university's cooperation and either obtain a list of student e-mail addresses or have the university e-mail the invitations to the students. This is an inexpensive method of sampling and so the RSG team recommends investigating the possibility with the major universities in the Houston region. The smartphone-based GPS data collection is highly suitable for students as they have nearly 100% smartphone ownership. Also, most university students live alone or with nonrelated roommates/housemates so there is no need to collect data for other household members.

TOLL ROAD USER SURVEY

A follow-on survey of toll road users identified from the survey data is a cost-effective option if H-GAC conducts an SP survey or survey of toll users' attitudes. As another option, intercept surveys or LPC at toll locations is a possible method for inviting more toll road users to participate in the household travel survey.

BICYCLE USER SURVEY

An intercept OD data along key cycling routes can provide useful data on cycling patterns which, along with bicycle count data, can be used to calibrate bicycle demand predicted by the H-GAC TourCast model. If the timing allows, such an intercept survey also provides an opportunity to invite cyclists to participate in the household travel survey.

RIDE-HAIL/CARSHARE USERS

The use of TNCs is of growing interest to planners in many regions. Based on recent experience, collecting multiple days of data from a large regional sample may provide enough TNC trips to include that option in mode choice modeling. Respondents can also be asked extra questions about their retrospective frequency of use of these options, or their attitudes toward them. Intercepting TNC users at frequent pick-up/drop-off spots and inviting them to participate in the household travel survey (HTS) is also an option, one which may obtain both residents and visitors in the sample.

AUTONOMOUS VEHICLE ATTITUDES/STATED PREFERENCES

Although it may seem quite early to ask people about CAV options they are not yet familiar with, the likely introduction of these options introduces a great deal of uncertainty into the long-range planning process. By setting a benchmark using current surveys, H-GAC can begin to monitor attitudes and preferences over time. If there are only a few questions, they can be added as part of the main HTS instrument. Otherwise, a follow-on survey would be a cost-effective option.

4.4 | TRANSIT ON-BOARD SURVEYS

H-GAC is currently conducting a transit on-board survey, so these recommendations are general recommendations/guidelines for the future.

METHODOLOGY/SAMPLING

- Use on-board tablet-based intercept surveys at a 10% sampling rate of all boardings.
- Conduct an additional on-to-off survey, with 20% sampling of all boardings.

FREQUENCY/TIMING

- Every 3 to 7 years, depending on consideration of new projects or FTA New Starts projects.

COST

- $1 million+ for 40,000+ on-board survey responses plus on-to-off survey

4.5 | AIRPORT SURVEYS

An airport survey measures ground access travel to and from the airport and reveals visitors' trips to the region. The visitors are a self-selected group who choose to arrive by air and include international visitors for whom no other data are available.

METHODOLOGY

- Conduct tablet-based surveys asking respondents about their trip to the airport. For visitors, ask questions about their stay in the Houston region.
- Intercept respondents at airport gates.
- Possibly include SP questions about ground access preferences.

SAMPLING

- Use OAG Aviation Worldwide Limited data (OAG.com) for future flight schedules.
- Can specify mix of domestic and international flights.
- Possibly include airport employees. (They are already covered by HTS and passive data but may be of interest if the airport is contributing funding to the survey.)

EXPANSION

- Use FAA data for passengers.
- Airline Ticket Sample (DB1B) data.
- T-100 Segment data.
- Use airport's data for employees.

FREQUENCY

- Every 2-3 years for a longitudinal understanding of mode choice and factors affecting mode choice.
- May depend on supplemental funding from airports.

COST

- ~$200,000 to $500,000 depending on methodology

4.6 | COMMERCIAL VEHICLE SURVEYS

H-GAC is currently building a new commercial vehicle model based on aggregate passive data but may wish to consider collecting disaggregate data to later update that model.

METHODOLOGY

The main recommendation is to use a smartphone application to collect the commercial vehicle data. The advantages are analogous to those for HTSs, including the following:

- Less burdensome, making recruitment and retention easier.
- Higher rate of survey completion and accuracy.
- Fewer instances of missed or underreported trips.
- More observed driver-days given multiple days of travel for each respondent.
- Includes GPS data on commercial vehicle drivers without the need for a separate survey.

SAMPLING

- Include 600-800 establishments
- 60%-70% of the sample includes a cross-section of establishments in various industries.
- 30%-40% of the sample are establishments in the truck transportation and freight industry.
- Include 2,400-3,200 drivers.
- Consider key geographic distinctions within the H-GAC region and establishment size and industry.
- Oversample industries likely to use service or delivery vehicles.
- Include incentives.

EXPANSION

- Expand to represent total population of establishments in the region.
- Distinguish between establishments that employ their own drivers and those that use transportation or services.

FREQUENCY

- Every 5 to 10 years.

COST

- Ranges widely.
- Examples range from $350,000 to $1.5 million.

4.7 | USE OF PURCHASED PASSIVE DATA

The RSG team *does not* recommend conducting visitor surveys, establishment surveys, external surveys, or special generator surveys (other than possibly at the airports). Instead, the RSG team recommends using purchased passive data for these purposes. Although cell tower-based (AirSage) data has been the most commonly used type of passive data to date, the RSG team recommends using location-based services (LBS) data if possible due to its greater accuracy and increasing availability.

Table 4 shows the different travel markets and trip types that need to be covered in the H-GAC regional model. The key trip type, predicted by the TourCast model, are the internal trips made by residents of the region. They are the focus of the HTS and transit on-board survey. If an airport access survey is carried out, that would deal mainly with resident and visitor internal trips, although it could also capture some I-X and X-I trips made by nonresidents driving to depart from a regional airport.

Otherwise, disaggregate location-based services (LBS) data are recommended as the primary data source for modeling all I-X, X-I and X-X trips, and modeling I-I trips made by visitors and commercial vehicles. LBS data are also important as a supplemental source for the resident internal market. It will be important in calibrating/estimating destination choice models and calibrating the model for special generators.

TABLE 4: DATA SOURCES RECOMMENDED FOR VARIOUS MARKETS AND TRIP TYPES

MARKET	INTERNAL – INTERNAL (I-I)	INTERNAL – EXTERNAL (I-X)	EXTERNAL – INTERNAL (X-I)	EXTERNAL – EXTERNAL (X-X)
Residents	• Household travel survey (HTS) • Transit on-board survey; Airport survey (APS); • Disaggregate LBS data	• Disaggregate LBS data • HTS*	• Disaggregate LBS data • HTS*	N/A
Visitors/ nonresidents	• Disaggregate LBS data • Airport survey (APS)	• Disaggregate LBS data • APS *	• Disaggregate LBS data • APS *	• Disaggregate LBS data
Commercial Vehicles	• Disaggregate LBS data • Commercial vehicle survey (CVS)	• Disaggregate LBS data • CVS *	• Disaggregate LBS data • CVS *	• Disaggregate LBS data

* Main purpose is to capture internal (I-I) trips, but also captures some I-X and X-I trips.

RECOMMENDED USES IN H-GAC MODEL DEVELOPMENT

The RSG team recommends using purchased passive data for the following elements of H-GAC model development:

Resident Travel Patterns (OD and TOD)

- Calibrate work and nonwork OD patterns by time period from the TourCast destination choice and TOD models.
- Consider new destination choice estimation methods combining disaggregate HTS and passive data.
- Undertake more detailed modeling and calibration for Special Generators (e.g., airport, medical center, major shopping malls, universities).

Visitor Travel Patterns

- Use disaggregate LBS data (and possibly airport intercept survey data) to update visitor travel models.

External Travel Patterns

- Use disaggregate LBS data to update external models to predict XX trips between pairs of external stations, as well as IX and XI trips between external stations and internal zones.

Trucking Patterns

- Use existing aggregate passive data to develop/calibrate commercial vehicle travel model (work already underway.)
- Consider using more recent and detailed disaggregate LBS data.

Attraction Rate Estimation

- Use disaggregate LBS data to update attraction rates in the H-GAC 4-step models, if desired.

RECOMMENDED PASSIVE DATA ACQUISITION

The RSG team recommends that H-GAC purchase a LBS dataset capable of supporting segmentation by residence location (home location zone within the region for residents, or most likely external station used for nonresidents).

Besides residence location, the data should include the following:

- All trip types (II, XI, IX, XX), with trip end locations coded to transportation analysis zone (TAZ)/external station level.
- Adequate spatial accuracy and quantity (duration) of data to enable thorough analysis of OD patterns for special generations in the region.
- Trip end purposes identified as home, work, or other, based on imputed home and work locations.

- Expansion factors or information necessary for expansion

If possible, purchase of disaggregate LBS trace data would be preferable to allow H-GAC more flexibility in aggregating, imputing, and expanding the data. If disaggregate data purchase is not possible or affordable, aggregate LBS data are also an acceptable option. (As a last resort, cellular data could serve some purposes, but with less spatial and temporal accuracy, and greater trip-length bias than LBS data.)

The truck GPS dataset already purchased by H-GAC should be used in combination with the purchased LBS dataset, to "de-duplicate" the truck trips, leaving a remaining dataset representing personal vehicle trips. As an alternative, consider the purchase of a new disaggregate truck GPS dataset that covers the same time periods as the new aggregate LBS dataset to allow more accurate disaggregate de-duplication of truck trips.

Expansion

The RSG team recommends a multitiered approach to expansion of passive data, including the following:

- Geographic penetration methods for data validation/cleaning.
- IPF for external stations, airports, and other special generators.
- Iterative screenline fitting, if possible.
- Application of one or more of the following methods:
  - Parametric scaling.
  - Direct ODME.
  - Indirect ODME.
- Include disaggregate LBS trace auditing as part of the sample design if also conducting a smartphone-based GPS travel survey.

4.8 | RECAP OF MAIN RECOMMENDATIONS

PRIMARY RECOMMENDATIONS FOR THE HOUSEHOLD TRAVEL SURVEY

- Use address-based sampling (ABS) with geographic oversampling and incentives.
- Use smartphone-based GPS data capture for up to 7 days as the primary retrieval method.
- Allow a travel diary-based, one-day survey option (online or telephone) for individuals without smartphones.
- Conduct a household travel survey of approximately 10,000 households.
- Survey a supplemental sample of university students from e-mail lists, if universities are cooperative.

PRIMARY RECOMMENDATIONS FOR USE OF PASSIVE DATA

Purchase location-based services (LBS) data for all internal, external, and through trips that includes:

- Trip end locations at TAZ/external station level, particularly for special generators.
- Identification of region residents versus nonresidents.
- Imputed trip end purposes by home, work, and other.
- Expansion factors or information needed for expansion.

A purchase of disaggregate LBS data would provide more flexibility in terms of imputation, aggregation, and expansion.

SECONDARY RECOMMENDATIONS FOR OTHER SURVEY TYPES

Other possible surveys are less critical in terms of schedule and/or necessity and include the following:

- An airport ground access survey could be useful to study both resident and visitor travel. Joint funding from airports would help to fund multipurpose surveys.
- A new transit on-board intercept survey will not be needed for 5 years or more.
- A disaggregate, smartphone-based GPS commercial vehicle travel survey could be valuable for the next freight model update.
- Surveys of toll road users, bicycle users, or TNC/carshare users could be efficiently coordinated with the HTS for supplemental sampling or as a follow-on survey.
- Questions about attitudes/preferences for CAVs could help to set a benchmark to follow trends over time.

APPENDIX A. IDENTIFICATION OF MODEL UPDATE NEEDS AND TRAVEL DATA/SURVEY NEEDS (TASKS 2 AND 3 MEMO)

A.1 INTRODUCTION

The purpose of this memorandum is to identify the major objectives of the Houston-Galveston Area Council (H-GAC) travel demand forecast model update and enhancement process. Each section of this memorandum reviews the current characteristics of individual model components and identifies potential future updates of each component. The models/model components reviewed include the following:

1. Trip-Based Passenger Model.
2. AB Passenger Model.
3. OD and External Models.
4. Special Generator Models/Non-household Travel Markets.
5. Trip-based and Tour-based Commercial Vehicle Model.

Each section discusses the key variables and parameters for the model update process along with specific market segment considerations. Discussions of each model component focus on possible model updates or improvements—identified based on H-GAC priorities and examples from other regions—that future surveys may need to support.

Each section will also identify specific travel and traveler-related data items needed to support these identified updates and enhancements of the existing model structures. Further, the sections suggest specific types of travel surveys or datasets that offer the potential to collect these data items of interest.

A.2 TRIP-BASED MODEL

MODEL COMPONENTS AND CHARACTERISTICS

The H-GAC trip-based model is an advanced "4-step" model, which H-GAC last updated to a 2012 base year and validated in 2014, based on the H-GAC "Regional Travel Models 2012 Model Validation and Documentation Report" of August 2014. For resident internal travel, the model system contains the following "standard" components:

- Population synthesis.
- Trip generation models (using fixed generation rates, by purpose and person type).
- Trip distribution models (using a gravity model formulation).
- Trip mode choice models (addressing auto and transit travel).
- TOD distribution (using fixed factors).
- Network assignment (for auto and transit).

KEY VARIABLES AND PARAMETERS FOR UPDATE

The key variables and parameters that are used in the models and require updating include the following:

- **Population synthesis:** Household and person characteristics (e.g., marginal control totals) and population, by zone.
- **Trip generation**: Household demographics and trip rates, by household type and trip purpose.
- **Trip distribution**: Land-use data (e.g., employment, households, schools), and trip attraction rates by land-use type and purpose. Also, gravity model impedance function parameters based on travel times (or possibly generalized costs).
- **Mode choice models**: Mode choice model utility parameters, by mode and trip purpose. These include relative trade-offs between different cost and time components (VOT), and mode bias parameters. Both values of time and mode bias parameters can be related to demographic characteristics such as income.
- **TOD factors**: Observed TOD distributions, by trip purpose.
- **Network assignment**: Values of time, by trip purpose and income group.

These parameters and choice models could conceivably use new data in three separate ways:

- To fully re-estimate parameters (and possibly enhance the model specification).
- To re-calibrate existing parameters and specifications to match observed choice distributions.
- To validate the resulting models against observed network conditions (e.g., counts, speeds, boardings).

If H-GAC were to consider updating the parameters of the trip-based model based on new survey data, then it would not require additional data beyond what would be required to update the AB model, which is discussed in Chapter A.3. Thus, RSG did not include a discussion of data required to update the trip-based model.

MARKET SEGMENT CONSIDERATIONS

The resident models for internal trips use the following key segmentations:

- **Spatial**: 5, 263 zones (46 are external), which is considerably more than the 3,000 zones than used in the previous version of the model. These are also categorized into five area types—from central business district (CBD) to rural—based on land-use densities.
- **Temporal**: The model uses five time periods—AM peak, midday, PM peak, evening, and night. The “evening” period was added for the newest version of the model to capture some peak-spreading from the PM peak.
- **Modes**: The auto mode is split into three occupancy classes—Drive alone, Shared ride 2, and Shared ride 3+. (Toll vs. nontolled path choice was also previously handled in mode choice, but was moved to traffic assignment for the latest version of the model.) The transit mode is split into three access types—Walk to transit, auto driver to transit (park-and-ride), and auto passenger to transit (kiss-and-ride). The transit mode is also split by path type (local bus, express bus, commuter bus, light rail, commuter rail). Walk and bike are not included in the trip-based model. School bus is handled in trip generation rather than mode choice, by splitting the education

purpose into two subpurposes: one that is constrained to use school bus, and one that can use the other modes.

- **Purposes**: The purposes are HBW, home-based education (HB-ED), home-based shopping (HBNW-Retail), home-based airport trips (HBNW-Airport), other home-based trips (HBNW-Other), non-home-based from work (NHB-Work based) and other non-home-based (NHB-Other).
- **Demographics**: Census-based household distributions sorted by household size, number of workers, and income category are used to generate a synthetic population of households and persons. The trip production rates per person for each trip purpose are varied for each combination of these three dimensions (5 household size classes x 3 categories for number of workers x 5 income groups = 75 different production rates for most trip purposes). The models do not directly use person-level variables, although age distributions and employment status are captured indirectly through the different trip production rates.

POTENTIAL UPDATES/IMPROVEMENTS

The newest trip-based model for resident internal travel includes several advanced features:

- A large number of zones to accommodate small zone size in urban areas.
- Population synthesis to create a cross-classification of household types in each zone.
- Multiple transit sub-modes in mode choice and assignment.
- Treatment of airport trips as a special generator.
- Weighting of time across modes for impedance in the gravity model.

In some other regions, further advancements have been made to trip-based:

- Including an auto ownership model, and using auto availability as a variable to further segment households, which would allow market segmentation defined by both auto sufficiency and income. Auto ownership is a standard survey item in HTSs; thus, this would not create any new survey needs.
- Using a discrete destination choice model specification rather than a gravity model for trip distribution. Discrete destination choice models are used in the AB model system, so this would not require any additional survey data relative to the AB model needs.
- Using regression equations for trip production that are sensitive to the accessibility logsum measure from the destination choice model (predicting induced or suppressed trips). This change would require more advanced modeling methods, but it would not require additional data beyond what is in a standard HTS.
- Using a TOD choice model that is sensitive to relative congestion levels rather than fixed factors. Again, this enhancement would require more advanced modeling methods, but it would not require additional data beyond what is in a standard HTS.
- Adding walk and bike modes to mode choice, either separately or as a composite “nonmotorized” mode. To capture walk and bike travel accurately, it is important that HTSs capture short trips (e.g., a person taking a walk near her or his home for

exercise or someone making a short walk trip from work to get lunch or perform an errand). Also, to validate such a model, it would be useful to have bicycle count data along key bike routes and potentially bicyclist intercept surveys to also collect OD data. Note that it would also be possible to collect count data and OD data for pedestrians; however, that is less common in practice.

- Splitting out a home-based University purpose (as is done in the AB model and mentioned in the Special Generators Section 5.2). University students who live off campus can be captured in typical HTSs, although their response rates tend to be lower than most other segments of the population. Therefore, geographical oversampling in university areas is often useful. Targeted sampling of students living on campus can often be done via university e-mail lists.
- Adding a new mode for Uber, Lyft, and any similar ride-hailing services. This enhancement is discussed further below in Chapter A.4.
- Incorporating subzone or micro-zone geographies that improve spatial accuracy for modeling short walk or bike trips or walk access to transit. This enhancement is also discussed further below in Chapter A.4. Using various levels of geography in a single model system is a more frequent practice for AB models.
- Using some simple representation of tours to better model non-home-based trips (e.g., "hybrid models").

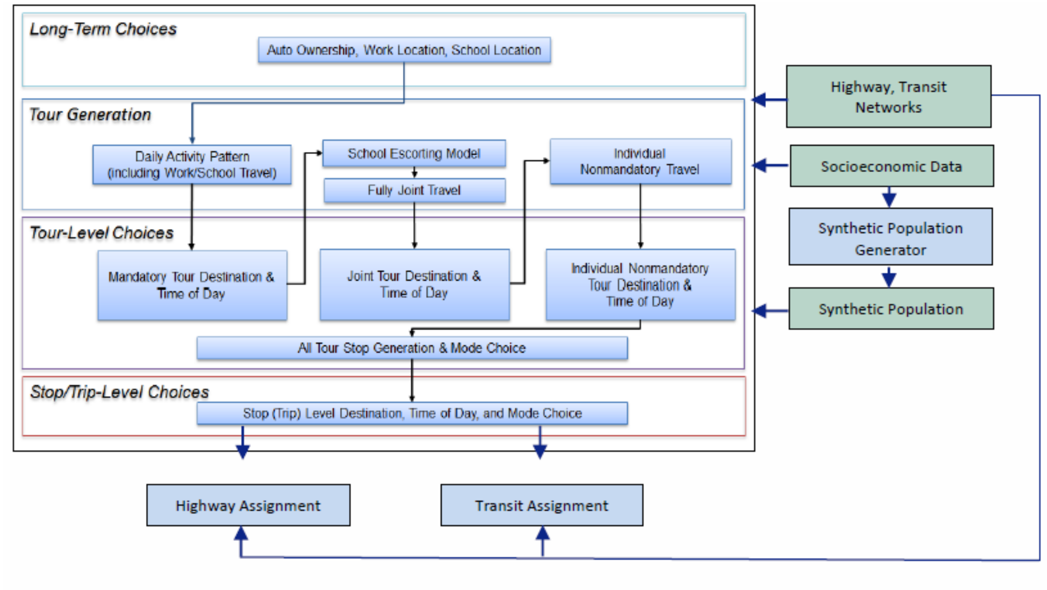
Most of these improvements would add new features to the trip-based model that the H-GAC AB model already includes. So, while these various improvements might be worthwhile if H-GAC were intending to use the trip-based model as its main forecasting model into the future, they may not be worth the effort or expense if the use of the trip-based model is to be phased out over time in favor of using the AB model.

A.3 ACTIVITY-BASED TRAVEL MODEL

MODEL COMPONENTS AND CHARACTERISTICS

The H-GAC AB model uses the TourCast model structure and software. The information for this section is based on the Cambridge Systematics "H-GAC Model Validation Report" (*H-GAC_val report draft 5.pdf*) provided by H-GAC. The H-GAC AB model structure, shown in Figure 9, is like that of other TourCast implementations in Minneapolis and Baltimore, and it is also like the structure of the CT-RAMP AB models used in Atlanta and the Bay Area.

FIGURE 9: TOURCAST MODEL STRUCTURE



The H-GAC TourCast model system has components in common with nearly all the AB model systems currently in use in the United States:

- Long-term choice models of usual work and school locations and auto ownership.
- Models that ultimately generate tours at the person level, with subsequent models that predict any intermediate stops on those tours.
- Destination choice, TOD, and mode choice models at both the tour level (round-trip) and the trip level.

In addition, the H-GAC TourCast model includes several models that explicitly simulate coordination of travel across household members:

- A model that predicts the Daily Activity Pattern type (e.g., stay at home, work/school, other out-of-home) simultaneously for all household members.
- Models of generation of and participation in “fully joint” nonmandatory tours, where two or more household members make the entire tour together.
- A model of household members chauffeuring/escorting other household members to school. In this case, the entire tour may not be joint, as parents often drop children at school and then return home or travel on to work or other activities.

The TourCast component of the entire H-GAC model system replaces the trip generation, trip distribution, mode choice, and TOD factoring steps for resident internal travel in the trip-based model. In most other respects, the model system mirrors the trip-based model system. The highway and transit network assignment steps, the truck/commercial vehicle models, and the models of external and nonresident trips are the same as those used in the trip-based model. The zone system and the underlying land-use data are also the same as those used in the trip-based model, although the retail employment is split out into more categories for use in the AB model. The AB model also uses the home-based-other and non-home-based airport trip purposes from the trip-based model as a "special generator." The population synthesis methods were updated for the AB model, and the new synthesized population will be aggregated to supply demographic inputs to the trip-based model.

KEY VARIABLES AND PARAMETERS FOR UPDATE

The TourCast models use the following key variables and parameters:

- **Tour and stop generation**: Household and person demographics, and model utility parameters explaining the frequency of distinct types of tours for several types of persons and households.
- **Tour and trip destination choice**: Land-use data (e.g., employment, households, schools), and tour and trip attraction functions ("size variables"), by land-use type and purpose. Various impedance and accessibility variables, including logsum parameters from the mode choice models.
- **Tour and trip mode choice models**: Mode choice model utility parameters, by mode and trip purpose. These include relative trade-offs between different cost and VOT components, and mode bias parameters. Both VOT and mode bias parameters can be related to household and person demographic characteristics such as income. Mode nesting parameters may also need to be re-estimated for nested models.
- **Tour and trip TOD models**: TOD utility parameters explaining tour and trip departure times and arrival times, and activity durations, by tour and trip purpose and household and person characteristics.
- **Usual work and school location models**: Similar parameters and utility terms to the tour destination choice models, but explaining the usual locations rather than the locations visited on an individual tour. Accessibility variables from home, by various modes of travel, are important in these models.
- **Auto ownership models**: Utility parameters to explain the number of cars owned as a function of household characteristics, and the relative accessibility to destinations by auto as compared to other modes.
- **Household interaction and joint travel models**: Various model utility functions to explain activity pattern coordination, joint tour-making, and chauffeuring to school by various household members. Household and person characteristics are important in these models, as is the quality of the data indicating joint travel.

AB models contain more complex utility functions and use more variables when compared to trip-based models. Many of the variables are conditional on higher-level models, such as tour or trip scheduling models that depend on the "time windows" remaining in the day after scheduling higher-priority tours. There can also be additional market segmentation variables, as described below.

As was the case for the trip-based model, these parameters and choice models in the AB model can use new data in three distinct ways:

- To fully re-estimate parameters (and possibly enhance the model specification).

- To re-calibrate existing parameters and specifications to match observed choice distributions.
- To validate the resulting models against observed network conditions (e.g., counts, speeds, boardings).

The validation process is much the same as for a trip-based model, but the re-estimation and re-calibration processes can be much more involved because there are more models and more parameters per model, and typically more data processing steps involved.

Regarding travel survey needs, an AB model with the structure of TourCast can be estimated or calibrated using a standard and modern HTS design. However, specific aspects of AB models should be considered when designing an HTS questionnaire and sampling plan:

- **Complete household-days and person-days**: In addition to trips and tours, the TourCast model structure uses person-days and household-days as behavioral units in the models. Therefore, it is important to define a "completed survey" for a household as at least one full day of travel data for every member of the household, with no partial travel days or missing household members. (For small children, the travel data are typically provided by proxy by the adults. Note: In the Task 4 memo—Appendix B--the RSG team provides a more in-depth discussion of proxy reporting in HTSs.)
- **Complete and accurate data of household members traveling together:** Because TourCast includes models of joint travel, it is important that the data regarding which household members participate in each trip and activity are accurate and internally consistent. It is standard for the survey validation to check the consistency of such data in real time during data collection.
- **Data on usual work locations for all workers and usual school locations for all students**, regardless of whether they visit those locations during the survey travel day(s). TourCast includes models of usual work and school locations at the longer-term level, so such data should be collected for *all* workers and students, regardless of whether or not they make work or school tours on the survey travel day(s).
- **Complete and accurate data on trip departure and arrival times**: The TourCast model uses 30-minute time periods, and schedules travel and activities consistently across the simulated day. It is important that the self-reported TOD data be fairly accurate and—to the extent possible—checked for internal consistency during data collection. Stand-alone GPS device and smartphone-based GPS data collection can provide the most accurate TOD data.
- **As few missing trips and activities as possible**: Comparison of diary-based HTS data with stand-alone GPS device and smartphone-based GPS data has indicated that trips tend to be underreported using diary-based methods, and that it is typically the shortest distance trips and the shortest duration activities that tend to be omitted. The trend toward smartphone-based GPS data collection will reduce this issue, but diary-based surveys should include extra prompts to attempt to capture all trips and stops, even if respondents do not consider them important.

MARKET SEGMENT CONSIDERATIONS

The TourCast model uses the following key segmentations for resident models for internal trips:

- **Spatial**: 5,263 zones (46 are external), the same as for the trip-based model.
- **Temporal**: Uses the same five time periods—AM peak, midday, PM peak, evening, and night—for assignment, but the AB TOD models use half-hour time periods, allowing a more detailed simulation of activity scheduling.
- **Modes**: Like the trip-based model, the auto mode is split into three occupancy classes—Drive alone, Shared ride 2, and Shared ride 3+. The toll vs. non-tolled path choice is handled in assignment. The transit mode is split into two access types—Walk to transit and Drive to transit, with no distinction between park-and-ride and kiss-and-ride. Transit path type choice (local bus, express bus, commuter bus, light rail, commuter rail) is handled in network path-building and assignment, rather than in the mode choice model. A major difference from the trip-based model is that walk and bike modes are modeled explicitly in mode choice, as is school bus.
- **Purposes**: The model uses 10 tour purpose types: work, school (K–12), university, meal, shopping, personal business, social/recreation, escort, fully joint nonmandatory tours, and work-based subtours (trip chains that start and end at the same workplace). Because the model is tour-based, there are no separate non-home-based trip purposes that need to be modeled differently.
- **Demographics**: Just as for the trip-based model, the AB model uses Census-based household distributions by household size, number of workers, and income category to generate a synthetic population of households and persons. The key distinction for the AB model is that it can potentially use any variable on the household and person records in the synthetic population. As with most of the AB models used in the US, the TourCast model uses a segmentation of person type into eight categories, and this proves to be a key segmentation in many of the models:
  - Full time worker.
  - Part-time worker.
  - Adult (university) student.
  - Seniors (age 65+, regardless of work status).
  - Other nonworking adults.
  - Child age 16 or older.
  - Child age 5–15.
  - Child age less than 5.

The fact that AB models run at the person level and the household level, and that person-level demographics are important, has implications for travel survey sampling and weighting, and data processing.

In designing a sampling plan, it can be valuable to "oversample" specific types of people or households or specific types of travel behavior, to have enough such cases in the data to estimate and calibrate models to accurately represent that demographic group or type of behavior. Specific examples are:

- People who often make transit trips.
- People who often make bicycle trips.
- People who often walk to work or school.
- People who make trips on toll roads.
- People who use park-and-ride lots.
- People who work from home.
- People who are university students.
- Young, nonfamily households.
- Households with low incomes.
- Households that do not own any cars.

The Task 4 and 5 deliverables will include details and recommendations on sampling plans and oversampling strategies to obtain an adequate number of such persons and households for modeling.

It is also important that survey questions be designed to capture enough detail to identify these types of people and behaviors. Critical details for collection include the following:

- Detailed transit access and egress modes (e.g., park-and-ride vs. kiss-and-ride).
- Whether tolled facilities were used during relevant car trips.
- Whether the person's usual workplace is at home, and whether the person did paid work at home on the survey day(s). (Note that unpaid work, such as volunteer work, is typically captured using a separate activity purpose for nonhome destinations.)

As mentioned in Chapter A.3, it is also important that the survey is designed to capture all types of trips, including short trips and walk or bike trips for exercise (i.e., not to a specific destination).

POTENTIAL UPDATES/IMPROVEMENTS

In regions across the US, some further enhancements have been made (or are being made) to AB models. This section lists some of those enhancements, although it should not be interpreted as a recommendation that H-GAC should adopt these.

Incorporating subzone or microzone geographies that improve spatial accuracy for modeling short walk and bike trips, including walk and bike access to transit: The flexibility of household- and person-based microsimulation modeling frameworks such as TourCast makes them adaptable to using distinct types of geographic units for different purposes in the model system. For example, all DaySim implementations and most CT-RAMP implementations in the US use microzone geography in addition to TAZs. In some cases, the microzones are individual parcels, but more typically they are Census blocks (or an intersection of Census blocks and TAZs). Note that this goes beyond the common practice of splitting zones into "subzones" according to the number of residence in different transit access distance bands. The microzones are used to define land-use and destination choice alternatives, and to provide more accurate distances and times for short-distance trips by walk, bike, and auto. Using microzones along with local information from an all-streets network allows a more detailed representation of bicycle and pedestrian level of service for short trips—and provides more accurate travel times for short car trips that are intrazonal or between adjacent zones. This feature can be combined with assignment of bike or walk trips on an all-streets network. It also provides more accurate representation of walk access and egress distances to transit. It can also be useful for modeling bike access to transit, which RSG has done in an AB model for Copenhagen. In terms of data needs, using microzones requires more extensive use of fine-level demographic and employment data, such as Census and Longitudinal Employment Household Dynamics (LEHD) Census block-level data and parcel-level data, where available. For HTS data, the accuracy of geocoding activity locations becomes more critical. This is becoming less of an issue with the growing use of smartphone and GPS-based survey methods and the now-standard use of Google Maps interfaces in online travel survey methods.

Using a separate zone system for transit based on stop and station locations, rather than using the same TAZ system as used for auto: Again, the flexibility of simulation frameworks such as TourCast would allow the use of a zone structure for transit assignment and skimming that is different from the zone structure used for auto. This allows the transit skims to be focused in areas with more stops and service, and to represent the actual transit stop-to-stop routes and service levels more closely. When combined with microzone geographies and shortest path walk distances from all-streets networks (see above), this also allows accurate modeling of walk distances from microzones to stops at both ends of the transit trip. This approach of using a separate stop-based zone system for transit along with microzone-based walk distances is currently used in AB models in San Diego, Chicago, and Philadelphia, and is being adopted in the Bay Area. The main advantage is a more accurate representation of transit accessibility and levels of service in the models. With the transit zones designed around the transit route system, each stop-to-stop transit zone pair serves a clearly-defined transit route or set of routes, which also makes it easier to map the predicted transit trips to specific transit routes for assignment. Shifting to this method would not introduce any new data needs, as the same types of transit network information and transit survey information would still be used in modeling and validation.

Explicit modeling of parking location choice in parking-constrained areas: This approach could be used in areas such as the Houston CBD or the Texas Medical Center, where parking right at the destination address is often not possible for those without reserved parking spaces. The model can include both off-street and on-street metered and unmetered spaces and can include capacity constraint to ensure that demand does not exceed supply for a given location. For example, the SFCTA AB model searches all parking locations within a walking radius of destinations in San Francisco and simulates the choice among available parking locations as a function of parking price, drive time to the location, and walk time to the destination. A shadow pricing mechanism is used to enforce capacity constraint at each location at each TOD and can also be a proxy for parking search time and wait time as locations become full. Adopting this approach requires collection of extensive data on parking supply, pricing, and utilization. This approach is also useful if HTS data can obtain parking locations and destination locations separately in cases where a person does not park at the destination address. (This can also be imputed from GPS trace data in smartphone-based GPS data collection.)

Explicit modeling of parking location choice for park-and-ride transit trips: This works analogously to modeling parking location choice at the destination end of car trips, as explained, but is at the tour origin end of transit tours. All DaySim model implementations and most CT-RAMP implementations simulate the choice of a park-and-ride lot from the available lots as a function of drive access time, parking cost, and the attributes of the transit trip from the lot to the destination (e.g., fare, frequency). A shadow pricing mechanism is used to enforce capacity constraints at each lot at each TOD. Compared to modeling parking location choice at destinations, the data requirements for modeling park-and-ride lot choice are not as onerous, because there are typically a limited number of park-and-ride lots in a region. Although there are also typically a limited number of park-and-ride trips observed in a typical HTS, the sample size could be increased through targeted recruiting of respondents at the lots (via intercept or via LPC and mailing invitations). Transit on-board surveys could also identify park-and-ride lot users and ask them additional questions to help better model park-and-ride lot choice. It is also important that HTSs and transit on-board surveys ask enough detail to be able to identify kiss-and-ride trips separately from park-and-ride. Treating park-and-ride and kiss-and-ride as separate modes in mode choice models will also help to model park-and-ride more accurately.

Modeling vehicle type choice and allocation of vehicles to trips: Although all AB models in the United States include a model to predict how many cars each household has available for use, no AB models currently in use predict which types of vehicles are owned or which types of vehicles are used on any trip. Vehicle types could include vehicle body types and size (e.g., sedans, compacts, SUVs, pickups) and fuel types (e.g., gas, diesel, hybrid electrics, plug-in electrics). Since different types of vehicles may tend to be used on different types of trips, a vehicle type choice model would ideally be combined with a model that allocates vehicles across household members for the various simulated trips. Modeling the body and fuel type of vehicles used for each trip could improve the accuracy of modeling greenhouse gas and other pollutant emissions. Because most recent HTSs ask the year, make, model, and fuel type of all household vehicles—and the vehicle used for each trip, the data to estimate such models already exists in most cases and would require few, if any, changes to existing survey questionnaires. It is possible that new vehicle technologies—such as CAVs and their potential effects on household vehicle allocation—will spur interest in including vehicle type choice and allocation models in AB model systems.

Modeling the growing use of "ride-hailing" modes such as Uber and Lyft: Some AB models already include "taxi" as an option in mode choice models, and it is straightforward to include ride-hailing as another type of taxi mode. Because the characteristics of using Uber and Lyft are still quite different from traditional taxis, these services should be treated as separate modes in modeling and in survey questions. In initial data from the recently completed SANDAG HTS, there are over 800 reported Uber and Lyft trips, compared to only about 100 taxi trips. These numbers suggest that there will be enough observed cases in household survey data over the next few years to calibrate the ride-hailing mode share in mode choice models. To be most useful, such models should also be able to represent ride-hailing services using CAVs rather than conventional vehicles. In larger cities, they may also be used as access modes to transit, which would be another multimodal option to model. A potential issue with modeling ride-hailing demand is the associated modeling on the supply side—representing the operation and dispatching of ride-hailing vehicles on the network and the resulting geographic variation in wait times, availability, and pricing. This has not been considered an issue for modeling conventional taxis, but this issue may be more important for ride-hailing because the availability and pricing is more demand dependent. In addition to adding "Uber, Lyft, etc." as an answer category to the mode questions in HTSs, it may be useful to obtain data from the service providers themselves if it becomes available.

Starting to model the potential future effects of CAVs: As alluded to in the two preceding paragraphs, one significant issue in long-range regional planning is how to represent the great uncertainty around possible future growth in CAV use. Multiple dimensions of this uncertainty make CAVs difficult to incorporate in the context of regional planning. For example, the rate of adoption is highly uncertain, as this aspect is affected by the development of technology and the changes in regulations and infrastructure to accommodate the new technology. In addition, the use of CAVs could follow different future paths. Although it seems likely that the earliest use will be in the context of ride-hailing fleets within limited urban geographies, the longer-term use could either continue to mainly follow this "sharing economy" concept—with most CAVs being shared fleets—or could transition to private CAV ownership and use—particularly in less-urban areas. It is unclear how much influence regional government can have over the eventual transition path, as much will depend on auto manufacturers, ridesharing service providers, state and federal regulators, insurance companies, and the vehicle users' preferences and resources. Data are not yet available on any of these questions. Although much modeling is being done, it is hypothetical and exploratory at this point. A good deal of research is being done into adapting AB models to predict CAV ownership and use in an exploratory, scenario-based fashion. (Note that RSG is currently conducting such research for FHWA, combining the DaySim AB with the TransModeler dynamic traffic assignment [DTA] in Jacksonville.) H-GAC may wish to add similar exploratory modeling capabilities to the AB model as examples emerge elsewhere. In terms of data collection, there will likely be no "revealed preference" questions to ask on actual CAV use over the next five years. Several MPOs have included survey questions to gauge respondents' receptiveness to using CAVs. It may be interesting from a research perspective to gauge people's responses to such questions, but there is no clear benefit to asking such questions in terms in the short term, before anyone has had any actual experience with CAVs.

More detailed modeling of "work-at-home" behavior: Working at home is a growing phenomenon, and it can take many forms—people working at home as their usual workplace, people telecommuting more often, or people working for employers located in other regions or states and making weekly or monthly long-distance commute trips. In some

AB models, the usual work-location model can include "work at home" as a specific location alternative, as is done in the DaySim models. Survey questions about each person's usual workplace should include separate response categories for "work from home" and "no usual workplace," which may apply to construction workers, landscapers, painters, and others who tend to work at different locations each day. For people who do have a regular out-of-home usual workplace, occasional telecommuting from home can be accommodated as a special alternative in the day-activity-pattern models, as is done in some CT-RAMP models, or this practice can be handled indirectly through a "work tour frequency model." In H-GAC's TourCast model, the Household Joint Daily Activity Pattern model essentially acts as a "work frequency" model for working adults in the household and is also influenced by the activity patterns of other household members. Some workers may also work at an office for part of the day and at home for another part of the day. Therefore, "work at home" may warrant its own survey questions. As an extra survey question asked each day, some surveys ask a question such as "How much did you work at home/telework for pay" on the assigned travel date.

More detailed modeling of "seniors" work and travel patterns: The current H-GAC AB model treats anyone age 65 and over as the "Senior" person type, regardless of worker status. A significant percentage of the population continues to work past the age of 65, and it appears that even more people are likely to do so in the future. "Seniors" who continue to work clearly have different activity patterns than those who retire completely, so it would make more sense for the "Senior" person type to include only nonworkers, as is the case in most other AB models. The various models for workers' travel can still include age-related effects, so including workers age 65+ in the working person types does not mean that they need to be treated the same as all other workers in the models. This change in the model system would not require any changes in the travel survey design. (Older age groups tend to have among the highest response rates to travel surveys, so there is typically no shortage of data on older workers.)

More advance models of intrahousehold interactions: TourCast models in other regions include a refined daily activity pattern (DAP) model which introduces a wider variety of daily pattern types. Some of the more recent CT-RAMP models have also included a fourth DAP type, which includes *both* out-of-home mandatory and out-of-home nonmandatory activities. These model refinements may be useful in a future model update and would not require any changes to a household survey instrument. Beyond this change, there would be a risk in introducing more complex models of intrahousehold interactions. Such models are highly complicated to estimate and program into the software, and there is no straightforward evidence that they will improve the usefulness of the model system—or at least enough to justify the extra time and expense needed to create the models.

Using shadow pricing to doubly constrain work-location choice (and school location choice) models: "Shadow pricing" is a way of programming iterative adjustments in forecasts so that demand eventually equals supply within an acceptable margin. This mechanism was mentioned in the context of destination parking and park-and-ride lots as a way of applying capacity constraint to parking choice. For work location, the concept is similar—the number of people working within a microzone or zone should not exceed the number of jobs available there. The same is true for students going to school in a (micro)zone and the number of school enrollment spaces available. Shadow pricing is used for usual work-location models in all DaySim and CT-RAMP implementations, essentially using the same doubly-constrained formulation that is used for home-based-work trips in a trip-based model—although in a more reliable way. Shadow pricing is also used separately for University and K-12 school locations in most DaySim models. Shadow pricing does not require that any additional land-use data or travel survey data be collected, although it does place greater demands on the land-use data on employment (and school enrollment) being accurate. Shadow pricing is typically used in base-year model runs. The decision on whether to update the shadow prices for future-year model runs depends on how closely one wishes to constrain the model to the forecast of the spatial distribution of future-year employment.

Using the AB model in combination with DTA: H-GAC is currently using DTA and traffic microsimulation for some corridor studies. In the future, AB model output could serve as an input to DTA, and eventually full AB model-DTA integration might be practical. This raises the question whether there are specific AB model updates that could aid integration with DTA methods. DTA methods tend to be more sensitive to static assignment methods as to exactly where trips enter and leave the road network. In that sense, using microzone geography as the basic spatial unit to predict trip end locations (as described above) would aid in providing more detailed trip information to the DTA. Otherwise, the AB model is already “DTA-compatible” in terms of providing trip departure times with a high amount of temporal detail, and in terms of providing full trip chains (i.e., tours), that are consistent in time without overlapping durations. (People are not predicted to be in two or more places at once.). Making these changes would not require more detailed HTS data, but a DTA network generally requires significantly more detail regarding traffic signal timing, intersection turning movements, screenline counts, and traffic speeds, among others.

Incorporated more detailed VOT functions and distributed VOT: Another benefit of the flexibility of an AB microsimulation framework is that every person could have a different VOT for each tour or trip they make, depending on how much of a hurry they are in at that moment, the unpleasantness of the travel mode, and other factors. The DaySim AB models, and the SANDAG CT-RAMP AB model have incorporated the VOT functions from the SHRP2 C04 project, which was based on analysis of a variety of revealed preference and SP datasets from several regions of the country. The cost coefficient includes segmentation by household income and vehicle occupancy, while the time coefficient includes segmentation by travel purpose, and an optional random component, drawn from a log-normal distribution. If the VOT for each tour is written to the output record and used to divide trips into different VOT classes for traffic assignment, then the use of VOT distributions in the AB simulation can be important in toll studies, as it is typically the “tail” of the distributions with high willingness to pay to save time that are most likely to pay tolls. If H-GAC adopted this approach, it would be possible to do revealed preference or SP surveys in tolled corridors to measure VOT. However, since such SP surveys were conducted in the past, it is also a valid approach to adopt parameters and distributions from other regions' models, so additional survey data may not be needed to establish VOT estimates. As part of any household survey, revealed preference data can be captured by asking whether or not a toll was paid for any auto trips, and, if so, on which facilities (since a single trip may use more than one tolled corridor). Asking how much toll was paid is less common in surveys, since respondents tend to have difficulty giving an accurate answer, and the toll level can be imputed using network path-building software or, if GPS data capture is used, by observing the toll entry and exit points and times of day.

A.4 ORIGIN-DESTINATION AND EXTERNAL MODELS

External travel is an important ancillary component of demand modeling. External travel includes trips to and from locations outside the model region's boundaries and trips passing entirely through a model region without stopping. Although these trips comprise a relatively small portion of the trips in the region, they contribute disproportionately to vehicle miles traveled because of their length relative to other trips within the region. It is important to account for these trips separately because of their different sensitivity to factors (e.g., VOT) and different modeling data requirements.

MODEL COMPONENTS AND CHARACTERISTICS

External auto and truck demand are modeled separately by H-GAC. H-GAC's new AB model does not include external travel (H-GAC Activity-Based Model – Model Design Plan Report, Section 9.3). Rather, the new model retains the trip-based model's components for estimating external-external and external-internal/internal-external auto trips. External truck trips, in contrast, are handled as part of H-GAC's new commercial vehicle models and its external data needs are also discussed under the section of this memo addressing that component. The "H-GAC Travel Model 2014 Validation Report" for the trip-based model states that external auto demand was last updated based on vehicle classification counts at external stations conducted by H-GAC in 2011. However, this 2011 update was limited to scaling/frataring based on the updated counts, while the underlying OD patterns for through trips and attractions for inbound/outbound trips are still based on the 1995 external travel survey.

KEY VARIABLES AND PARAMETERS FOR UPDATE

The precise form of the variables or parameters for an updated external model may vary depending on whether H-GAC intends to add further segmentation (e.g., to distinguish between resident and nonresident external flows) or add simulation components for external travel to the AB model system. Regardless of the ultimate model form carried forward, the critical information to be incorporated in the model is essentially the same. The two key components are external trip OD patterns and traffic volumes at external stations; both components must be broken out by auto and truck.

Acquiring new data on external OD patterns should be an important priority for the model update. This is because the external OD data on which the current model is based was collected over 20 years ago. (Passive data collection now offers more cost-effective data for external travel than traditional surveys; the Task 4 memo will discuss this in more detail). Although commodity flow data provides valuable information related to external truck travel patterns, it can be different than truck OD patterns in several important ways, including intermediate stops by trucks (e.g., for fuel, meals, required rest breaks) and empty truck movements; these are not reflected in commodity flows. Therefore, external truck OD data offers important added value beyond commodity flow patterns for modeling external truck movements. Classification counts at external stations are also important for properly scaling expanding external trips and ensuring the correct overall amount of external auto and truck traffic.

MARKET SEGMENT CONSIDERATIONS

Beyond the key segmentation of autos and trucks by vehicle type, the next most common and important segmentation in external travel is between resident and nonresident auto trips. This distinction could be important if H-GAC decided to incorporate external travel into the AB model simulation framework at some point in the future. To do this, residents' external travel would be simulated together and within the main AB model framework as a new tour type; nonresident travel would still require an ancillary simulation model component. Separate data would be needed for resident and nonresident external travel to support the development of such a framework. For this reason, external OD data that can be segmented by travelers' residence inside or outside the region may offer added value for future model development. Travel models also occasionally include further segmentation of external auto trips by work and nonwork purposes. This segmentation allows comparison and validation of the work components to Census journey-to-work flow information. (This is collected in the ACS at the home municipality-to-work municipality level--Production-to-Attraction format). Therefore, external auto data that can be segmented by work and nonwork purposes may offer additional value.

POTENTIAL UPDATES/IMPROVEMENTS

As discussed, segmentation by purpose and resident/nonresident may enhance the model. This segmentation could be added in either the existing trip-based framework for external travel or in the AB model or an AB model style simulation. Using external OD data—such as properly expanded passively collected data—to update the model offers significant value in ensuring the validity of the external travel model components.

Traditionally, external travel data were collected through special intercept surveys along the model cordon. However, privacy and safety concerns have led to increasing difficulties in fielding such surveys as evidenced by the fact that no such survey has been conducted in the region in over 20 years.

As a result, various passive data collection methods have been employed to study external travel patterns over the past 15 to 20 years. The first widespread passive method was the use of video LPC, sometimes in the form of license plate matching at entry and exit external stations and sometimes with follow-up postcard surveys mailed to travelers based on addresses provided by one or more state department of motor vehicles (DMV). While LPC matching could provide reasonable estimates of through traffic patterns, the process tended to defy full automation and be costly because of significant labor requirements. Moreover, difficulties were often encountered with obtaining addresses from DMVs; delays from processing the data often resulted in significant delays between the observed travel and receipt of the follow-up survey, and survey response rates were often low. As a result, LPC surveys have seen less use in recent years with the development of other passive data alternatives.

More recently, Bluetooth readers have offered an opportunity to passively observe device identifiers in vehicles at external stations and develop through-travel OD matrices through matching. Although this method also still requires fielding, it is typically much less labor intensive than LPC methods. It does result in a significantly smaller sample, often on the order of 4-9%. Unlike video methods, it can capture night travel patterns, which can differ importantly from daytime patterns, but unlike video methods, it cannot distinguish between vehicle types and there are questions about whether the sample is biased toward higher-income travelers. Despite these issues, due to its economy, the method has seen increased use in recent years.

Finally, fully passive methods have emerged within the past few years which do not require fielding of equipment but rely on processing of datasets collected/produced for other reasons, generally from mobile devices or in-vehicle devices. Several different data sources and underlying technologies fall into this general category including cell tower signaling data (e.g., AirSage), navigational GPS data (e.g., INRIX, American Transportation Research Institute [ATRI], TomTom), and LBS data (e.g., Cuebiq). Compared to using Bluetooth devices at external stations, as described above, these sources are effective not only for estimating the OD patterns for external-external trips, but also for Internal-External and External-Internal trips. Some of these sources are specific to vehicle types (e.g., ATRI for multiunit trucks), while others cover the traveling population at large. Sample sizes vary from less than 1% to close to 10% of trips. These methods are generally the least expensive since they require little labor. However, data expansion costs are often separate from data acquisition costs and this difference can skew the comparison with other sources where data expansion is included. Moreover, some vendors provide some preliminary or basic data expansion but additional adjustment may be necessary. Even so, these methods can provide cost-effective data on external travel patterns. Unlike LPC or Bluetooth, they can provide not only through traffic OD patterns but detailed OD patterns for inbound and outbound travel which are often dominant for large metropolitan areas. Some sources of passive OD data can provide resident/nonresident segmentation of external travel demand. However, while some data vendors sell data with imputation of work locations/purpose, imputed work commuting patterns differ significantly from other sources including household diary surveys, the Census's journey-to-work data collected as part of the ACS, and the commute patterns in the Census/BLS joint LEHD data derived from administrative records. Therefore, segmentation between work/nonwork travel may require the combination of multiple datasets such as ACS and LEHD together with passive OD data.

A.5 SPECIAL GENERATOR MODELS

Special generators are land uses[3] that attract travel that is unique compared to other land uses. As a result, special generators often receive special treatment in travel models. In trip-based travel demand models, special generators are paired with trip attraction rate factors that attempt to replicate the magnitude of travel attracted to them. An equivalent treatment in tour- and AB models adjusts the destination choice size term to match observed total attractions. At a minimum, these adjustments require understanding total travel to/from special generators, by tour or trip purpose, which is a required element of any special generator travel survey. However, special generators often have unique travel characteristics in which the TOD of travel, the mode of travel, the origin\trip length, and even the resident status of the traveler varies considerably from other types of travel. In such cases, special travel models may be developed to accurately represent travel to these sites, and such models often require more tailored survey instruments—which is made most efficient by leveraging the base HTS and customizing the key elements rather than conducting a separate survey.

The Houston-Galveston region has several such land uses, but the available documentation does not describe how these are treated in the H-GAC travel models. The following lists represent special generator candidates in the H-GAC model and recommend the data that could be collected at each site to improve the model's ability to replicate travel patterns.

AIRPORTS

The H-GAC region contains two major airports:

1. George Bush Intercontinental: This airport served 43,023,224 travelers in 2015, making it the tenth busiest airport in United States.
2. William P Hobby: This airport served 12,095,482 travelers in 2015, and it is a hub for Southwest Airlines.

Airports have the following unique travel characteristics:

- Trip rates are based on total enplanements rather than employment data.
- They tend to attract travel from throughout the region.
- They require special treatment of travel modes (e.g., taxi, rental cars, parking lot shuttles, and transportation networking companies).
- Parking supply and pricing are often key issues that need to be addressed.
- Important travel markets for airport travel include resident status and purpose, which have implications on mode use, origin\destination of trips to\from the airport, and VOT.

[3] Land uses that have been treated as special generators include airports, universities, military bases, hospitals, amusement parks, casinos, and major shopping centers.

Required Data

Site Characteristics

- Total number of enplanements and transferring passengers for each year to be modeled.
- Information on average rental car costs and number of cars rented on an average weekday.
- Parking availability, location, and price structure; utilization is helpful for model calibration.
- Parking lot shuttle routes and schedules.
- Any other relevant information.

Passenger Characteristics

- Trip to airport information:
    - Origin location.
    - Origin activity type\place type\purpose.
    - Time departing.
    - Time arriving at airport.
    - Mode information.
    - Parking information.
    - Party size.
- Travel information:
    - Trip purpose.
    - Duration.
    - Destination (city\country).
    - Airline\flight number (for expansion purposes).
- Traveler information:
    - Resident status\home location (including in-region residents and visitors—and out-of-region residents and visitors, which are less common).
    - Employment status.
    - Student status.
    - Age.
    - Household vehicle availability.
    - Household size.
    - Number of workers in household.
    - Number of adults in household.
    - Household income.

Typically, site-specific data are acquired from each airport. Airport master plans typically provide current and future forecasted enplanements and transfers. Site infrastructure information (e.g., parking supply and price) can sometimes be obtained from master plans or via web searches. An airport can occasionally provide parking utilization and other demand-related information; alternatively, this may require additional data collection. Air passenger information is best collected via a targeted survey at airport departing gates where passengers are waiting to board their flights. This requires airport permission and the appropriate security clearances from the Department of Homeland Security for survey staff.

It is often necessary to develop a special market model to accurately represent ground access to/from airports. This model must address trips made by both resident and visitor air passengers, and commercial vehicle travel; travel for airport workers is typically handled well by the resident AB model.

Since travelers for work purposes typically have a higher VOT than nonwork travelers, airport travel models typically segment airport trips by purpose (work versus personal\recreational). Some airport models further segment trips based on whether they are serving a local origin\destination or generating an external-internal trip. Given the size of the H-GAC region, such segmentation may not be necessary.

Airport models also often explicitly consider rental car, taxi, and hotel\parking shuttle travel modes in addition to private auto and transit. Note that rental car is made available only for visitors while private auto is much less likely for visitors. Airport mode choice models should also consider Uber and Lyft, given the prevalence of transportation networking companies as alternatives to traditional taxis. The choice of mode to airports is also significantly influenced by the availability and cost of on-site versus off-site parking. For this reason, airport mode choice models often consider the location and type of parking as a subchoice for private autos.

A key determinant of choice of mode to the airport is the length of stay for the air passenger, particularly for residents who trade off the cost of parking versus taxi\Uber\Lyft. For most travelers, the break-even cost point in terms of length of stay is one or two nights (two or three days of parking is equivalent to the round-trip cost of taxi\Uber\Lyft, although the break-even point may be longer in large regions with longer average trip lengths to the airport). Consideration of this factor has motivated the development of simulation-based models of airport travel as an advancement over trip-based treatments.

The SANDAG Airport Ground Access Model is one such model system. It includes a disaggregate travel party generation component based on daily enplanements, and attributes each travel party with resident status, purpose, size of party, type of passenger (arriving or departing), length of stay, and other attributes before modeling their origin or destination and mode. The model utilizes the same level-of-service skims as the resident AB travel model and outputs trip lists in the same format as the resident models, with consistent time period attribution. This provides flexibility and consistency in the assembly of trip tables for assignment to transport networks.

UNIVERSITIES

Major universities are typically treated as special generators because of the unique travel patterns exhibited by students who attend these institutions. Student travel to/from major universities is typically shorter than to/from other universities because student residential location choice is often predicated on the location of the school.

For many major universities, most students who attend reside in either on-campus housing, off-campus group-quarters housing, or off-campus apartments or other nonfamily housing. In addition to—or perhaps because of—their relatively short trip lengths, student travel often exhibits a higher nonmotorized mode share than other travel, including to/from community colleges and trade schools. Houston, however, is somewhat unique in that there is less on-campus or near-campus living at universities compared to other state universities. Thus, having information on where students live relative to the university is critical. University surveys are potentially cost-effective strategies, as universities can provide e-mail addresses for students for a web-based survey to collect university-targeted information.

Parking supply and transit are commonly important for university planning, so the RSG team recommends collecting information to address these issues. An internet search revealed the following universities in the H-GAC region, sorted by enrollment. Community colleges are not included because these students are typically adequately represented in HTSs. Further, it is possible to include special, targeted question in a HTS to collect information on travel patterns of the students who attend community colleges.

Houston Universities

1. University of Houston: Approximately 43,800 students.
2. University of Houston Downtown: Approximately 12,400 students.
3. Texas Southern University: Approximately 9,600 students.
4. University of Houston Clear Lake: Approximately 8,600 students.
5. Prairie View A&M University: Approximately 7,000 students.
6. Rice University: Approximately 6,700 students.
7. University of St. Thomas: Approximately 3,700 students.
8. Baylor College of Medicine: Approximately 3,000 students.
9. Houston Baptist University: Approximately 2,250 students.
10. Texas A&M University at Galveston: Approximately 2,100 students.
11. South Texas College of Law Houston: Approximately 1,000 students.

University student travel surveys typically include many of the same questions as traditional HTSs and are typically designed after or in conjunction with the HTS. However, student travel surveys are distinct from traditional HTSs in several ways:

- The definition of a complete household is limited to the student respondent, since many students live in nonfamily households.
- Some household-level information—such as autos owned—is typically only asked for the student due to less significant carsharing across nonhousehold members.
- Additional student-level data are obtained during the recruitment phase, including:
    - Year of enrollment.
    - College\department enrolled in.
    - Parking permit held, if any.

  - Primary campus attended, if student attends university with multiple campuses.

- Additional travel data can be obtained during the retrieval phase (both of which are automatically captured using GPS-enabled smart phone surveys), including:
  - Location of parking.
  - University building attended for on-campus destinations.
- Custom wording is introduced in this (and other special generator) surveys to ensure clarity of instruction regarding travel – such as trips on campus and trips off campus.

REQUIRED DATA

Site Characteristics

- Current and future enrollment and faculty\staff projections.
- Location of on-campus student housing and number of beds.
- Location and capacity of off-campus student housing such as student-only apartment complexes and fraternity\sorority housing.
- Location of student, faculty, and visitor parking and number of spaces.
- Parking permit programs and cost.
- Restrictions on off-campus parking in surrounding residential areas such as residential parking permit programs.
- ZIP Codes of those enrolled to look at block-level estimates.

Although most tour-based models include a university tour purpose, student travel behavior for students attending major universities often demands more in-depth treatment, including calibration to site-specific travel patterns through the introduction of site-specific alternatives, parameters, and constants. Several tour-based models have included synthetic population controls that are fed by the outputs of a university student residential location choice model. This helps ensure that the travel patterns of students to major universities reflect the location of student housing and university accessibility.

HOSPITALS

Hospitals are characterized by unique travel patterns, including many part-time staff, night-shift workers, significant numbers of patient and nonpatient visitors, and commercial vehicles like ambulances and delivery trucks. The Houston region includes at least two dozen major hospitals (Table 5).

TABLE 5: LIST OF MAJOR HOSPITALS IN THE HOUSTON REGION

HOSPITAL	WEBSITE
Texas Medical Center	http://www.tmc.edu/
Methodist Hospital	http://www.methodisthealth.com/
St. Luke's Episcopal Hospital	http://www.stlukestexas.com/
University of Texas M.D. Anderson Cancer Center	http://www.mdanderson.org/
Park Plaza Hospital	http://www.parkplazahospital.com/en-US/Pages/default.aspx
Memorial Hermann-Texas Medical Center	http://www.memorialhermann.org/locations/texas-medical-center/
Menninger Clinic	http://www.menningerclinic.com/
TIRR Memorial Hermann	http://tirr.memorialhermann.org/
San Jacinto Methodist Hospital	http://www.methodisthealth.com/sjmh.cfm?id=36844
Memorial Hermann Northwest Hospital	http://www.memorialhermann.org/locations/northwest/
Memorial Hermann Memorial City Medical Center	http://www.memorialhermann.org/locations/memorial-city-medical-center-er/
Methodist Willowbrook Hospital	http://www.methodisthealth.com/willowbrook-hospital
Texas Orthopedic Hospital	http://texasorthopedic.com/
Texas Children's Hospital	http://www.texaschildrens.org/
Ben Taub Hospital	https://www.harrishealth.org/en/services/locations/pages/ben-taub.aspx
Memorial Hermann Katy Hospital	http://www.memorialhermann.org/locations/katy/
Lyndon B. Johnson General Hospital	http://www.lbj.uth.tmc.edu/
Intracare Hospital North	http://www.intracare.org/
West Houston Medical Center	http://westhoustonmedical.com/
Cypress Fairbanks Medical Center	http://www.cyfairhospital.com/en-US/Pages/default.aspx
St. Joseph Medical Center	http://www.sjmctx.com/
The Woman's Hospital of Texas	http://womanshospital.com/
Westbury Community Hospital	http://www.westburyhospital.com/
Clear Lake Regional Medical Center	http://clearlakermc.com/
Memorial Hermann Memorial City Hospital	http://www.memorialhermann.org/locations/memorial-city/

Of note, is the Texas Medical Center (TMC) near the Museum District—southwest of downtown Houston. TMC is a hub of hospitals, research facilities, medical schools, and medical offices with over 106,000 employees and estimated 10 million patient encounters per year.[4] Parking is constrained at this facility, rendering transit a critical access mode for medical staff, other facility employees, students, and patients. Data from TMC facilities are limited.

Medical visits are handled explicitly by the maintenance purpose in the current H-GAC travel model. It would be helpful to inventory the number of in-patients and out-patients at each hospital on an average weekday, to determine the goodness-of-fit of the H-GAC travel model in matching the magnitude of travel to each hospital. If these data do not currently exist for each hospital, then traffic counts at or near the hospitals may be used to determine if the model replicates existing traffic patterns. The process may warrant site-specific size terms, or the estimation of a size term that includes hospital square footage or the number of beds in addition to employment.

More detailed data on the origin of trips to/from hospitals may be warranted if there are insufficient numbers of observations in the household survey to obtain a reasonable distribution. This would require visitor surveys of the type described in the Texas A&M Transportation Institute report (*Improved Trip Generation Data for Texas Using Work Place and Special Generator Survey Data*, May 2015). Another option is the use of passive OD data to and from identified medical facilities for estimation.

A potential model enhancement to match the travel patterns of workers at hospitals would be to introduce occupational segmentation in the work-location choice models and use occupation in the TOD choice models. Although occupation was collected in the last HTS, it was not used in the travel model specification due to difficulties in forecasting. However, with population synthesis tools that can utilize both household- and person-level controls, the inclusion of worker occupation as a control may now be considered.

VISITOR ATTRACTIONS AND SPECIAL EVENTS

The current H-GAC models do not have a separate and fully developed visitor model component to represent the travel of nonresidents within the region. However, the trip-based model does address this travel market specifically within the context of Galveston Island, the Bolivar Peninsula, and the coastal portion of Brazoria County. This is accomplished by adding NHB trips loosely based on estimates of occupied hotel rooms and seasonal housing in these areas. The provided documentation for the AB model does not indicate any similar treatment of nonresident or visitor travel.

Beaches, museums, amusement parks, casinos, and sporting events require special treatment in travel models because they attract a high number of attractions relative to employment, and they are often key destinations for overnight visitors.

Some of the top visitor attractions in Houston include the following:

[4] Texas Medical Center. *Facts and Figures*. http://www.tmc.edu/about-tmc/facts-and-figures/

- Galveston Island: This national tourist destination offers a wide range of tourist attractions: beautiful beaches, historic districts, mansions, museums, water park, dolphin watching, and state parks. Port of Galveston has 1.7 million cruise passengers. Moody Garden, a premier educational and leisure facility, has more than 2 million visitors annually.
- Surfside Beach: It attracts both day-trip and overnight visitors, along with many nonseasonal visitors and second-homers.
- Space Center Houston: the official visitor center of NASA's Johnson Space Center.
- The Museum District: with 19 museums, including the Museum of Fine Arts, the Houston Museum of Natural Science, the Children's Museum, the Menil Collection, the Holocaust Museum, and the Contemporary Arts Museum.
- Hermann Park: including the Houston Zoo, the Miller Outdoor Theatre, and the Japanese Garden, among other attractions.
- Sporting Events: including Toyota Stadium (Houston Rockets) and Minute Maid Park (Houston Astros).
- NRG Park: Besides being the stadium for Houston Texans, this multivenue park also hosts various concerts, exposition, and special events, led by the international Offshore Technology Conference and the popular Houston Rodeo and Livestock Show (it attracts more than 2 million visitors every March).
- Major Parks: Large, dedicated park spaces like Memorial Park—a 1,466-acre urban park in the northwest portion of the I-610—and Buffalo Bayou Park—a 160-acre green space running through the city.

Visitor surveys are often used to gather information on travel to these sites, along with attendance estimates (either official data or sample counts). Typically, attendance data are available for ticketed locations such as amusement parks, museums, and sporting events. However, often only annual attendance data are available publicly; these data must first be converted to average weekday attendance. For other sites, attendance data must be obtained by sampling or other methods.

Some sources of passive Big Data on OD patterns can be segmented by residents and visitors to the region and provide valuable information on visitor travel patterns. As with survey data, passive data should be carefully expanded to estimates of attendance or other counts.

Methods of modeling visitor travel within regions varies depending on the size of the visitor travel market and its effect on the policies of interest to be analyzed by the modeling system. For example, although Portland Oregon has a much smaller visitor travel market than other large cities such as San Francisco or Seattle, Portland Metro developed a trip-based visitor model based on local data specifically to improve downtown Streetcar ridership estimates. Other regions, such as Las Vegas, Oahu, and San Diego, have developed visitor models because their impacts on transport demand are much more broadly significant, especially in certain parts of the region.

Certain parts of the Houston region attract a significant number of visitors; particularly Galveston Island. Downtown Houston also caters to business travelers and conventioneers. These areas warrant development of special market models. H-GAC has several options to model visitor travel. Passive OD data could be used to generate synthetic trip tables for representation of auto visitor trips on the auto network. Alternatively, visitor travel survey data could be used to develop visitor travel generation, destination, TOD, and mode choice models. If full visitor models are developed, the RSG team recommends utilizing a disaggregate tour-based method to ensure better consistency with the resident AB model. The visitor tour-based model would have a simpler tour and stop generation model, and tours would not need to be scheduled into available time windows for full schedule consistency.

Resident travel to special events and attractions can be modeled by adjustment of destination choice size terms to match observed average weekday attendance at each site. The H-GAC region does not host any significant military bases.

MAJOR SHOPPING CENTERS

Although shopping centers are sometimes treated as special generators in travel models, it is not clear whether special treatment is absolutely required, as it is with most of the other special generators listed previously. The H-GAC model includes a shopping trip purpose that should be adequate to measure travel to each major shopping center in the H-GAC region. Traffic counts at major shopping centers can be compared to estimated volumes to determine if there is significant error requiring special treatment. Driveway counts and parking utilization studies may also be used to ascertain whether the models adequately measure total attractiveness at each site. If necessary, visitor surveys can be conducted at major shopping centers, as described in the Texas Transportation Institute (TTI) report. Alternatively, StreetLight or other data may be acquired to compare to travel patterns revealed in the HTS.

A.6 COMMERCIAL VEHICLE MODEL

Commercial vehicle models represent all travel associated with commercial activities, other than commuting or business travel made in personal vehicles. These commercial activities can include moving people, moving goods, or providing services. The commercial vehicles that move people include rental cars, taxis and TNC vehicles, school buses, shuttle buses and paratransit vehicles. Commercial vehicles moving goods include mail delivery, trash collection, warehouse delivery, parcel pick-up and delivery, and construction vehicles. Vehicles that are used to provide services include household/building services such as plumbers and cleaning services as well as public safety, utility maintenance, and retail support functions. Most of these commercial vehicle activities require specialized models. H-GAC is currently developing a truck model to simulate commercial activity to move goods. This tour-based modeling approach has also been used to simulate commercial services. Additional models to simulate commercial activity around moving people are receiving more attention with the increase in TNCs.

TRIP-BASED TRUCK MODEL

H-GAC currently has a trip-based truck model that estimates travel for moving cargo and for providing services for commercial activities. Cargo trucks include both internal and external truck movements and service trucks are focused only on internal truck movements, which is frequent practice for both trip-based and tour-based truck model systems.

The Cube Cargo platform was used to develop the trip-based truck model. It includes elements for trip generation, trip distribution and mode choice for truck and rail modes. The model relies on estimates of commodity flow, segmented by commodity, to produce the tonnage of goods moved to, from, through and within the Houston-Galveston region. The Cube Cargo model relies on economic inputs to connect production and consumption of goods.

TOUR-BASED TRUCK MODEL

H-GAC is developing a tour-based truck model. The scope for this model calls for the following characteristics:

- Operation at the TAZ level.
- Modeling of truck trip chains to compose tours and identification of the purpose of tour, at a minimum for internal truck travel and as data permits, for external travel.
- Estimation of the number and type of stops on a tour and the purpose, location, and TOD of stops on a tour.
- Sensitivity to the truck type, characteristics of stops, and level of congestion in the highway network.
- Ability to account for trucks making incomplete tours and empty trucks.
- Estimation of truck travel, by TOD.
- Ability to test various truck demand and truck-oriented roadway operations management strategies and policies, such as truck-only and shared-use managed lanes or truck-only and truck-free zones/facilities and congestion pricing.
- Ability to account for internal truck travel within the study area (internal-internal demands), truck travel between inside and outside the study area (internal-external and external-internal demands), and external truck movements crossing through the study area (external-external demands).

The truck-based tour model that H-GAC is developing will use data from the Freight Analysis Framework (FAF), IHS TRANSEARCH data, collected truck GPS data, probe-based truck data, vehicle classification counts, TAZ-level demographic data, and parcel land-use data—and estimation based on local data (GPS and Bluetooth). An establishment survey could also be useful to estimate truck or freight touring models or to simulate urban goods movements on an urban or regional level.

KEY VARIABLES AND PARAMETERS FOR UPDATE

The following information (including, but not limited to) could be developed or updated for the truck model using an establishment survey:

- Establishment name and location.
- Nature of business (NAICS).
- Types of goods/commodities shipped or services provided.
- Quantity of goods/commodities shipped.
- Number and types of vehicles.
- Establishment size and number of employees.

Similarly, a commercial vehicle travel diary questionnaire could collect information including, but not limited to, the following:

- Tour day(s)/TOD of each stop.
- Number of stops.
- Exact location information for stops on tour.
- Reason(s) for stop.
- Trip length.
- Vehicle type.
- Gross vehicle weight or cargo weight.
- Company information, if applicable (e.g., industry type, number of vehicles).
- Type of goods (commodities) transported.

The establishment survey and commercial vehicle travel diary would be useful to validate the supply chain model and truck touring model. These data sources can also be helpful for the external truck travel in that they capture truck trips or tours that involve travel outside of the region. Passive truck GPS datasets may also provide useful data. Surveys will provide the ability to connect the commodities that trucks are carrying with observable patterns from passive truck GPS data.

MARKET SEGMENT CONSIDERATION

The primary market segmentation for truck touring models is by commodity or by vehicle type. Commodity type is often based on NAICS and vehicle type is typically based on FHWA truck classification types.

POTENTIAL UPDATES/IMPROVEMENTS

Three potential updates are possible to the truck touring model under development at H-GAC. The first potential update is a model for the external goods movements (through movements and movements that start or end in the region). External goods movement models are typically based on supply chain methods and include networks for the United States and other global destinations. A proposal to use the Texas SAM-V3 for heavy trucks, which provides one future forecast of external goods movement, but it is useful to understand the effects of various economic and investment forecasts on these external movements. In addition, supply chain methods are multimodal, allowing the supply chain model to respond to rail, sea, air, or pipeline alternatives to transporting goods by truck.

The second potential update to the truck touring model is an integration of the supply chain and truck touring models so that the goods entering and leaving the region are consistent with the goods being distributed around the region. These two updates provide the means to evaluate the effect of transportation policies or investments in the region on the external travel and on the distribution of goods within the region.

The third potential update to the truck touring model is to develop a commercial vehicle services model that simulates tours of service-related travel. These services can represent a significant portion of commercial vehicle miles traveled and were represented in the H-GAC trip-based truck model.

A.7 SUMMARY AND CONCLUSIONS

The previous sections of this report presented an overview of the various model/component options available for consideration by H-GAC. These sections also discussed the key variables and possibilities for update or improvement. Table 6 summarizes these options and considerations. Some of these improvements will have implications for data collection. The memorandum for Tasks 4 will discuss travel survey methods detail to provide the necessary context for H-GAC's decision-making process.

TABLE 6: POTENTIAL MODEL UPDATE NEEDS FOR H-GAC

MODEL/COMPONENT	KEY VARIABLES/PARAMETERS	MARKET SEGMENTS	UPDATE/IMPROVEMENT CONSIDERATIONS	MOST RELEVANT TRAVEL DEMAND DATA TYPES
Trip-based model	• Trip generation rates • Trip attraction rates • Impedance functions • Values of time • TOD factors • Mode constants	• Residence subregions/ area types • Trip purposes • Household size • Household workers • Household income • Auto availability (potentially)	• Add auto ownership and segmentation • May not be worthwhile given the shift to AB model	• HTS data • University student travel survey data • Transit on-board survey data • Traffic volume and speed data • Origin-dest. survey/passive data • Establishment survey data
AB model	A variety of model parameters, with key parameters related to: • Values of time • Logsums/accessibilities • Activity scheduling and household coordination • Demographics	• Residence subregions/ area types • Activity purposes • Household size • Household workers • Household income • Auto availability • Person type • Potentially other demographics	• Add microzones to better model walk, bike • Add stop-based zone system for transit • Capacity-constrained parking location choice • Vehicle type and allocation models, including CAV • Modeling Uber and Lyft, among others • Better model work at home and telecommute	• HTS data • University student travel survey data • Transit on-board survey data • Traffic volume and speed data • Origin-dest. survey/passive data • Establishment survey data • Bicycle or pedestrian count data • Bicycle intercept OD data • Toll/VOT survey data

MODEL/COMPONENT	KEY VARIABLES/PARAMETERS	MARKET SEGMENTS	UPDATE/IMPROVEMENT CONSIDERATIONS	MOST RELEVANT TRAVEL DEMAND DATA TYPES
OD and external	• External trip OD patterns • Traffic volumes at external stations	• Auto versus truck trips • Resident versus nonresident auto trips • Work versus nonwork trips	• Look beyond commodity flow patterns • Acquire new data on external OD patterns (replace 1995 data) • Consider use of properly expanded passive data (validation)	• OD survey/passive data (auto and truck)
Special generators	Site-specific data and parameters for: • Airports • Universities • Hospitals • Visitor attractions • Special events • Major shopping centers	• Occupational segmentation • Trip purpose segmentation • Resident versus nonresident auto trips	• Integrate traffic counts or parking utilization to determine attractiveness of site • Identify origin of trips to/from site • Integrate a university student residential location choice model • Conduct visitor surveys or university surveys • Introduce occupational segmentation in work-location choice models • Look at passive data to compare travel patterns	• Visitor intercept survey data • Airport intercept survey data • University intercept survey data • Special event intercept survey data • Intercept surveys for other major generators (hospitals, malls)
Freight/commercial	• Location • Business (NAICS) • Commodity type(s) and quantity • Vehicle types and volumes • Size and number of employees • Vehicle tour data	• Commodity (NAICS) • Vehicle type (Class)	• Develop a model for external goods movements • Integrate the supply chain and truck touring models	• Commodity flow data • Establishment survey data • Freight carrier travel diary or active GPS survey data • OD survey/passive GPS data for freight

APPENDIX B. TRAVEL SURVEY METHODS PRACTICE REVIEW (TASK 4 MEMO)

B.1 INTRODUCTION

This technical memorandum ("memo") is for Task 4: Travel Survey Methods Review. This memo accompanies the memo produced for Tasks 2 and 3: Identification of Model Update Needs and Travel Data/Survey Needs and provides detailed descriptions of both passive data methods and traditional travel survey methods.

Passive data sources in Tasks 2 and 3 include Bluetooth, cell tower, truck and auto GPS navigation, and LBS. For each of these data sources, the project team investigated current methods and identified advantages, disadvantages, and costs related to the application of these methods.

Tasks 2 and 3 recommended considering the following travel survey methods:

- HTSs.
- Intercept/OD surveys.
- University surveys.
- Visitor surveys.
- Airport surveys.
- Other special generator surveys.
- SP surveys.
- Commercial vehicle travel surveys.
- Establishment surveys.

For each of these survey methods, the project team explored the best methods in practice. The project team also reviewed the advantages, disadvantages, anticipated costs, and opportunities for integrating these traditional sources with passive data sources for accuracy and cost effectiveness. This memo provides the Houston-Galveston Area Council (H-GAC) with information necessary to identify the most appropriate data sources and collection methods to support their travel planning and forecasting programs.

B.2 PASSIVE DATA METHODS

BLUETOOTH

In-Practice Sources and Methods

Bluetooth devices can be used to gather OD data. These data are often classified as "passive" because the collection does not involve the active engagement of travelers. Unlike most of the other sources of passive OD data, Bluetooth data collection requires in-field activity in the form of the deployment of Bluetooth detectors; most other forms of passive data are produced/collected for other purposes.

As a result, Bluetooth OD data are occasionally more expensive than other passive data sources. However, these data are often more economical to collect than traditional data collection methods like intercept surveys or video LPC. Bluetooth typically provides data for only a limited number of detector locations and only for a relatively limited period of observation (days or weeks vs. months or years), making it somewhat less of a "big data" source than other passive OD data. Because of the need for the placement and monitoring of detectors, there are no nationwide vendors of preexisting Bluetooth datasets. Instead, various firms specialize in collecting Bluetooth data.

Like other types of data, Bluetooth data can be processed to provide aggregate trip OD matrices. But unlike some commercial passive data sources, the disaggregate data are also generally available. However, Bluetooth origins and destinations are detector locations. These detector locations are not typically true trip origins or destinations in the sense of activity locations, but rather origins or destinations for specific types of travel analysis, such as where trips enter or exit a corridor or a cordon area. Bluetooth data are typically anonymous and frequently include limited data on routing, but these data can be designed to provide important high-level routing information in some circumstances. Moreover, travel times are also often processed as part of the processing of trip information, so OD travel times (and occasionally OD travel time reliability) are produced as byproducts of the production of trip OD matrices.

Bluetooth data are typically used for distinct applications given the aforementioned characteristics. Unlike other data types, Bluetooth data are not well-suited to regional applications and modeling as it can only support a limited number of zones as a detector device is required for each zone. However, Bluetooth data are particularly well-suited to corridor studies and understanding through (external-external) trip demand in a region. Although it is sometimes used for the latter, this may be becoming less common as other passive OD data sources provide a less expensive option and data on inbound/outbound and through external trips. The main application for Bluetooth is for corridor-level OD studies, such as in support of the development of express lanes.

Unlike other data types—in which intermediate stops must be filtered out on long trips—Bluetooth data often excludes intermediate stops by design, although this varies. In general, Bluetooth can support both long-distance corridor studies and short-distance corridor studies.

Advantages/Disadvantages

The key advantage of Bluetooth is its ability to provide a reasonably decent sample of facility- or route-level OD data for all vehicles (not just trucks). Its representativeness and expansion is also better established and less uncertain than other passive data methods. The key disadvantage is its relatively high cost and its inability to provide information on true trip origins/destinations (limited number of locations).

Precision and Coverage

Like other data types, Bluetooth OD matrices can be obtained for most time periods of interest, including average weekday, average weekend day, individual day of the week, and even down to individual hours of the day (or possibly less). Data collection/observation periods vary, but these can range from several days to several weeks—longer periods of data are sometimes collected.

Bluetooth data are generally of intermediate locational precision—like LBS data—in the range of 10 to 100 meters. However, careful placement of directional detectors can often accurately determine location (at closer to 10 meters) to identify vehicles as being in the lanes in a particular direction on a facility. In practice, this means that Bluetooth's precision can sometimes approximate GPS's precision.

The sample size of Bluetooth data varies by region, but it is generally between 4–9% of vehicles on the road. This sample size may increase over time as newer, Bluetooth-enabled vehicles comprise a larger portion of the fleet.

Representativeness and Expansion

Systematic biases related to trip length are not suspected in Bluetooth data. This differs from other types of data and is attributable to the fact that observations—rather than being opportunistic or event-based—are controlled using detector devices. Concern exists that Bluetooth samples may be skewed toward higher-income segments of the population with newer vehicles with more technology options; however, there is little research to support or refute this claim. Also, unlike other data types, Bluetooth data are typically expanded to travel counts during data processing. Multiple expansion factors are typically used during this process and commonly used methods are believed to produce representative data.

Segmentation

Bluetooth data cannot be used to determine travelers' residences or which vehicles represent visitors to a region. These data cannot be used to identify vehicle classes or impute travel purposes.

Purchase and Implementation Costs

Bluetooth data are generally less expensive than traditional methods (e.g., intercept surveys), but more expensive than other, fully passive data sources.

CELL TOWER (AIRSAGE)

In-Practice Sources and Methods

Cell phones regularly communicate with their networks through control channel messages. This cell tower signaling can locate and track individual cell phones using trilateration and other inferences with signals sent between phones and towers. This was one of the first technologies harnessed to provide passive OD data on a large scale. Its development occurred after two of the four largest cell phone service providers in the United States partnered with AirSage, a data vendor, to process and sell derived data products, including OD trip tables, based on their tower signaling information. The resulting anonymous AirSage dataset is based on data from over 100 million devices and provides coverage for most areas in the country (although there are gaps in some, particularly rural, areas). Disaggregate, cell-based data are not available. Data are drawn from cell phone users, and this is generally assumed to represent the adult traveling public—including truckers, who cannot be separately identified.

Cell-based data are frequently used to support regional applications such as modeling. It was generally first used for external travel patterns and this is still one of its most common uses, but its use has been rapidly expanding to include model validation and even model calibration and parameter estimation. It has also been used to support new data-driven modeling frameworks such as pivot-point methods and constant rich destination choice models. Given its limited spatial precision, cell-based data can only provide direct observations of facility or corridor-level demand under unique circumstances, such as rural interstates with no nearby parallel corridors. However, cell-based data can be used in conjunction with a network assignment model and select link analysis to provide estimates of corridor-level demand.

The size and the number of zones within an area is also limited by the spatial resolution of the data, and pricing considerations also make more zones costlier. For these reasons, cell-based data often cannot be obtained for all zones in a regional model; aggregation or grouping of some zones into districts is commonly required. The spatial resolution of cell-based data approximates CBGs. Like block groups, the resolution is better and can support smaller zones in denser urban areas versus more rural areas. The number of block groups in a region is a starting point when estimating the maximum number of zones cell-based data might support in a region. However, this is just a rough rule of thumb and starting point for understanding cell-based data precision. These data can vary substantially between and within regions due to cell tower locations; it is important to verify and understand the precision cell-based data can provide for a region of interest.

Cell-based data can support long-distance and visitor travel analysis and modeling and is better suited to this task than GPS data. Unlike GPS data, device IDs are persistent for a month or more in cell-based data. Long-distance, multiday, and short-distance "visitor" trips made outside of the traveler's home region can be identified reliably. Moreover, for many types of long-distance travel analyses, it is important to understand travelers' "true" destinations rather than intermediate stops (e.g., for food, fuel, rest) that they make. Providers can process cell-based data for an additional fee, which filters intermediate stops to better understand long-distance travel patterns. Correcting for trip-length biases in the data are especially important in datasets that include both long- and short-distance trips.

Advantages/Disadvantages

Cell-based data are often (but not always) the least expensive data on OD patterns for all persons/vehicles and often (but not always) has the highest sample penetration. ID persistence supporting imputation of residence and trip purpose is another advantage. Minor advantages include the premium option to filter out intermediate stops on long-distance trips (i.e., passing through the region but stopping in it), and more established algorithms for imputing residence and trip purpose (although LBS algorithms are quickly maturing/catching up). The key disadvantage is its limited spatial (and temporal) resolution. It also does not support identification of vehicle class.

Precision and Coverage

Cell-based OD matrices can be obtained for most time periods of potential interest, including average weekday, average weekend day, individual day of the week, and multihour periods within the day. The spatial resolution or precision of data is limited. Locations are generally only known with a precision of more than one hundred meters and sometimes only within one to two kilometers in areas of limited tower coverage, but precision tends to be better in urban areas with better tower coverage. Cell-based data are typically purchased in observation/data collection periods of one month, although sometimes multiple months of data are purchased and often some discount is available for purchases of multiple months.

Sample penetration can vary significantly depending on the market share of various cell phone service providers and, as noted previously, there are some areas with no coverage at all. Members of the project team have found these samples typically include approximately 6–10% of vehicles in a corridor. These samples may include observations from a significantly larger portion of the population, perhaps as much as 30% or more depending on service provider market shares. However, not all trips by a person are necessarily observed. Therefore, the portion of trips observed is less than the portion of the population included in the sample. These figures vary by region, and some regions may have even larger samples than this range while others (especially rural areas) may not achieve this level of penetration.

Cell-based data are most commonly obtained for a one-month period, which in some cases may result in a smaller net sample size, despite higher penetration, if compared to multiple months of LBS data.

Representativeness and Expansion

As with most types of data passively collected from mobile devices, the frequency of positional observations varies within the dataset. In the case of cell-based data, the frequency of signaling between the cell phone and the tower can vary significantly based on the tower technology, the individual make and model of phone, the phone’s operating system and settings, and the use of the phone. In some circumstances, a phone could be communicating with towers every few seconds; in other cases, a phone may go one hour or more without communicating with a tower, particularly when the phone is not in use. Infrequent observations of position lead to the omission of some trips in the data; the odds that a trip is omitted decrease as the duration of the trip increases. The result is a systematic bias in the data—longer trips are over-represented relative to shorter trips. (Bernardin et al., 2017) This trip-length bias has also been observed in GPS data (Bernardin et al., 2015; Zanjani et al., 2015) and is suspected in LBS data. Although the significance of the bias and the precise details of how it arises vary somewhat by data type, it appears to be a general problem in passive data that arises from varying or infrequent observations. Failure to account for such biases can lead to erroneous representations and faulty predictions of trip lengths, trip flows between origins and destinations, and present and future travel activity patterns. The varying frequency of observations also prevents the development of OD travel time or reliability metrics from cell-based data.

Cell-based data are typically expanded before its use based on proprietary estimates of service provider market share at imputed residence locations. This residence- or population-based expansion can mitigate biases related to market shares. However, this type of expansion does not address systematic biases that can arise in the data when people travel to and from locations with poor coverage or when the trip-length bias arises from the varying frequency of observations. Therefore, it is important to correct the expansion of cell-based data to address these systematic biases. This is generally done by developing expansion adjustment factors based on traffic count data. This effort and associated cost is not included in the purchase price of the data, but it is important to budget for.

Segmentation

Information on travelers' residences or home locations, which is supported by ID persistence in cell-based data, can also support the imputation of trip purpose (e.g., whether a trip is to or from the traveler's home or work location). However, several studies have shown significant differences between imputed purposes and reported purposes, leaving the accuracy of imputation methods in question.[5,6] One important source of difficulty in the imputation of purposes and difference between imputed and reported work locations is that imputation generally assumes that the place a person spends most their day at is that person's workplace. This classifies many students and volunteers as workers and their schools or volunteering locations as workplaces. Homes can also be misidentified as workplaces for third-shift workers. As an alternative to purpose imputation, Census data on commute flows can be used to segment cell-based trips into work and nonwork trips. Vehicle class and travel mode currently cannot be imputed or observed in cell-based data. However, cell-based data can be broken into truck and nontruck segments in combination with truck GPS data.

Purchase and Implementation Costs

Cell-based data pricing is a function of the population of the region, the number of zones, the number of demand segments (e.g., resident/visitor, time periods, trip purposes), and premium options like special processing for long trips. It is sometimes (but not always) cheaper than LBS data. Expansion to travel counts to correct for systematic trip-length bias is necessary and an additional cost beyond the purchase price.

TRUCK GPS NAVIGATION (ATRI; INRIX/STREETLIGHT)

In-Practice Sources and Methods

GPS data are derived from onboard vehicle devices or integrated systems, personal navigational devices, and (in some cases) personal mobile devices. Truck GPS data are dominated by data from onboard vehicle devices. Truck GPS was one of the first

[5] Bindra S. "Using Cellphone O-D Data for Regional Travel Model Validation." 15th TRB Planning Applications Conference, May 19, 2015, Atlantic City, NJ, May 19, 2015.
[6] Milone R. "Preliminary Evaluation of Cellular Origin-Destination Data as a Basis for Forecasting NonResident Travel." PowerPoint presentation at the 15th TRB National Transportation Planning Applications Conference, May 19, 2015, Atlantic City, NJ, May 19, 2015.

technologies used to provide passive OD data on a large scale. Some GPS datasets are still specific to trucks—even heavy or multiunit trucks—while other datasets provide some data on medium-duty trucks and noncommercial or private travel (see Section 2.4). Like other types of passive OD data, GPS data are often purchased or processed to produce aggregate trip OD matrices. However, in some cases, providers may share disaggregate GPS trace data, but only with significant limitations on use. One common consideration in whether disaggregate GPS data can be obtained is whether the organization obtaining the data can enter into a binding nondisclosure/data-sharing agreement. Government agencies and universities that are subject to "sunshine" laws are sometimes precluded from access to this level of the data, whereas private consulting companies may not be. However, while consulting firms may obtain access to the disaggregate data, they are generally prohibited from sharing these data with public agencies; instead, these companies can often only provide aggregate data products, model parameters, and similar.

Because of its high level of precision in both space and time, GPS data can provide not only trip OD matrices but also OD travel time metrics, including OD travel time reliability. Although less commonly used, this information can be valuable for modeling and many travel analyses. For instance, in the Tennessee statewide model, OD travel times from truck GPS data were used to validate the model's skims.

Two main providers of truck GPS data exist: ATRI and INRIX. INRIX sometimes sells disaggregate datasets directly, but more commonly aggregated INRIX OD data are purchased through StreetLight. The characteristics of the data products offered by providers vary. The principal difference is often the amount of processing done by the provider versus the amount of processing that is left to the user. ATRI generally offers data at a lower price, leaving most processing to the user. This can offer flexibility in how the data are processed, and for some applications this can result in a better final data product or lower total costs even after allowing for the cost to process the data. However, in other cases, a data product or platform with built-in processing like StreetLight may cost more than raw data but less than the combined cost of raw data and required processing. Understanding the full cost of data and processing required for an application helps determine the most cost-effective source of GPS data. Neither ATRI nor StreetLight offer the data expansion needed to render the data usable.

Truck GPS data are well-suited to regional applications like modeling. Truck GPS data's high-fidelity locational precision also supports facility- or corridor-level applications. (Nontruck GPS data likewise has the locational precision to support both types of applications, but sample penetration currently limits its usefulness.) The effort required to process GPS data for corridor-level analysis can vary significantly by provider. StreetLight provides tools to simplify the processing of the data for these purposes, whereas ATRI provides data that can support this type of analysis but that requires substantial processing, particularly to obtain results for multiple corridors.

Device or vehicle ID persistence varies among GPS datasets. Some truck GPS datasets have significant ID persistence while other truck GPS datasets (and all currently available nontruck GPS datasets) have device persistence of 24 hours or less. Limited device ID persistence significantly limits the usefulness of data in understanding long-distance (or visitor) travel patterns. The filtering of intermediate stops on long-distance trips is also of importance in many applications. For trucking, the filtering of intermediate stops is important for GPS data to be compared to or combined with commodity flow data. ATRI provides data that allows for this type of processing, whereas StreetLight currently does not. These dual, related issues pertaining to long-distance travel are important for statewide or intercity applications. They can still have some effect, but are generally much less of an issue, at the metropolitan scale.

Advantages/Disadvantages

GPS datasets are generally the only source of passive OD data specific to trucks, representing a key advantage. In some cases, the low cost of raw truck GPS data is also an important advantage. Its precision and sample penetration are also good.

Precision and Coverage

Truck GPS OD matrices are available for most time periods of interest, including average weekday, average weekend day, individual day of the week, and even down to individual hours of the day (or possibly less). Different providers offer default observation/data collection periods that can vary from a single month to multiple years. GPS data are the most precise source of locational data. Precision is generally in the range of 1 to 10 meters, and often less than 5 meters. This level of precision allows vehicles to be located not only in zones at their origins and destinations but to individual roadways along their routes. Both ATRI and INRIX/StreetLight offer sample sizes generally found in the range of 9–12% of trucks on the road.

Representativeness and Expansion

Truck GPS data was the first type of data in which the systematic trip-length biases were observed.[7,8] Infrequent observations is a similar concern, but this is less of a factor in truck GPS data. The composition of the vehicle sample may also contribute to this bias as anecdotal information suggests that the sample is skewed toward long-haul trucks. As noted, failure to account for this type of systematic bias can lead to erroneous representations and faulty predictions of trip lengths, trip flows between origins and destinations, and present and future travel activity patterns.

Like LBS data, GPS data are not typically expanded beforehand, so the user must expand the data. The data provider may provide a tool for scaling the data based on the average ratio of data observations to traffic counts. However, this scaling does not address systematic biases

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[7] Bernardin Jr, Vincent L., Steven Trevino, and Jeffery Short. " Expanding Truck GPS-Based Passive Origin-Destination Data in Iowa and Tennessee." 2015.
[8] Zanjani, Akbar Bakhshi, et al. "Estimation of Statewide Origin–Destination Truck Flows from Large Streams of GPS Data: Application for Florida Statewide Model." Transportation Research Record: Journal of the Transportation Research Board 2.2494. 2015.

like those related to trip length or frequency of observation. Therefore, data expansion involving multiple expansion factors based on traffic counts is required.

Segmentation

The limited ID persistence in GPS datasets prevents the imputation of trip purposes. However, GPS data, unlike other data types, typically provides information on vehicle class, with data on heavy trucks or broken out between heavy- and medium-duty trucks and private/personal vehicles.

Purchase and Implementation Costs

Truck GPS data costs can vary significantly depending on the level of processing. Relatively raw data can often be inexpensive; more processed data—packaged with analysis tools—can be expensive relative to other data. However, it is important to consider the full cost of processing in addition to the data purchase price. Including the cost of processing often makes the two approaches more comparable, but this does not always result in one or the other being more cost-effective. It is important to recognize that data expansion to truck counts, which corrects for known systematic trip-length bias, is not included by either ATRI or INRIX and is an additional cost to consider.

AUTO GPS NAVIGATION (INRIX/STREETLIGHT; TOMTOM)

In-Practice Sources and Methods

GPS data are derived from onboard vehicle devices or integrated systems, personal navigational devices, and (in some cases) personal mobile devices. Although auto GPS data typically includes more data from personal mobile devices than truck GPS data, it still tends to be dominated by in-vehicle device data. These data have been shown to have a significant demographic bias toward higher-income populations.[9] (McAtee, 2017) Auto GPS data also differs significantly from truck GPS data in its sample penetration. While truck GPS datasets typically provide data for 9–12% of trucks on the road, auto GPS data typically provides data for less than 1% of autos, and sometimes less than 0.5%.

Auto GPS data has seen increased use since INRIX began partnering with StreetLight, which packages it with tools and sells it to support facility-level OD analysis (which the precision of GPS data supports). However, its use is still much less common than cell-based data and may decrease in response to the growing availability of LBS data. Its limited sample penetration may also undermine its usefulness in analysis of daily/short-distance travel patterns. However, there is some evidence that its limited sample may be more adequate for external travel patterns. Its ability to cleanly identify trip ends at external stations is also an advantage, so this external travel or facility-level OD data may become its main application.

[9] McAtee, Sean. "Validating trip distribution in Southeast Michigan using GPS data." Transportation Research Board Applications Conference. 2017.

Advantages/Disadvantages

The main advantage of auto GPS data is its locational precision. GPS data are the most precise source of locational data. Precision is generally in the range of 1 to 10 meters, and often less than 5 meters. This level of precision allows vehicles to be located not only in zones at their origins and destinations, but also on individual roadways along their routes. This supports analysis of ODs for individual facilities (and for external stations). The main disadvantage of auto GPS data is its sample penetration and representativeness. With sample penetration of less than 1% of autos in a corridor, auto GPS data are believed to be biased in important ways that may limit its appropriateness for some analyses, particularly of short-distance/daily travel patterns. Lack of ID persistence to support the imputation of residence and trip purpose is another disadvantage.

Purchase and Implementation Costs

Auto GPS data are most commonly purchased through StreetLight and as part of a package with truck GPS data, sometimes LBS data, and analysis tools. These data are generally part of a subscription package. Price varies significantly, primarily due to a region's population. Data expansion to traffic counts, which corrects for known systematic trip-length bias, is not included by either data provider; this is an additional cost that must be considered.

LOCATION-BASED SERVICES (CUEBIQ; STREETLIGHT)

In-Practice Sources and Methods

LBS data are aggregated from smartphone and other mobile device applications ("apps"). The LBS data are not based on a single technology like cell tower signaling or GPS; rather, these data represent the best location available to mobile apps at a point in time, which could come from GPS, Wi-Fi or Bluetooth beacons, or cell tower signaling under various circumstances (although its reliance on the last is limited). Most LBS locational data comes from Wi-Fi beacons and GPS. LBS data are the newest type of passive OD data and has only recently become available for widespread use in transportation analysis as of 2017.

Currently, the main provider of LBS data in the United States, Cuebiq (which sells its data both directly and in packages through StreetLight), claimed its sample was drawn from over 180 major mobile apps with over 50 million users in the United States. Like cell-based data, privacy considerations generally limit data to aggregate trip OD matrices, although disaggregate data may also be available. Data are drawn from mobile internet device (i.e., smartphone and tablet) users, and this is generally assumed to represent the adult traveling public—including truckers, who cannot be separately identified.

LBS data are well-suited to regional applications like modeling. The locational precision of LBS data helps better support (in theory) facility- or corridor-level applications than cell-based data; however, these data are not as reliable as pure GPS data. Currently, like cell-based data, direct observations of corridor-level demand from LBS data are not available. However, this may change in the future and a subset of more precise LBS observations may function like GPS data to provide direct estimates of corridor-level demand. Regardless, like cell-based data and all passive OD data, LBS can support indirect estimates of corridor-level demand using a network assignment model and select link analysis.

The size (and number) of zones within the region that LBS data can support is large (larger than cell-based data), and LBS data can generally provide data for a regional travel model's zone system. Some pricing schemes may involve the number of zones as a factor in the cost, but the predominant pricing scheme to date has offered an unlimited number of zones, with the price varying based on region population.

Advantages/Disadvantages

The key advantage of LBS data is its combination of relatively good locational precision and good sample penetration. It also offers the advantage of ID persistence to support residence and trip purpose imputation. LBS data may offer slightly lower sample penetration and is sometimes slightly more expensive than cell-based data (but not always). Its lower penetration is also sometimes offset by a longer observation period. It does not support identification of vehicle class.

Precision and Coverage

Like cell-based data, LBS OD matrices exist for most time periods of potential interest, including average weekday, average weekend day, individual day of the week, and multihour periods within the day. More fine-grained temporal resolution (down to the hour) may be available, but its reliability is not yet known. In contrast to cell-based data, LBS data offer better spatial precision, although resolution is less than what is available with GPS data. Locational precision is generally between 10 and 100 meters, with most data observations precise to better than 50 meters. Precision exceeds that of cell-based data due to the availability of multiple technologies to provide locational information.

Sample penetration can vary by region due in part to the varying popularity of apps in different markets. However, sample penetration is expected to be less variable than in cell-based data given the substantial number of apps LBS draws on. Based on a limited number of observations, project team members have found LBS data to include 5–8% of the vehicles in a corridor. The sample is believed to include up to 15% of the population, but with varying frequency of observation both between individuals and for individuals over time depending on app use. This current sample penetration appears—based on a limited number of observations—to be like (but slightly lower than) cell-based data (this generalization will not apply to all regions) and substantially higher than auto GPS data. Moreover, the LBS data sample has steadily increased, and it is possible its sample penetration may be higher soon. Therefore, it is important to verify sample penetrations in each region at the time of data acquisition. LBS data are often provided for multiple months, increasing the overall sample size and offsetting slightly lower penetration rates.

Representativeness and Expansion

The frequency of locational observations varies within the LBS dataset. This matches most other types of passive OD data and is expected to lead to a systematic bias related to trip length or duration (this has not yet been confirmed in LBS data since it has only recently become widely available). Trip-length biases in LBS data may be less than in cell-based data, but these biases are still expected to be significant. As noted, failure to account for this type of systematic bias can lead to erroneous representations and faulty predictions of trip lengths, trip flows between origins and destinations, and present and future travel activity patterns in general.

LBS data are currently not typically expanded beforehand, so users must expand the data. The data provider may provide a tool for scaling the data based on the average ratio of data observations to traffic counts. However, such simple scaling does not address systematic biases like those related to trip length or frequency of observation. Therefore, the project team recommends data expansion involving a system of multiple expansion factors based on traffic counts.

Segmentation

Like cell-based data and unlike most GPS data, LBS data have longer device ID persistence. In theory, this persistence can support long-distance and visitor travel analyses. At the time of this memo's publication, these were not yet standard options offered by data providers, but imputation of resident/visitor status is believed to be available soon. Imputation of purpose (like with cell-based data) is not currently offered, but is also expected eventually. Although not yet verified, it is expected that the accuracy of imputed purposes would be like that of cell-based data due to similar imputation algorithms. As with cell-based data, the project team recommends that imputed purpose information be used with caution until the accuracy of imputed purposes can be verified against reported purposes. Vehicle class and travel model currently cannot be imputed or observed in LBS data. However, like cell-based data, LBS data can be divided into truck and nontruck segments through combination with truck GPS data.

Purchase and Implementation Costs

LBS data are most commonly purchased through StreetLight and as part of a package with truck and auto GPS data and analysis tools, generally as a subscription. The price can vary significantly, but primarily based on region population. Data expansion to traffic counts, which corrects for suspected systematic trip-length bias, is not included by either provider and an additional cost that should be considered.

B.3 TRAVEL SURVEY METHODS

HOUSEHOLD TRAVEL SURVEYS

Data Contents and Accuracy

A HTS typically collects the following data:

- From the recruitment survey:
  - Household characteristics.
  - Person characteristics of each household member.
  - Vehicle characteristics of each household vehicle.

- From a retrieval survey for assigned travel day(s):
  - Trip characteristics for every trip made by each person.
  - Modes and routes used for each trip segment.

For use in AB model estimation and calibration, the survey data are processed to group trips into tours (home-based and work-based trip chains), and to group tours into person-days and household-days. Because the H-GAC TourCast model system uses a more detailed classification of travel choices and alternatives than that typically used in trip-based model systems, data accuracy is a critical consideration along several dimensions.

Locations

In addition to TAZs, H-GAC may wish to update the AB model to use "microzones" for a more detailed description of land use and more accurate distances for short trips (as discussed in the Task 2/3 memo). All trip ends should therefore be geocoded as accurately as possible. At a minimum, the retrieval of travel data should use a real-time map-based interface, such as Google Maps, or GPS-based data collection via smartphones.

Times

Capturing accurate trip departure and arrival times (which are the same as activity start and end times) is also important. Not only are these times used for estimating or calibrating activity-scheduling models, but they can also be used to impute travel times for data quality control. Self-reported travel times from trip diaries or from memory often contain inaccuracies due to rounding or poor recall. Thus, GPS-based data collection tends to be more accurate in capturing travel times.

Modes and Routes

It is important to capture all modes used for a given trip, including access and egress modes, transfers, and vehicle/service types for all legs of transit trips. For auto trips, it can be useful to capture parking details and parking locations for any trips where the parking place is a nonnegligible walking distance from the destination. These types of details are often captured inconsistently in diary-based surveys, particularly for trips that involve multiple modes. GPS-based surveys require some type of prompted recall to capture self-reported mode use. (In many cases, it is possible to impute the mode used from the GPS trace data, particularly for walking as an access or egress portion of a trip.) Even when self-reported mode data are captured, GPS traces can be used to impute or verify locations and other data in trips that include multiple modes (e.g., transit boarding and alighting points). GPS-based data also can be used to observe the route taken for any trip, including auto trips, although detailed analysis methods are necessary to impute entire routes in cases where the trace data are ambiguous. (RSG has recently developed such imputation/unlinking procedures for transit trips in smartphone-based GPS survey data in San Diego, California, and Columbus, Ohio.)

Activities

Consistently capturing the purposes of all activities is also important for AB models that segment activities across types. The recruitment survey typically predefines the usual work or school locations for all household members, and this information can help verify or impute the purpose for most work and school activities. For GPS-based data collection, prompted recall—respondents' self-reported activity purpose for all trips—can improve activity purpose data as post hoc calculations using land-use data are less accurate. It is also important to include enough different activity types in the lists shown to respondents to capture specific activity types that may be of interest. For example, if the data will be used to estimate physical activity, then separating exercise/active recreation from other types of recreation is useful.

Although some surveys have asked for details on in-home activities, including multiple activities for each at-home time span, the project team does not recommend requesting this information. This level of detail for in-home activities is not needed for the H-GAC AB model system, and such questions increase respondent burden. In addition, respondents tend to find such questions intrusive and tend to answer them inconsistently (some people provide more detail than others). More typical is to ask broad questions about in-home activities at the full-day level, such as "Did you spend any time doing paid work while at home? If so, how much time did you work at home?." Also, the person-level questions in the recruitment survey about workers' usual work locations and students' usual school locations should include "work from home" and "home school" as separate answer categories.

Household Joint Travel

The H-GAC TourCast model system explicitly predicts joint travel and activities across household members. Thus, it is important that the travel data for different household members who travel together are accurate and consistent in terms of the items listed above—trip end locations and times, modes used, and activity purposes (although it is possible that different household members participate in different activities at the same location). Typically, people are also asked to identify other household members who traveled on each trip, and these data can be cross-referenced for consistency. Ideally, online travel diary data retrieval software contains a "trip copy" feature that automatically copies trip details to all other co-travelers in the household, thus ensuring data consistency. With GPS-based data collection, copying trips across different devices is less feasible, although GPS-based times and locations will be consistent across co-travelers in any case. For children and some adults, some trips are provided by proxy, as discussed in a following section, and a "trip copy" feature is useful to speed up proxy reporting, as any trips that were made together with the respondent are then already included for the other household member.

Data Completeness and Nonresponse

Item Nonresponse

Item nonresponse applies to missing data for questions where the survey data are otherwise complete. Missing data can be problematic for data weighting and expansion, and tends to make the data more difficult to use in model estimation and calibration. On the other hand, some respondents find certain questions about income and race/ethnicity to be intrusive. While item nonresponse is difficult to avoid in mailed back self-completion surveys, it is easier to control in online, smartphone, or other computer-based surveys. The project team typically recommends allowing item nonresponse only for income, race/ethnicity, and any health-related questions (e.g., body mass index [BMI]) and requiring complete data for all other data items. In practice, 5–15% of respondents typically decline to provide their household income. The percentage can be reduced somewhat by following up the detailed income question with another that asks for income within broader categories (e.g., five answer choices instead of 10 more detailed answer choices) for those who refuse to answer the more detailed question.

Missing Trips

Nonreported trips are one of the more problematic issues affecting diary-based travel surveys. When participating by traditional methods, anywhere from 10–20% of respondents report not making any trips on their assigned travel day. While many of those cases are accurate, there is also compelling evidence that many of them are "soft refusals" in the sense that it is the easiest way to complete the survey without refusing to participate in the first place. Recent evidence from smartphone-based GPS surveys suggests that the true frequency of people remaining at home all day without traveling is 30–50% lower than reported in diary-based surveys. Consistent with this finding, AB models that are calibrated to unadjusted diary-based data typically produce too few trips when compared to external validation data, and adjusting the fraction of "stay-at-home days" is one of the most efficient ways of calibrating the models. To address this issue, GPS-based data has historically been collected for a subsample of respondents and used to adjust the trip rates for calibration. (As discussed in the weighting section below, newer data collection methods allow for more accurate forms of adjustment in calibration and estimation.)

Missing Household Members and Proxy Reporting

In the past, some HTSs—including the NHTS—have not required that every household member provide complete travel data for the assigned travel day—some percentage of incomplete households were allowed. That said, for a few years now, most regional or statewide HTSs have required complete travel data for the assigned day for either all household members or all household members age five or older. Because the H-GAC TourCast model system contains models of joint travel across household members, allowing incomplete households would bias the data and any models estimated or calibrated using the data.

The project team recommends that H-GAC require that all household members provide complete travel data for a given day for that household travel day to be considered a complete response. One possible exception to this requirement is to not require complete travel days from preschool-age children (e.g., under age five). In cases where those children travel together with other household members, their travel is captured indirectly via other people's trips. Since young children less frequently travel on their own, the only missing data would be instances when a young child is accompanied by a nonhousehold member, such as a nanny, a grandparent, or the parent of a playmate. For older children—particularly young teenagers—the number of trips they make on their own is more substantial.

A typical approach is to also ask the adults to provide proxy reporting of any trips that their children make without them (since joint-trips will have been captured in the adults' diary). While proxy reporting is likely to capture the more regular trips and home-based trips, such as trips to/from school or friends' houses, it may be more likely to miss shorter intermediate stops that children make during those tours. This is also an issue for traditional methods when proxy reporting is allowed for adults, where one adult reports travel for another household adult, with that adult not present (this does not occur with a smartphone app given that each person uses his or her own phone). As discussed later, if such proxy reporting is allowed, the project team recommends flagging these reports in the data to facilitate bias corrections.

Household Travel Data Collection Methods

The next section discusses methods for sampling and recruiting households. This section compares current "standard" travel data collection methods to a newly emerging method, which is smartphone-based GPS travel data collection.

Diary-Based and Smartphone-Based GPS Travel Survey Methods: Pros and Cons

GPS-based data collection has been used in travel surveys for the last decade or more—typically for a subsample of respondents to compare and adjust to diary-based travel data. Until recently, GPS-based data collection in MPO travel surveys has relied on purpose-specific "black box" GPS tracking devices that were mailed to respondents, who then carried them with them for a specified data collection period and mailed them back after the study ended. The GPS data collection was typically done for a small subsample (e.g., 10%) to calculate trip rate bias correction factors. There have also been a handful of "GPS-only" surveys, including those in Cincinnati and Cleveland, and a large "GPS-only" sample in the San Francisco Bay Area as part of the 2012 California Household Travel Survey.

Major drawbacks to using the "black box" GPS devices for HTSs have included the following:

- Device and shipping costs are quite expensive (particularly since some fraction of devices are never returned).
- Stand-alone GPS devices only capture time and location, so any questions like modes used, activity purposes, co-travelers must be asked online after asking respondents to upload the GPS trace data. This procedure is also costly and burdensome for

participants and can be subject to recall error if the elapsed time between GPS capture and the online recall survey is too long.
- People are not accustomed to carrying stand-alone GPS devices and often forget to bring them when leaving home, forget to keep them charged, or leave them in their vehicles instead of carrying them to the destinations.

Smartphone apps can leverage GPS without the shortcomings associated with stand-alone GPS devices. Participants install the app on the device they carry with them anyway, and seven days is the typical data collection period. Respondents are asked to report all details of their trips within the same smartphone app whenever it is convenient. Respondents who own smartphones already keep their devices nearby and charged and frequently check them for notifications.

The project team has deployed an RSG-created smartphone-based GPS data collection app, rMove, that uses GPS to track respondents' trips. To date, RSG has conducted small-scale surveys in Indiana, Seattle, Raleigh-Durham, Calgary, Washington, DC, and Burlington (VT). RSG also conducted large-scale rMove surveys in Columbus, Ohio, and San Diego, California, in the fall of 2016 and the spring of 2017. Although RSG does not have first-hand experience using comparable smartphone apps (which tend to be proprietary), it is likely that the pros and cons listed below will apply to other smartphone survey apps as well.

Compared to "standard" travel data collection methods using travel diaries and subsequent telephone or online data retrieval software, the advantages of using smartphone apps for GPS data collection include the following:

- Less respondent burden as respondents do not have to recall trip times, enter addresses, or locate trip ends on maps. Instead, their travel is automatically captured and displayed for them on a map via the app.
- More accurate collection of trip end locations and times. (Co-travelers will register the same locations and times.)
- Trace data to impute routes used, changes of mode, access and egress times, waiting times, and parking locations, among others. These data can be visualized in analysis.
- Ability to capture all the same trip details (mode, purpose, vehicle used, co-travelers) as in diary surveys, but with less recall error. Questions can be answered immediately after the trip is recorded in the app, instead of waiting until the travel day is completed. (In rMove surveys that RSG has conducted to date, the median time between the end of a trip and the person entering the trip details has been under two hours.)
- Ability to capture multiple days of travel with little additional cost. (In the rMove surveys, most respondents who have completed the first day have gone on to complete all seven days with surprisingly little attrition across days.). Ideally, the smartphone app can identify trips that are repeated from previous days and prepopulate the answers based on previous answers, to reduce respondent burden over time. (This is a feature of rMove.)

- Eventually lower cost per respondent. This method already lowers cost per collected travel day (the ability to collect up to seven or more travel days) because there is no longer a need to produce and mail out travel diary materials. Currently, the costs for smartphone-based GPS travel survey methods are comparable to those of diary-based methods on a per-respondent basis but are less on a per-respondent-day basis when capturing multiple days per person. (With either approach, the major survey cost is in recruiting the respondents, not in collecting the trip data.)
- Younger respondents (millennials) seem to be just as willing as other age groups to participate; this group traditionally tends to be underrepresented in diary-based surveys.

Disadvantages of smartphone-based GPS travel surveys do exist when compared to diary-based methods, although the project team expects most of these to diminish over time:

- Approximately 77% of US adults own smartphones, which means that nearly one-quarter of the population does not use a smartphone. Children with smartphones may not be allowed by their parents to use them for the survey. Thus, to obtain a full, representative sample, it is necessary to either loan or give smartphones to those who do not own them or use a mixed approach with both smartphone and traditional diary-based methods, as discussed below.
- Although smartphone battery life has not been a major issue to date, using a GPS-based app does consume additional battery power. The more accurate the traces obtained (in terms of seconds between points and the displacement needed to trigger the app for a new trip), the more battery power required. Battery life and accuracy of trace data are issues for older smartphone models.
- What the smartphone interprets as the start or end of a "trip" is not always what the respondent thinks of as a trip. A long delay in traffic can be picked up as a trip end, while a short stop to drop off a passenger can be missed by an app. The apps have features and prompts for respondents to split or merge trips when this occurs.
- Occasionally, trips are missed when respondents forget to bring their phones or lose a GPS signal (e.g., tunnels lacking Wi-Fi). The apps should have a feature that respondents can add missing trips after the fact, either online or, preferably, in the app itself. This feature is also crucial for proxy travel reporting, along with the "trip copy" feature mentioned above.
- Respondents who are concerned about data privacy may be more concerned with automatic GPS tracking (although it seems likely that such respondents would also avoid filling in travel diaries). In follow-up nonresponse surveys, data privacy has *not* been mentioned as a common reason for not participating in a smartphone-based GPS travel survey; rather, respondents remain focused on ease of use and battery use.
- Each version of the app must be registered with both the App Store (iOS) and Google Play (Android), which requires some time. Thus, it is not possible to make last-minute changes to the functionality of the app; the app has more traditional software QA/QC measures that prevent these last-minute changes.

Combining the Methods

Smartphone-based GPS and diary-based travel survey methods can be combined in two ways. First, a small subset of respondents could use smartphones while most respondents use travel diaries. This approach is analogous to past subsample approaches using custom GPS devices, although in this case there is no need for respondents using smartphones to complete travel diaries for the same days as those data would be redundant. Second, everyone who owns a smartphone could use the app and the traditional diary-based collection method could be deployed for people who do not own a smartphone (and children under a certain age who do not have parents' permission to use their smartphone for the survey). This approach requires consideration of several options, including the following:

- Loaning or giving smartphones to some or all adults who do not own them.
- Giving people who own smartphones the option to use the diary method, if they prefer.
- Requiring that all adults in the household use the same method (smartphone or diary) or allowing mixed methods across household adults.

The reason that mixed methods across members of the same household is a complex issue is that smartphone-based GPS data collection is feasible for multiple days, while diary-based collection is rarely done for more than one or two days. Since the H-GAC AB model predicts joint travel and activities, some models can only be estimated or calibrated using data for days when all eligible household members' travel data are complete. The project team will provide more definitive recommendations as to the best approaches for combining smartphone-based GPS and diary-based data collection methods in the Task 5 memo.

Sampling and Weighting Issues

Address-Based Sampling vs. Random Digit Dialing

Regardless of whether diary-based or smartphone-based GPS travel survey methods are used to retrieve travel data, the costliest part of a HTS is recruiting the households to participate. In the past, the most common recruitment method was random digit dialing (RDD). RDD involves selecting operational telephone numbers at random from landline phone numbers and doing all recruitment by telephone. RDD is no longer an effective method for recruitment for several reasons:

- RDD cannot reach households that do not have a landline telephone, and recent statistics show that a substantial and growing number of US households no longer have a landline and are cellphone-only (CPO) households. Over 50% of young adults now live in CPO households.
- Many people now have caller ID and screen their phone calls. They will not answer calls from phone numbers they do not recognize, so most RDD calls go unanswered.
- RDD is set up for people to respond to the survey by telephone, whereas RSG's recent experience is that 75–80% of people choose to answer travel surveys via the internet rather than by telephone interview.

- The aforementioned issues associated with RDD are all more acute with younger age groups, which further skews RDD samples toward older age groups.

The use of RDD has declined steadily to the point where it is rarely used anymore for HTSs. Now, the most commonly used recruitment method is ABS, which typically relies on the following steps:

- The sampling rates are specified by geographic areas such as ZIP Codes, Census tracts or CBGs.
- A random sample of addresses is purchased with the specified geographic distribution from the US Postal Service's address database.
- A prenotice postcard introducing the survey is sent to the purchased addresses, so that they will be more likely to notice a second mailing with the more detailed survey materials. (They are typically sent out in batches over time to allow monitoring of response rates achieved and adjustment of the invited sample, if necessary.)
- A second invitation packet mailing is done with more complete information about the survey.
- Further reminder postcards can be sent for those who have not responded. If there are listed phone numbers matched with the addresses, then phone calls can be made to those respondents to recruit them to participate.
- If a respondent completes the recruitment survey (via a URL to an online survey or by phone) and agrees to participate, then they are assigned a (starting) travel day. (For a smartphone-based GPS travel survey, they are sent via text or e-mail a URL and password to download and register the app.)

Although ABS can potentially reach any household with a mailing address, and there is no better alternative currently available, it still has some limitations:

- It does not reach those living in group quarters like college dormitories or military barracks.
- Younger people and people with lower incomes tend to change addresses more often, so their listed addresses are more likely to be out of date.
- The overall response rates are low—between 3–10%. (Mailing fewer initial invitations with more follow-up reminders would increase response rates *and* increase costs.). Incentives are important for this reason (more on this later).
- Low response rates tend to mean a high potential for some degree of selective nonresponse bias. Older households and higher-income households tend to have the highest response rates, and younger households and lower-income households have the lowest response rates. (Using smartphone-based data retrieval for the subsequent travel portion helps to address the age bias, but it does not address the income bias.)

Targeted and Compensatory Oversampling

In the past, the emphasis in sampling for HTSs has often been to obtain as representative and as unbiased a sample as possible. There has been a corresponding emphasis on so-called "probability sampling," where the relative probability of including any given household in the sample is assumed to be known based on population data, and these probabilities can be used to expand the sample to be representative of the full population.

From a modeling standpoint, it is often more important to target the hard-to-reach groups in terms of demographics and travel behavior and try to obtain more of them in the sample than it is to attempt to obtain a representative sample (which, with the types of biases mentioned, is nearly impossible). For recent surveys, RSG and others have recommended substantial “targeted oversampling” of groups that tend to show different travel behavior or comprise a small percentage of the general population, such as zero-vehicle households, low-income households, young single-person households, transit users, and bicycle users.

This targeting can be achieved effectively by using much higher sampling rates in CBGs that contain the highest proportions of such households or persons, according to ACS data. (A useful feature of ABS is that it allows greater control over the geographic distribution of the sample.) Although such geography-based “oversampling” has been used in some past HTSs, the level of oversampling has rarely been high enough to achieve the desired effect in terms of providing adequate data for modeling. In some cases, it has not even been strong enough to compensate for underlying nonresponse biases.

For data for AB model estimation, the project team recommends using two types of increased sampling rates. The first type overcomes nonresponse biases that can be anticipated from past surveys. For example, if one expects the response rates from CBGs with a high percentage of low-income households to be only two-thirds of the response rate anticipated from other block groups, then 50% more invitations should be sent out to those CBGs to compensate for the lower expected response rates. This is meant only to provide a representative sample, so it is not “oversampling.” The term “compensatory oversampling,” as used here, describes this type of sampling rate adjustment.

On top of “compensatory oversampling,” the project team recommends using strong “targeted oversampling” on block groups that are highest in terms of the types of demographic groups or mode use that is desired. For example, it is often observed in the ACS commute data that most people who commute by bicycle live within a small minority of block groups. To effectively obtain more bicycle commuters in the survey sample, those block groups with the highest bicycle mode share should have an invitation rate at least three to five times higher than the “normal” invitation rate for block groups that are not a target for oversampling. (In many past reported surveys, the ratio of sampling rates for oversampled areas versus other areas has typically been less than 2, which is rarely sufficient to provide the increased sample sizes for hard-to-reach groups and behaviors desired for model estimation.)

Note: To use ACS block group data, it must be from the combined five-year ACS data tables (The more recent one-year ACS data are only available for geographic units of 60,000 or more, such as towns or counties.) In some cases, such as fast-growing areas or targeted areas for “smart growth,” the planning agency may wish to designate specific areas for target oversampling without relying on ACS data. An example is PSRC, which used targeted oversampling for the designated Regional Growth Centers in the Seattle/Tacoma region.

Use of Incentives

With ever-declining response rates for HTSs, offering incentives to complete the survey can be a cost-effective method to increase survey response rates and representativeness. This is standard practice now, including the NHTS, which offers a $20 gift card incentive. (Lower-income households are typically least likely to respond, but these households may be influenced most by incentives.) Incentives can be offered in terms of cash or as gift cards to popular retailers like Amazon, Walmart, or Starbucks, among others (typically with the respondent choosing).

Incentives can be offered per household or per person (in either case, a complete household travel day should be required to receive the incentive). Offering incentives for each person is more expensive, but this can help recruit larger households, which are also typically underrepresented in HTS samples.

In states or regions that do not offer direct incentives, it may be possible to offer a raffle/sweepstakes type of prize offer, although experience has shown that these are less cost-effective than direct incentives. For example, the Connecticut's recent HTS compared a guaranteed incentive to a raffle prize in their pilot study. These results (Table 7) indicate that the state saved money by offering a guaranteed incentive gift card; this is consistent with the project team's experience in other regions.

TABLE 7: STATE OF CONNECTICUT PILOT TESTING GIFT CARD VS. RAFFLE RESPONSE

RESULTS TYPE	OFFERED GIFT CARD	OFFERED RAFFLE PRIZE
Invited	2,301	4,282
Recruited	179	141
Completed	144	106
Recruit Rate	7.8%	3.3%
Complete Rate	6.3%	2.5%

Possible Added "Convenience" Samples

In addition to geography-based oversampling, there are other methods for sampling groups that are traditionally underrepresented through ABS, or that have small incidence in the actual population and a larger desired sample size for modeling.

A common type of "convenience sampling" is for university students. University students who live in dormitories are usually not reached at all with ABS, but other university students living off campus (but not with parents) typically also have low response rates. With some cooperation from the colleges, is often possible to obtain e-mail lists of students from campus administrators and send out invitations for an online survey. Since recruitment is the most expensive part of a HTS, this low-cost recruitment makes university surveys much less expensive per respondent than household surveys. Other ways that university surveys can be easier and less costly to reach include the following: 1) only online response is possible, with no telephone call center needed; and 2) only the student is surveyed rather than the entire household (except for students who still live at home with their families).

E-mail lists provided by administrators can be effectively used for surveying military base residents (and employees) and university students. Military personnel also contend with security restrictions, which may preclude respondents from using GPS location tracking or reporting on-base movements.

Other convenience samples can use vanpool membership e-mail lists, carshare membership e-mail lists, and other mode-specific membership e-mail lists. The other main type of convenience sampling is intercept sampling for certain behaviors of interest. Examples include the following:

- Travelers intercepted at park-and-ride lots (or via license plate photos).
- Travelers intercepted at downtown parking garages (or via license plate photos).
- Toll road/managed lane users identified via license plate photos or transponders.
- Transit users intercepted at stations or in vehicles (e.g., during an on-board survey).
- Bicyclists intercepted en route (e.g., during a bicycle count survey or OD survey).
- Nonresident visitors intercepted at hotels, convention centers, or airports, among other locations.

In most cases, these surveys are done to generate their own type of data, such as count data or occupancy data for model validation. These surveys can also be used to invite additional respondents (and their households) to participate in the HTS to increase the representativeness of some behaviors in a form that is directly useful for estimating the AB model components. However, intercepting a traveler while making a specified trip type does not guarantee that they will repeat that same type of choice while participating in the household survey, but it is more likely—particularly in a multiday survey context.

The use of convenience sampling can complicate the weighting process, as discussed in the next section.

Weighting the Data for Descriptive Analysis and Model Calibration

Weighting the survey data to represent the broader population is important for descriptive analyses and for deriving model calibration targets. For model calibration, some additional adjustment of weights may be useful, as discussed here.

In general, weighting of household survey data follows two steps:

1. Initial weighting based on sampling probabilities: If the sampling rates are determined geographically, then this step just requires identifying each separate sampling area within which all households had equal probability of being sampled and then estimating an initial weight for each area that equals the number of households living within the area (e.g., from the most recent ACS data) divided by the number of households in the survey sample.
2. Adjusted weights to match ACS-based marginal distributions: This step involves starting with the initial weight for each household and using a method such as IPF to

simultaneously match several marginal distributions, based on the most recent ACS data. If the marginals are for large areas—PUMAs, counties, or larger—then the one-year ACS data may be sufficient for the marginal targets. For the AB model system, which simulates individual persons and uses person type as a key variable, the project team recommends using both household-level and person-level marginal distributions for weighting. Some examples of target variables include the following:

- Household residence PUMA.
- Household size.
- Household number of workers.
- Household income group.
- Household vehicle ownership.
- Household presence/absence of own children.
- Person gender.
- Person age group.
- Person worker status (e.g., full time, part time, not employed).
- Person university student status.
- Person ethnicity/race.

If "missing" responses are allowed for household income or person race/ethnicity, then it is necessary to impute the data for those cases before weighting the data.

A region like Houston has a large enough population to conduct the weighting separately for different subregions. One approach for weighting that seems to work well and provide reasonable geographic accuracy is to weight each Census PUMA separately. The H-GAC region has 54 PUMAs—38 in Harris County and 16 in the rest of the region. PUMAs each include a similar population, which helps avoid small cell size issues in weighting. HTSs typically include 0.4–0.8% of the households in a region. A typical PUMA includes approximately 50,000 resident households, so a survey sample includes approximately 200–400 households within each PUMA. When needed, adjacent PUMAs with similar demographic profiles can be combined in weighting to avoid small cell size issues and prevent the resulting weights from becoming too large or too small in the IPF process.

PUMAs have another attractive feature—they are the geographic unit available in the ACS PUMS microdata. Using the microdata instead of the published ACS tables to derive weighting targets allows for a more flexible definition of the targets (not dependent on which tables happen to be available from the US Census Bureau). This method also permits easy fixes for the inconsistencies between ACS household-level weights and ACS person-level weights.

If the data combine smartphone- and diary-based data, then weights can be further adjusted by comparing trip rates from the data types. This has been frequent practice for recent survey with GPS-based subsamples, but having fully compatible data from both methods will allow it to be done in a more sophisticated way. The project team recommends the following steps:

- Estimate a model of the probability of staying home all day (zero trips in a person-day), using collection method ("diary-based") as one of the explanatory variables, plus important sociodemographic variables.
- For each diary-based person-day with zero trips, calculate the ratio of the model predicted probabilities of making no trips applied with and without the "diary-based" variable, and use the ratio to adjust the weight on the person-day. Adjust the weights on diary-based person-days with one or more trips in the opposite direction to compensate.
- Compare the average number of trips/person-day by OD purpose combinations, modes, and times of day for the different collection methods, and use the results to adjust the trip-level weights for the diary-based data. (Since the two methods are used by different types of respondents, ideally this analysis would also use regression models to control for sociodemographics and then apply the models with and without "diary-based" bias identification variables to calculate the method-specific biases that should be adjusted for.)

However, the most effective way to adjust for any method-specific biases in the data is in model estimation rather than in weighting and calibration. Because the smartphone-based GPS travel survey data are fully compatible with the diary-based data, the two types of data can be used simultaneously in model estimation. (That was not the case for most GPS data collected in past surveys.) A dummy variable for the diary-based observations can be used in estimating any models to capture biases specific to the data collection method. (This is analogous to using a dummy variable for data reported by proxy, to capture biases due to indirect reporting. The dummy variable is used in estimation to allow for biases, but not used in model application.)

If "convenience" samples are used for recruiting, then it may not be possible to include those responses in the weighting process if they are known to be a nonrepresentative sample of the general population. This is particularly true for "choice-based" sampling (e.g., recruiting people at transit stops or park-and-ride lots). In that case, the data are still useful for mode estimation, which typically does not use weights, but not used in descriptive analyses or model calibration. Some types of convenience samples can be weighted if they are representative of a population for which the actual size is known. For example, a sample of students recruited via university e-mail lists can be expanded to match data on university student enrollment.

The Frequency of Conducting Travel Surveys

In past decades, MPOs tended to perform HTSs every 10 years or so to coincide with the decennial Census, which was the only source of reliable demographic data for expanding and weighting the data. More recently, as the US Census Bureau move to the continuous ACS—with demographic data released on a rolling, annual basis—some MPOs and departments of transportation are pursuing more frequent data collection. For example, PSRC in the Seattle region and the Metropolitan Council in the Minneapolis region have moved to two-year data collection cycles. Also, in North Carolina, the Raleigh-Durham region MPOs are considering a similar move. Other options would be to move to a one-year cycle (annual surveys), or to a less frequent cycle such as four-year or five-year, which would still be more frequent than the "traditional" 10-year cycle.

Generally, the sample size should be inversely proportional to the survey frequency, though cost and intended data use can also inform sample sizes. So, if one were to set a sample size of 10,000 households for a survey done every 10 years, then this would translate to 2,000 households per survey on two-year cycle, 4,000 households per survey on a four-year cycle, and so on. An exception to this recommendation may be made in cases where a survey has not been done for several years before the first cycle. In that case, it may be desired to collect a larger sample size in the first cycle to provide enough data to "jump start" the modeling process, but then supplement that with smaller sample sizes in subsequent survey cycles. That was the approach used the three regions mentioned above (Seattle, Minneapolis, and Raleigh-Durham), and may also be appropriate for H-GAC.

Determining the frequency of collecting HTS data requires considering several issues. Some are related to the intended uses of the data and its effectiveness for these purposes, while others are related to survey costs and budgeting.

The Use of the Data for Descriptive Trend Analysis

In addition to funding considerations, a strong motivation for more frequent data collection is to observe trends in travel behavior more quickly as they occur over time. This is a key use and benefit of some of the large annual national travel surveys conducted in many countries.

The Statistical Reliability of the Sample Size

If the sample size is inversely proportional to survey frequency, an offsetting disadvantage of having more frequent data is that the sample size in any given year is relatively small. While 1,000 households may be adequate to measure trends in some common behaviors at the regional level, it is likely less adequate for observing trends in less common travel choices (e.g., transit mode share, bicycle mode share) or for comparing trends between subareas of the region.

The Use of the Data for Model Calibration

The primary use of HTS data is to create observed targets for calibrating travel models—providing measures such as household trip rates, trip-length distributions, mode shares, and TOD distributions. Ideally, these measures can be provided for different travel purposes and for key market segments like income groups or car ownership categories. Travel models are typically calibrated for a specific base year, with all the explanatory network and land-use variables and demographic distributions created to represent that year. As updating a model base year can be a time-consuming and costly process, it is typically done in conjunction with creating a new long-range regional plan, which is done every four years or so. Survey data collected more often than this will need to be combined across survey cycles for model calibration, and the choices observed from some of the survey cycles may not be consistent with the underlying travel conditions and land uses that are represented in the base-year model input data. This is analogous to the issues in using the five-year ACS data to obtain demographic estimates—the data are combined across years to obtain larger sample sizes and more statistically reliable estimates, but the multiyear data are not fully consistent with any single year and most of the data reflect conditions in previous years (which may or may not be the same in the most recent year).

The Use of Data for Model Estimation

Model estimation is like model calibration but goes a step further in using discrete choice model estimation to re-estimate some or all the travel model parameters, possibly changing the model specification to include new types of travel choices or new choice alternatives. The concerns with frequent data collection are like those for model calibration. For model estimation, the survey data needs to be merged with data representing explanatory variables like network travel times and costs and destination employment levels. Unless those background data are updated each time that new survey data are collected, some of the survey choice data will need to be merged with explanatory data that is from a different year. This type of inconsistency is likely to be a larger issue for model estimation than for model calibration, since estimation is a more rigorous statistical process and tends to be more sensitive to inaccuracies in the input data.

Expanding and Weighting the Data

The previous sections discussed the issue of combining samples from different survey years. A travel survey measures the behavior of the population during the time period in which the data are collected. So, the data should be expanded and weighted to the population for each specific year when it is collected. However, the smaller the sample size in any given survey cycle, the less spatial detail or demographic categories that can be used reliably in weighting. When combining samples from different survey cycles in analysis, the data then needs to be reweighted in some way to represent the average population across time. This is done by the Census Bureau for the multiyear ACS data—each year's sample is weighted to that year's population estimates, and the estimates used for weighting the multiyear samples are averaged across the years. The single-year ACS samples are the best to use for large-area estimates because they are most recent and represent a specific year. However, the single-year ACS sample size is deemed inadequate to provide estimates for any areas below 60,000 in population. As a result, the five-year combined sample with averaged weights is used to provide estimates at the tract and block group levels and for any geographies used in the Census Transportation Planning Package. Fortunately, when combining and weighting travel survey data collected across multiple years, there are corresponding ACS multiyear demographic estimates with which to weight the data.

The Per-Household Cost of Collecting the Data

While many HTS costs are directly proportional to the sample size, there are also fixed costs, particularly those related to (re)starting the collection process, designing, and drawing a sample, and monitoring the fieldwork over a longer elapsed time. Some fixed costs are lower because they are minimized in a recurrent survey program (versus conducting a new survey every decade) due to the ability to maintain and reuse many design elements. For example, the study logo and print materials for the region were designed for an earlier year can be reused (with minor modifications) for a potential data collection effort in later years.

That said, some fixed costs still occur with each data collection cycle. It is useful to balance the desire for more current and detailed data with the logistical realities of collecting the data and considering the value of the data for its end use. With small samples (e.g., 1,000 households) there is a marginally higher cost per household due to economies of scale, as certain fixed costs must be spread over fewer households at a time and some expenses are affected by volume pricing. For example, the postage for printed study invitation materials is often higher (per household) with a smaller sample than a larger sample as there are often discounts for mailing larger quantities at one time.

Survey designs should also be refreshed, and quality checks should be conducted prior to each data collection cycle, though this can be managed to a degree by minimizing changes between cycles. The fewer changes that are made in the survey design, sample design, and weighting procedures from cycle to cycle, the lower the survey start-up costs will be for each cycle. Consistency in the survey and sample design and weighting over time is also beneficial for performing trend analyses, since changes in survey design or methodology can influence the survey results.

Weighting datasets (and potentially combining datasets across years) for each survey cycle is an added cost, but there are benefits to doing this. One could conceivably postpone the weighting and do it jointly on multiple years of data, but if data are not weighted in concert with data collection, then they will not be available for trend analysis, so there seems less value in collecting data more often if does not provide more recent information that can be used in analysis.

Exact costs can vary significantly depending on survey and sample design choices, such as smartphone sample and targeted oversample quantities and how often to combine and weight multiyear datasets. The project team will provide more detail on costs in the Task 5 memo when recommending a limited number of options for consideration.

The Ability to Target New Questions or New Behaviors More Often

Keeping the survey consistent from cycle to cycle has its benefits, but conducting surveys more often provides an opportunity to add new questions or revise existing questions. Often this can be done without compromising the long-term consistency of the core survey questions. For example, there can be a small set of "rotating questions" that are intended to be changed each time to ask about emerging issues or behaviors of interest. Recent examples have included questions about use of/interest in using ridesharing services and carsharing and bikesharing systems, questions about potential interest in using CAVs, and questions about use of travel information smartphone apps. However, if the purpose of these questions is to monitor trends over time, then they should be repeated each survey cycle rather than rotated in and out. Also, some minor changes can be made to survey questions that do not affect trend analysis or add cost. A recent example has been to add "Uber/Lyft" as another answer category in the mode question, in most cases separate from the "taxi" category. On balance, the ability to adapt the survey questions over time is a benefit of doing more frequent surveys; ensuring consistency over time is also given high priority and changes are made sparingly and thoughtfully.

The Ability to Update Survey Methods Over Time

Conducting HTSs more frequently can also facilitate more rapid shifts toward newer data collection and sampling approaches as these become available. For example, smartphone-based GPS travel survey data collection will continue to become more standard as the data quality continues improving and the cost per household decreases. (With multiday data collection, the cost per respondent-day for smartphone-based GPS data collection is already lower than for online/telephone diary-based collection.) Additionally, smartphone ownership continues to increase, making this a more viable option for travel surveys—the Pew Research Center indicates that as of November 2016, 77% of US adults had a smartphone.

However, changing survey methodologies can make trend analysis challenging, particularly when the surveys are several years apart. This issue has arisen with the NHTS in recent years, and it will again be an issue when the most recent NHTS data becomes available next year. Compared to the previous survey in 2009, NHTS has changed both sampling method (from RDD to address-based) and main data collection method (from telephone to online). As explained later in this memo, more frequent data collection combined with split-sample approaches can allow a rapid shift in methods across survey cycles while still accommodating consistency over time for trend analysis.

Budget Amounts and Budget Cycles

Regardless of what timing might be best from other perspectives, collecting survey data requires that enough budget be available. In the past, the timing of large HTSs has sometimes been opportunity based—the survey was done when enough funding could be obtained and included in the budget. Collecting a smaller number of households more often may be easier to budget for since the cost of each survey is less and may be regarded as a regular, annual, or biennial cost. This approach assumes some amount of budget stability over time. An unexpected gap in funding can mean having to cancel or postpone the survey for a given cycle, with a resulting gap in any trend analyses and a potential shortage of data for model calibration or estimation. While such a temporal gap is a severe problem for panel surveys, where the analysis relies on having regularly spaced "waves" of responses from the same respondents, it is less of a problem for recurrent survey programs with repeated cross-sections where new respondents are invited for each cycle. For cross-sectional surveys, a lack of funding in each survey cycle could be compensated for by increasing the budget and sample size in a subsequent cycle. Although there still might be a gap in trend analyses, the data across time would still be as useful for model calibration and updating if the resulting (combined) dataset had the same number of total households as there would have been without the gap in funding.

Summary

Table 8 summarizes the primary advantages and disadvantages of moving HTS data collection to more frequent cycles. These trade-offs exist along a continuum, as both the advantages and disadvantages become more pronounced as the data collection frequency increases from every 10 or so years to every year. The important question to ask when deciding on frequency is whether there is a point somewhere along that continuum that provides most of the advantages while avoiding most of the disadvantages.

TABLE 8: ADVANTAGES AND DISADVANTAGES OF MORE FREQUENT DATA COLLECTION

ADVANTAGES	DISADVANTAGES
More recent data on trends and behavior	Smaller sample size per survey cycle
Ability to add/rotate new questions more often	Need to combine data from different cycles
Ability to shift to new methods more rapidly	Per-household survey cost marginally higher with small samples
Less funding needed per survey cycle	May be inconsistent with model base-year data

Data for Potential Areas for Future Model Development

The Task 2/3 memo described several possible directions for future AB model development for H-GAC. This section describes how special types of surveys could be designed for several areas, possibly using follow-up surveys to the main HTS. Data from subsequent surveys could be used to expand the capabilities of the AB forecasting model or to do exploratory, descriptive analyses. The subsections below discuss what types of additional questions or surveys would need to be added to future data collection programs and what types of targeted sampling might be valuable.

In some cases, the project team suggests using "nonprobability" methods to recruit additional respondents who are known to make specific travel choices. An example would be to use LPC at park-and-ride lots to send out additional survey invitations to households most likely to use the park-and-ride mode. The entire household would be invited to participate in the full HTSs, just like any other invited household, so that the data can be used in all aspects of AB model estimation. Typically, however, such "convenience" samples are not included in the data expansion and weighting, so they cannot be used in general descriptive analyses across the full population that require weighting. The potential value of the additional data in choice model estimation (which typically does not use expansion weights) is great enough that it may warrant a shift from a strictly probability-based sampling strategy.

The discussions for each of the different topic areas below generally consider three distinct types of questions:

- Revealed preference data: Factual questions about recent or past behavior or constraints on behavior.
- SP data: Hypothetical questions about choices in potential future scenarios.
- Attitudinal data: Qualitative questions about attitudes, perceptions, and intentions.

In general, it may be possible to include a few questions of the first type in the core questionnaire for a HTS—without making the core survey unreasonably long. Including extensive attitudinal or SP questions may require selecting specific respondents and inviting them to participate in another, follow-up survey. This sequential approach has an advantage in that it can allow the survey designers to create customized questions based on actual choices reported in respondents' travel diaries (or smartphones).

Use of Bicycle and Pedestrian Modes (Active Transportation)

Given the possible benefits of walking and biking both in terms of reducing traffic congestion and improving public health, this is likely to be a topic of growing importance for policy and modeling. RSG and others are conducting modeling research to predict changes in the level of walking and biking for different purposes as a response to changes in land use and infrastructure. In some cases, this modeling has been extended to also study changes in BMI and other indicators of physical health. Collecting data on health outcomes is a substantial area of survey research in the field of epidemiology that is probably beyond the scope of the next survey. However, potential exists for increasing data collected on walking and biking behavior. There may also be potential to seek funding cooperation from regional or state public health agencies. For example, joint recruitment for both health-related and travel-related surveys could help share recruitment costs while also allowing cross-analysis between the datasets. (However, the project team is unaware of any cases at the time of this writing where this has been done.)

Revealed preference data. Because walk and bike trips are relatively rare to capture in traditional travel diary surveys, some surveys have asked broader questions about peoples' typical walking and biking behavior, such as the typical number of walk and bike trips they make per week for different purposes. For example, the most recent NHTS included such additional questions for California residents. Such questions, however, do not provide data that has enough spatial information to use in modeling walk and bike behavior at the detailed level found in AB models.

It would be more beneficial to increase the number of walk and bike trips that are likely to be collected as part of the core HTS. This can be done by oversampling in geographic areas where residents are likely to make the most walk and bike trips. For example, the ACS data on commute mode to work is available at the CBG level and can be used to target specific neighborhoods for data collection.

Another method for target sampling is to field an OD intercept survey. This method can be used as the basis for recruiting additional sample for the HTS while also providing useful supplemental data on OD patterns and trip purposes (like the data from a transit on-board survey). The intercept approach may be particularly effective at increasing the number of bicycle users in the sample by intercepting cyclists along selected corridors and routes. (RSG recently used this approach in the San Diego region.)

The shift to smartphone-based GPS travel surveys will also be useful for capturing more walk and bike trips, as short walk trips and “loop trips” (walking or biking for exercise) are often omitted from travel diary surveys. (Even with current, non-GPS methods, the capture of walk and bike loop trips for exercise can be greatly improved, as has been done in some recent surveys.) The collection of multiple days per of GPS data per respondent will also provide more nonmotorized trips. GPS data also provide information on the route used by pedestrians and bicyclists, which is useful for studying preferences for specific types of infrastructure and safety improvements. GPS trace data can also be used to impute the walk access and egress portions of auto and transit trips.

SP and attitudinal data. SP exercises regarding walk and bike behavior can be problematic. Although several SP studies of bicycle route choice have been done in the past, superior GPS-based revealed preference (RP) data now exists and is available for that purpose, as noted above. SP studies of mode choice and a potential shift from auto toward walking and biking may suffer from the problem that many people may wish to walk and bike more and may say that they would do so in an SP survey context, but in reality they would not do so because of safety considerations or physical inertia. Both of those issues are difficult to treat realistically in an SP context. Safety aspects are dependent on the design of specific facilities and intersections, and people who do not currently walk or cycle often would not be aware of the safety implications of different infrastructure designs in a hypothetical survey context. Therefore, SP questions on this topic may not produce reliable information for predicting behavior, although they might indicate peoples’ wishes. However, simpler attitudinal and explanatory questions around walking and biking behavior could be useful. Figure 10 and Figure 11 show example questions from a recent survey in Utah.

FIGURE 10: SAMPLE ATTITUDINAL STATEMENTS RELATED TO WALKING AND BIKING

How strongly do you agree or disagree with the following statements?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would bike on streets also designed for bicycles even if they are slightly out of my way					
Overall, there are enough SIDEWALKS in my region to meet my travel needs					
I support using transportation funds to help pay for projects such as sidewalks and bike paths					
The ability to walk & bike to places in my neighborhood is important to me					
Having to share the road with motor vehicles is the main reason I don't bike more often					
Overall, there are enough BIKE PATHS in my region to meet my travel needs					
I would like to walk &/or bike more often, but I have trouble fitting it into my current lifestyle					

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FIGURE 11: A SAMPLE QUESTION REGARDING REASONS FOR NOT USING BIKE

For what reasons don't you bike?

Please select all that apply.

- Too busy (didn't have time)
- Takes too long to bike to the places I go
- My health (or health of someone in my household) doesn't allow me to bike
- No showers/changing facilities to use after biking
- Too few OFF-STREET bike paths or trails
- Poor/unpredictable weather
- Too few ON-STREET marked bike lanes
- Do not own a bike
- Do not like/enjoy biking
- Need/want to use vehicle for work/school/other reasons (instead of biking)
- Feel unsafe biking in traffic
- Other, please specify:

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Use of Ride-Hailing, Carsharing, and Bikesharing Options

Ride-hailing, carsharing, and bikesharing systems are becoming increasingly popular. They offer qualitatively new options in terms of their convenience, flexibility, and ability to schedule at a moment's notice. Carsharing options include Zipcar and car2go, and ride-hailing options include Uber and Lyft. Use of a bikeshare system could also be investigated. By the time of the next HTS in Houston, it is likely that the use and variety of such options will grow even further. These options will certainly influence the relative use of conventional transit and dial-a-ride transit and of taxi services (which most urban models do not model well in any case). They may also influence car ownership levels, as some people will use them as an alternative to owning a (second) car, and that is likely to have indirect effects on the mode and destination for discretionary trips (e.g., someone might walk a half mile to the local shop instead of driving two miles to the supermarket).

RP data. The simplest option for obtaining disaggregate data on the use of these newer mobility options is to add them to the list of modes that respondents can report in a diary- or smartphone-based GPS travel survey questionnaire. Because carsharing systems all tend to require membership to use them, survey questions can also be added at the person level asking about current (and planned) membership in various services. Membership could then be modeled as a longer-term choice, like the current models for transit pass or toll transponder ownership. For ride-hailing services (Uber, Lyft), the membership cost is currently not an issue, and there are already enough of these trips in many cities to include them as a mode in mode choice models and calibrate the mode share based on HTS data. (Over 1,700 Uber and Lyft trips were reported in the 2016–17 SANDAG HTS.)

It may also be desirable to obtain a larger sample of members and users of these systems, to more accurately model how their travel patterns differ from other people. One method of doing so would to get sharing services to send out invitations to their members to participate in the regional travel survey. This approach has been used in past surveys to obtain increased participation of employer-based vanpool services. (Another option would be to obtain e-mail or postal address lists of the share service members, but that may not be possible due to privacy agreements.)

SP and attitudinal data. SP experiments might be a desirable approach to predict likely use in regions where ride-hailing, carshare, or bikeshare systems do not yet exist. These services already exist in the Houston region, so SP would only be warranted if one wanted to study demand for different types of services than those that already exist. Some regions have added extra attitudinal questions about the overall use of and attitudes toward using ride-hailing and carsharing options.

Choice of Auto Type and Fuel Type

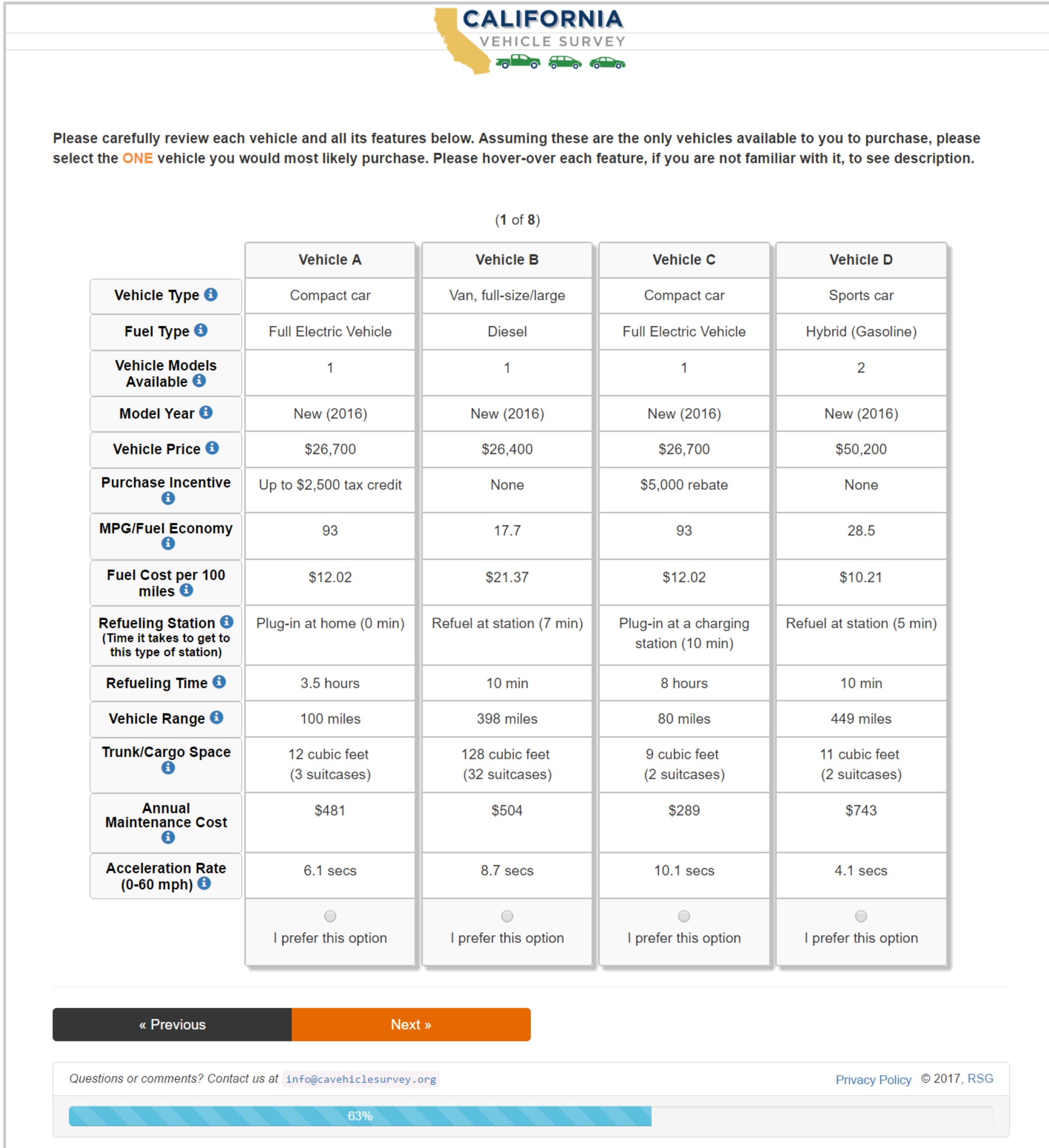
Currently, all AB model systems predict the level of auto ownership, but few—if any—predict what types of vehicles are owned, in terms of body type, fuel type, or fuel efficiency. As greenhouse gas and other pollutant emissions become more critical in transportation planning, and as new types of low-emission or zero-emission vehicles become more prevalent, it will be more important for urban models to predict which types of vehicles households own, and which trips for which vehicles are used. (For example, plug-in electric vehicles may only be used on shorter trips.)

RP data. The standard HTS questions on vehicle make, model, and vintage should also include fuel type, with the ability to distinguish between the various types of hybrid and plug-in electric vehicles. (Fuel cell vehicles may also be on the market at some point.) Since vehicle ownership decisions are quite major, it would also be possible to ask people not only about the vehicles they currently own (and when they purchased them), but about any vehicles they have recently sold or retired. That would provide data for a dynamic, transactions model of vehicle ownership, which could be more useful for policy analysis than a static, holdings model.

One possible method to increase the number of alternative-fuel vehicle owners in the sample would be to use video LPC and address matching to send survey invitations to owners of selected vehicle types (assuming cooperation from the motor vehicle department).

SP and attitudinal data. Many SP studies have examined vehicle purchase, particularly for the purchase of electric and alternative-fuel vehicles. For example, the California Energy Commission has its own vehicle fleet model and periodically conducts SP surveys to update the parameters. Figure 12 is an example from an RSG-administered survey; the list of relevant vehicle attributes is long and may make the SP choice exercise difficult for some respondents. In addition, now that alternative-fuel vehicles are more common in the marketplace, it may be possible to estimate adequate models using RP data on vehicle purchases. For these reasons, and because there are several existing SP studies on vehicle choice, this is unlikely to be a high priority SP topic area.

FIGURE 12: EXAMPLE OF A VEHICLE CHOICE SP QUESTION



CALIFORNIA VEHICLE SURVEY

Please carefully review each vehicle and all its features below. Assuming these are the only vehicles available to you to purchase, please select the ONE vehicle you would most likely purchase. Please hover-over each feature, if you are not familiar with it, to see description.

(1 of 8)

	Vehicle A	Vehicle B	Vehicle C	Vehicle D
Vehicle Type	Compact car	Van, full-size/large	Compact car	Sports car
Fuel Type	Full Electric Vehicle	Diesel	Full Electric Vehicle	Hybrid (Gasoline)
Vehicle Models Available	1	1	1	2
Model Year	New (2016)	New (2016)	New (2016)	New (2016)
Vehicle Price	$26,700	$26,400	$26,700	$50,200
Purchase Incentive	Up to $2,500 tax credit	None	$5,000 rebate	None
MPG/Fuel Economy	93	17.7	93	28.5
Fuel Cost per 100 miles	$12.02	$21.37	$12.02	$10.21
Refueling Station (Time it takes to get to this type of station)	Plug-in at home (0 min)	Refuel at station (7 min)	Plug-in at a charging station (10 min)	Refuel at station (5 min)
Refueling Time	3.5 hours	10 min	8 hours	10 min
Vehicle Range	100 miles	398 miles	80 miles	449 miles
Trunk/Cargo Space	12 cubic feet (3 suitcases)	128 cubic feet (32 suitcases)	9 cubic feet (2 suitcases)	11 cubic feet (2 suitcases)
Annual Maintenance Cost	$481	$504	$289	$743
Acceleration Rate (0-60 mph)	6.1 secs	8.7 secs	10.1 secs	4.1 secs
	I prefer this option	I prefer this option	I prefer this option	I prefer this option

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63%

Autonomous Vehicle Technology and Productive Use of Travel Time

Another aspect of vehicle technology that is receiving growing attention among travel behavior researchers is vehicle automation and connectivity. Although it is fully autonomous vehicles (e.g., self-driving cars that lack need for any human input) that tend to capture imaginations, there are varying levels of vehicle automation, intercommunication, and "self-correction" that are likely to reach substantial market shares before fully autonomous vehicles do—at least in the private vehicle market. The major motivation behind such technology is to assist the driver when the vehicle senses that an unsafe situation is impending. In addition to improved safety, an ancillary benefit of such technology for drivers may be that it becomes safe enough that the use of cell phones, tablets, and portable computers by drivers is no longer prohibited. Thus, travel time in the auto may become more productive as people can read and write e-mails, nap, or perform work-related or social media-related tasks. Past research into the travel time productivity and the related effects on the VOT has focused on the use of commuter rail and commuter buses, where the seating and (often) wireless connections make productive work possible. As vehicle automation becomes more prevalent, similar productivity and VOT changes could also occur for auto travel time, particularly for longer-distance commutes.

RP data. If enough vehicles in use have some level of automation by the time of the next HTS, then it could be worthwhile to add questions to the vehicle portion of the recruitment questionnaire to ask which automation features (e.g., automatic emergency braking, lane-keeping assist) are present in each auto owned by the household. It could also be useful, for each reported trip, to ask which (if any) productive uses were made of the time spent traveling. Such a question could be as simple as a multiresponse yes/no list. Information on the duration of such activities during travel could also be requested, although that could increase response burden. In a smartphone-based GPS travel survey, it may be possible for the survey app to record what other apps (e.g., phone, EMS, e-mail, internet browsing) are being used on the phone at any given time. However, there may be privacy issues involved in collecting such data and difficulties in distinguishing which apps are actively being used versus those that are simply open but idle.

Taking steps to increase the sample size of respondents who own vehicles with some level of automation may be difficult unless such technology tends to be limited to a small number of identifiable make/model combinations, or unless such vehicles emit some sort of communications signal that can be detected by an external device. In those cases, it would be possible to use video LPC to invite owners of such vehicles to participate.

SP and attitudinal data. With the growing research interest in CAVs, more SP experiments may investigate how likely people are to purchase such technology and how it would influence their driving behavior and travel patterns. However, because most people have little experience using CAV technology, the realism and reliability of SP responses might be questionable. Simpler attitudinal questions regarding opinions and purchase intentions may be just as useful in this case. Even if such questions seem somewhat premature, it could be useful to set a baseline to monitor attitudes, preferences, and use of CAVs over time.

Modeling the Use of Transit

While the use of transit modes is already well represented in H-GAC's AB model, more detail on transit services and use could be represented. This includes qualitative aspects of transit service, such as reliability/information, crowding, station/stop amenities, and vehicle quality. It may also include more emphasis on mixed-mode options such as park-and-ride and bike-and-ride.

RP data. Most questions regarding use of transit are standard core survey questions, including all relevant details of actual transit trips, and the ownership of a transit pass and any employer subsidy available for transit. Some surveys also ask people how often they use transit or the number of transit trips they make per week. Such questions can be useful for descriptive analyses, but they tend not be useful for travel demand models as they lack enough temporal and spatial specificity.

Users of some mode options could be oversampled via intercept surveys at park-and-ride lots or bicycle parking facilities. Transit on-board surveys, discussed in a subsequent section, can also be a means to contact and invite additional transit users to participate in a HTS. ACS commute mode choice data can be analyzed at the block group level to identify neighborhoods where the transit mode share is highest, at least for the journey to work.

SP and attitudinal data. RSG and others have recently completed several SP surveys that included multiple transit service factors. Figure 13 and Figure 14 are from a survey that RSG conducted for Portland Metro that used drawings to classify several types of stations and stops, and then used that (and vehicle types) as SP choice attributes. Figure 15 is an example from a Thurston Regional Planning Commission (Washington State) study that included a more in-depth investigation of several different transit service factors and included standard SP choice questions and most/least types of questions as shown in Figure 15.

FIGURE 13: EXAMPLE OF QUALITATIVE LEVELS FOR TRANSIT SP EXPERIMENT

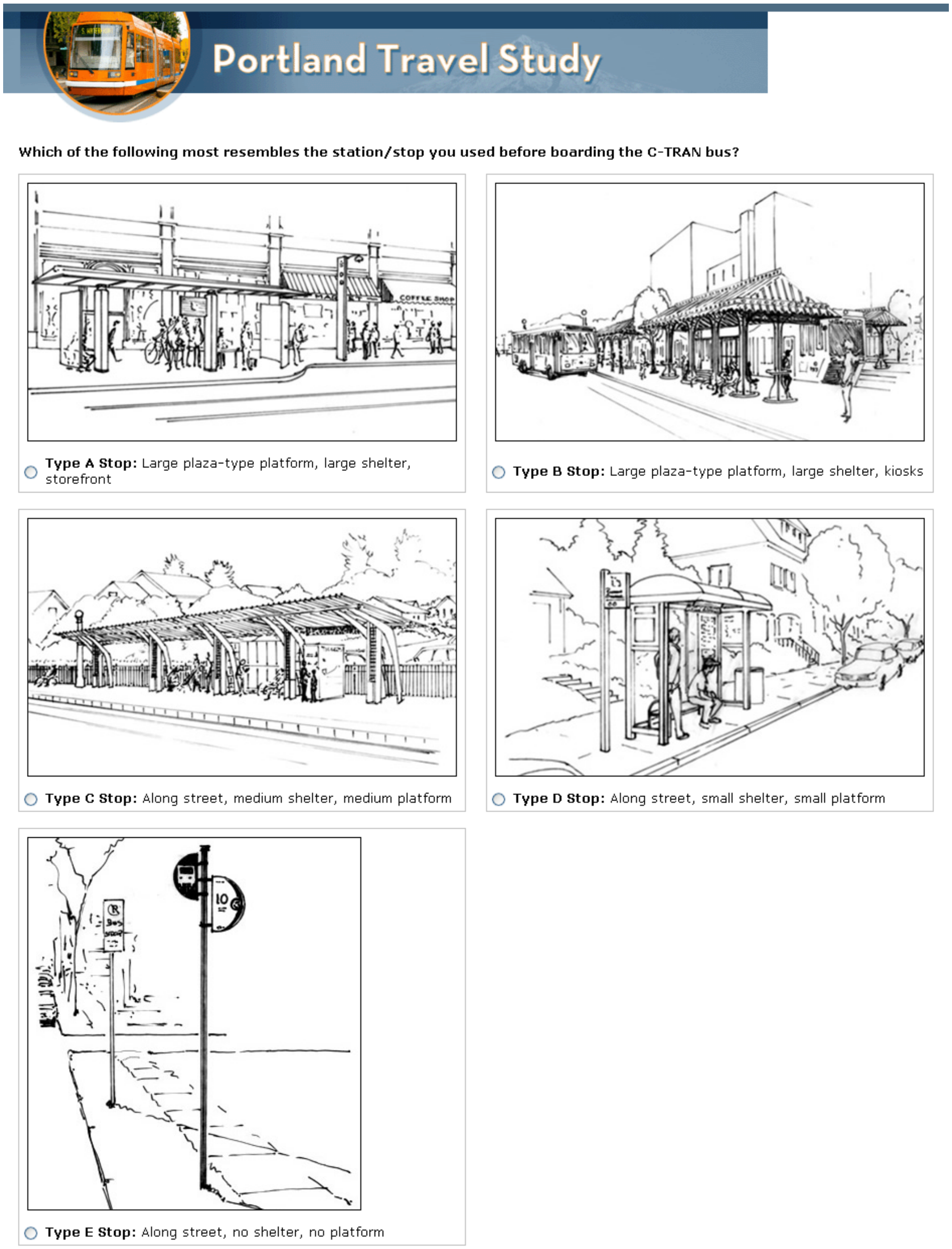

FIGURE 14: EXAMPLE OF A TRANSIT SP CHOICE USING THE QUALITATIVE STOP/STATION ATTRIBUTE

Which option is your FIRST CHOICE and which is your SECOND CHOICE for making your trip?

- **Please assume all three options are available to you.**
- Please look at each option carefully. Text in **red** may have changed.
- To review a definition, scroll your mouse over the different stop types below.

	Option 1	Option 2	Option 3
	Take Bus to MAX	**Take MAX**	**Drive**
	5 mins. drive to **Type C Stop**	**10 mins.** walk to **Type C Stop**	
	Park **on street**		
	Bus arrives every **20 mins.**	**MAX** arrives every **10 mins.**	
	4 mins. ride on Bus **10 mins.** transfer at **Type D Stop** **4 mins.** ride on MAX	**7 mins.** ride on **MAX**	**40 mins.** drive
	5 mins. drive to final destination	**10 mins.** walk to final destination	
	1-way fare: **$2.60**	1-way fare: **$2.60**	Parking cost: **$6.00**
First choice:	○	○	○
Second choice:	○	○	○

(Question 3 of 12)

Next Question

Questions or problems? Please Email us!

FIGURE 15: EXAMPLE OF TRANSIT SERVICE CHOICE, INCLUDING QUALITATIVE FACTORS

Please continue to think about the trip you have been describing.

If these were your only choices, which transit option are you MOST LIKELY to use and which are you LEAST LIKELY to use?

Please assume all other aspects of transit service are the same across all of the options.

Text in blue has changed.

	Option #1	Option #2	Option #3
Time Riding on Transit	24 mins.	25 mins.	28 mins.
Transit Fare (one-way)	$2.25	$2.25	Free
On-Board Seating Comfort	Seats are comfortable and a good size	Seats are standard	Seats are comfortable and a good size
Station/Stop Shelter	Effectively protects you from bad weather	Effectively protects you from bad weather	Limited or no shelter
Proximity to Services	NOT close to coffee shop, dry cleaners, grocery, etc.	Close to coffee shop, dry cleaners, grocery, etc.	Close to coffee shop, dry cleaners, grocery, etc.
MOST Likely	○	○	○
LEAST Likely	○	○	○

Next Question

Question 3 of 8

Modeling Use of Tolled Roads

H-GAC's AB model considers toll cost both in highway network assignment path choice and in mode choice.

RP data. The standard core questions in the HTS should identify trips for which tolls are paid, by facility. Asking toll cost is less important, as many respondents may not remember, and that can be imputed from other sources. (For GPS data, toll road use might be imputed, although this requires quite accurate location data to distinguish tolled lanes from adjacent general lanes.). As mentioned in a later section, a separate toll user intercept survey could be used to obtain more toll road users in the sample for a HTS.

SP and attitudinal data. Dozens of regions around the United States have conducted SP experiments on tolled roads. At this point, additional toll SP studies are unlikely to provide additional information, particularly in regions where actual toll roads are already operating to provide RP data.

Modeling the Effect of Travel Time Reliability

Growing evidence demonstrates that the risk of travel time delay—represented by day-to-day travel time variability—is as strong a consideration in travel choices as usual or "expected" travel times. This is particularly true for the choice of managed facilities where the risk of delay is perceived as being much less. Modeling and forecasting of reliability effects are still in the preliminary stages, although a good deal of work has been done, such as in the SHRP2 C04 and L04 projects and other projects in the SHRP2 series. Even if one can model the effects of travel time variability on the demand side, it is more difficult to simulate it on the supply side in an applied mode framework; this may not be possible until

DTA or simulation-based network models become applicable on the regional scale. For transit use, reliability is one of the "qualitative" factors mentioned previously.

RP data. It is difficult to determine the day-tODay travel time variability/reliability that survey respondents face and perceive when making their choices, particularly at the full OD level at which most trips and tours are modeled. The growing use of multiday GPS data collection may help to provide observed data on travel time variability for specific routes and OD pairs, and third-party data like INRIX may also contribute. As noted, these data are only useful for model estimation. For model application, the feasibility of predicting network travel time variability under future scenarios is still an emerging topic for research and practice.

SP and attitudinal data. Most existing research on travel time variability and the "value of reliability" has been based on SP experiments. Even in such a controlled scenario, reliability is a difficult subject to study, since travel time variability is a two-dimensional concept—the frequency of delays of different durations—and that can be difficult to portray to SP respondents in a meaningful way.

Choice of Residence and Workplace Location

The choice of residence is generally the purview of demographic forecasts or land-use models. Workplace location (and school location) are modeled explicitly in the AB model system. Land-use and location decisions are important drivers of travel behavior, and some in-depth research may be warranted if land-use policies become a primary focus area. Such data can also be used to calibrate and validate land-use models.

RP data. In addition to asking the current home and work addresses, it may be useful to ask the previous work address and previous residence address for anyone who had changed those addresses in the few years prior to the survey. A retrospective recall period of up to five years may be reasonable for such questions. This longitudinal data allows estimation of dynamic models of changes in residence or work location over time, which corresponds to the structure of some state-of-the-art land-use modeling approaches such as UrbanSim.

SP and attitudinal data. Residential choice has been a popular topic for SP questions in travel surveys. An example from a recent survey in Utah is shown in Figure 16. Figure 17 and Figure 18 show examples from the Atlanta SMARTRAQ survey, which supported much analysis in the residential choice literature. Figure 19 and Figure 20 show two relevant screens of attitudinal questions form the Utah survey. One question related to residence choice and another question was more generally related to transportation and land-use priorities. The list of possible factors that influence land-use choices is quite long, so it is important that any questions of this type be focused on useful modeling items.

FIGURE 16: EXAMPLE SP CHOICE SCREEN FOR RESIDENTIAL CHOICE

Which of the following home locations would you choose to live in if they were available to you?

Information in **bold** will vary from screen to screen.

	Option 1	Option 2
Housing types within 1/2 mile of your home:	**Mix** of single family detached houses (on **1/2 acre** lots), townhomes, apartments, and condominiums	**Only single family houses** on **1/2 acre lots**
Distance from home to destinations such as shopping, restaurant, public library, school:	**Less than 10 miles**	**10+ miles**
Transit distance and type:	**Rail station and bus stop** are a **10-mile drive** from your home	**Rail station and bus stop** are a **10-mile drive** from your home
Street design:	Primarily for **cars**	**Cars, pedestrians, and bicycles**
Parking:	**On-street** or in a lot near your home (free parking)	**On-street** or in a lot near your home (free parking)
Distance to work:	**Less than 3 miles**	**10 miles**
Home prices compared to where you live now:	**10% more**	**20% less**
I prefer:		

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FIGURE 17: EXAMPLE ATTITUDINAL QUESTIONS RELATED TO RESIDENTIAL CHOICE

If I were to move, I would like to find a neighborhood where...

	Strongly disagree	2	3	4	5	6	Strongly agree
I can walk, bicycle, or take public transit for some of my trips, even if this means that homes are smaller							
It is a lively and active place, even if this means it has a mixture of single-family houses, townhouses, and small apartment buildings that are close together on various sized lots							
There is plenty of distance between my neighbors and me, even if this means that I have to drive just about everywhere							
I can walk to stores, restaurants, and other important destinations, even if this means that commercial areas are within a few blocks (1/3 mile) of my house							

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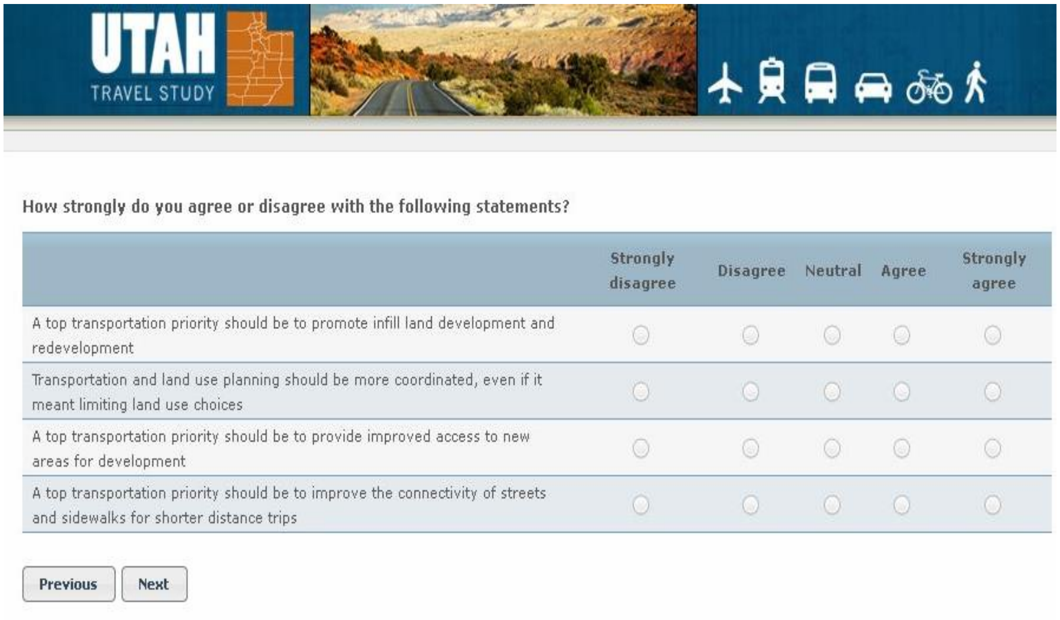
FIGURE 18: EXAMPLE ATTITUDINAL QUESTIONS RELATED TO LAND-USE/TRANSPORTATION RELATIONSHIPS



How strongly do you agree or disagree with the following statements?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A top transportation priority should be to promote infill land development and redevelopment	○	○	○	○	○
Transportation and land use planning should be more coordinated, even if it meant limiting land use choices	○	○	○	○	○
A top transportation priority should be to provide improved access to new areas for development	○	○	○	○	○
A top transportation priority should be to improve the connectivity of streets and sidewalks for shorter distance trips	○	○	○	○	○

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FIGURE 19: EXAMPLE SP CHOICE PAGE FOR RESIDENTIAL CHOICE

In the next two pages two pairs of neighborhoods are described. After reading the descriptions, please answer the questions that follow. Keep in mind that anything that we do not refer to in the neighborhood choices – such as school quality, public safety, or house size – is exactly the same between the two choices presented.

Neighborhood "W"	***Neighborhood "X"***
To ride public transit, like a bus or train, I have to go **1/4** mile from my house and it comes every **3** minutes.	To ride public transit, like a bus or train, I have to go **10** miles from my house and it comes every **5** minutes.
The distance from my home to the nearest **commercial district**, with things like a retail store, restaurant, movie theater and drug store, is **1** mile. Parking there is **limited, off-street and free**.	The distance from my home to the nearest **commercial district**, with things like a retail store, restaurant, movie theater and drug store, is **2** miles. Parking there is **limited, on-street and costs $3 per hour**.
The housing in my neighborhood consists of **only single family dwellings on 1/8 acre lots**.	The housing in my neighborhood consists of a **mix of townhomes, apartments, condos, and single family dwellings on 1/4 acre lots**.
My one-way commute to work is **1/4** mile.	My one-way commute to work is **20** miles.
Renting or buying a home in this neighborhood is **20% less** compared to your current neighborhood.	Renting or buying a home in this neighborhood is **5% less** compared to your current neighborhood.

33) *Assuming that there are no differences between the neighborhoods apart from the ones we mentioned, which neighborhood do you think you'd rather live in?*

Neighborhood "W" OR **Neighborhood "X"**

34) *How do you think you'd feel about living in* **Neighborhood "W"?**

0 1 2 3 4 5 6 7 8 9 10

dislike very much — neutral — like very much

35) *How do you think you'd feel about living in* **Neighborhood "X"?**

0 1 2 3 4 5 6 7 8 9 10

dislike very much — neutral — like very much

36) *The neighborhood you'd hope to find would be:*

0 1 2 3 4 5 6 7 8 9 10

more like **W** than your current neighborhood — like your current neighborhood — more like **X** than your current neighborhood

10

Parking Choice Behavior

The supply and price of parking are two of the most influential policy levers available to influence travel behavior. This is especially true in CBD areas and other areas like universities and medical centers where demand regularly exceeds the supply of free parking. In such areas, people who do not have a dedicated parking space available at their destination often must park on street or at an off-site lot or garage and then walk some distance to the destination. The current AB model does reflect the price of paid off-street parking. However, it does not predict either where people park when they must park off site or how far they must walk to their destinations. It also does not simulate the phenomenon where parking fills up during the day so subsequent arrivals may need to park further away. A microsimulation-based AB model framework would permit implementation of a parking location choice model as has been done in some other regions like San Francisco

RP data. A key piece of information for estimating a parking location choice model would be to know the parking address in cases when people do not park at the same address as their destination. Few recent travel surveys have consistently collected these data. One reason may be that collection of address data increases time required and respondent burden. These issues could be mitigated by only asking such questions when the destination is within certain predefined areas for which it makes sense to explicitly simulate parking location choice, such as major CBDs or university campus areas. Respondents may find it difficult to remember the nearest address to their actual on-street parking location, but they may be able to give the nearest intersection. In this regard, switching to a smartphone-based GPS travel survey format will provide such data with no added respondent burden (although it may require additional data processing). If desired, those who use paid CBD, hospital, or university parking could be oversampled by using LPC or intercept recruitment surveys in relevant parking lots and structures.

SP and attitudinal data. Many parking SP experiments have measured the trade-offs between parking type, parking price, parking search time, and destination walk time. Other types of parking SP experiments, such as the one in Figure 20 are to predict the demand for shuttles from remote parking lots as an alternative to nearby parking. However, it may not be necessary to rely on SP data with adequate spatial data on actual CBD parking supply and actual (RP) choices.

FIGURE 20: EXAMPLE OF PARKING CHOICE SP QUESTION

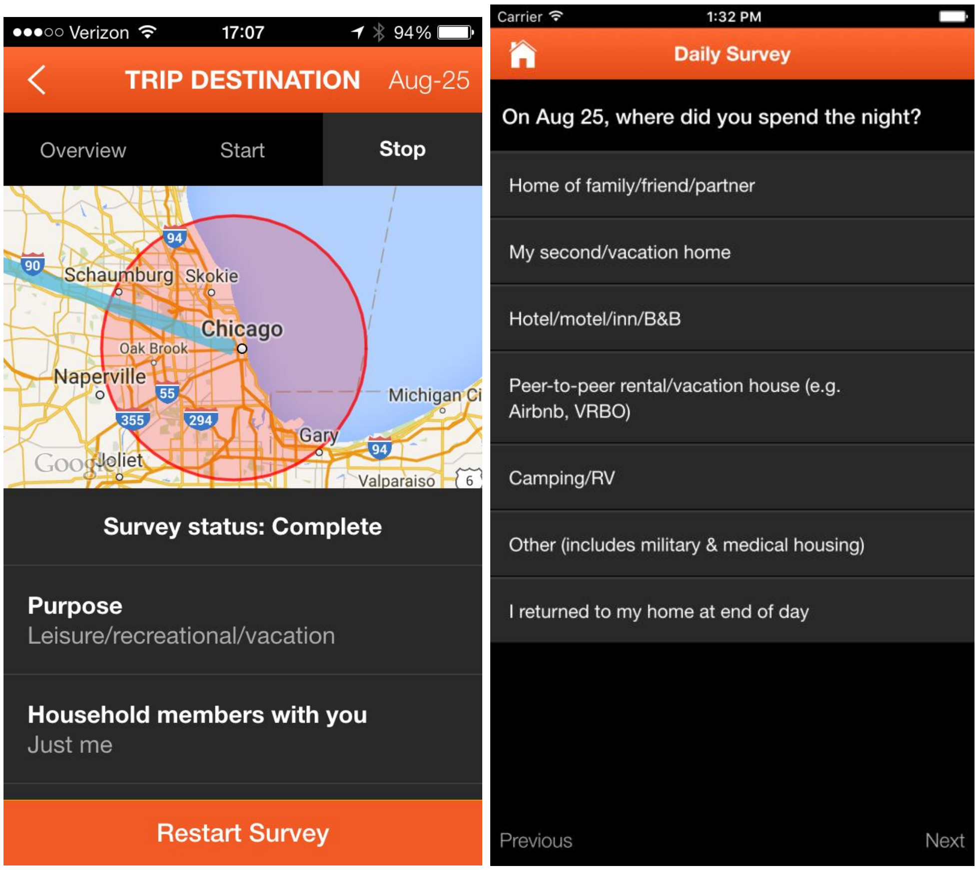
Long-Distance Travel Behavior

Although long-distance trips can comprise a substantial percentage of vehicle miles traveled, particularly in more rural areas, it is difficult to capture many long-distance trips in a typical travel diary survey. This is partly because such trips are rare for most households, and because someone who has made a long-distance trip is more likely to be out of town or not available on the survey travel day.

RP data. Some recent statewide travel surveys in California and Utah and recent regional travel surveys in Denver, Colorado, and Olympia, Washington, have included supplemental travel diary questions about long-distance trips; these were asked after the standard travel diary questions. Such questions often ask for all trips of 50 miles or more made by any household members in the four or eight weeks prior to the survey travel day. The exact distance limit and retrospective recall period may vary, but 50 miles and four weeks are typical values. Adding these questions places some extra burden on the respondents, especially those who make frequent long-distance trips. It is important to include an option for respondents to say that they made the same trip (same destination, mode, and purpose) multiple times during the retrospective period so that they do not have to report several identical trips. (This is particularly important for long-distance commuters—otherwise they often under-report their actual repeat commute trips.)

Using a smartphone-based GPS travel survey over a longer time—one month or more—is another way to capture long-distance trips. A customized smartphone app for a long-distance survey is being used for ODOT, with the app running for six months, and only asking about trips when the respondent is observed being more than 50 miles from their home location. Respondents are invited in three waves per year to ensure that all 12 months of the year are captured.

FIGURE 21: EXAMPLE LONG-DISTANCE TRAVEL DIARY SCREENSHOT FOR ODOT



SP and attitudinal data. Many SP studies have been done on long-distance travel, mostly in the context of proposed new high-speed rail options or toll roads on intercity routes. For example, as part of an ongoing National Cooperative Rail Research Program project, RSG carried out an SP survey of long-distance travelers in the Northeast Corridor and the Vancouver-Seattle-Portland corridor.

Employer-Based Travel Demand Management

In terms of value added, employer-based programs like flextime, compressed workweeks, and telecommuting allowances/incentives can reduce peak-hour traffic congestion. Employer-based subsidies and incentives like "parking buyout" programs can also be effective (although many times the actual subsidies that are offered are counterproductive). Current AB models can simulate what will happen if employees change their work schedules or subsidy levels, but these models cannot predict what percentage of employees would take advantage of specific travel demand management (TDM) programs or incentives.

RP data. As part of a core survey, employed respondents can be asked in some detail what types of work schedule options and monetary incentives are available to them, either formally or informally, and whether they take advantage of those. Some recent travel surveys have included such questions. To reduce respondent burden, such questions can be limited to one worker per responding household (e.g., the person who answers the recruitment survey).

SP and attitudinal data. The project team is not aware of past SP surveys that look in detail at what types of employer-based TDM programs employees might use if they were to be made available to them. Because RP data alone may not be adequate to estimate the type of models mentioned previously, this type of SP experiment could provide new and useful information.

Modeling Departure Time and Peak-Spreading Behavior

Departure time and peak-spreading behavior is related to the preceding topic since much of it pertains to commute schedule patterns, although it can be more general than that.

RP data. As an example, the 2006 PSRC HTS asked explicit questions about the variability in commute departure and arrival times over the previous 10 days. Such data can be used to improve modeling of usual work schedules. Multiday GPS trace data also provides data on daily variability in departure times for all purposes and can also measure day-tODay variations in route choice and travel speeds.

SP and attitudinal data. This type of SP question is paired with the questions on employer work schedule TDM options since the amount of peak-hour traffic congestion is likely to influence peoples' desire to travel at off-peak times. Several SP surveys have studied TOD road pricing and provide useful evidence. Often, SP experiments with TOD toll variations also offer a transit alternative, as using transit (particularly rail transit or buses on high-occupancy vehicle or high-occupancy toll lanes) can be an option for avoiding peak-period highway congestion.

Substitution of In-Home and Out-of-Home Activities

Substitution of in-home and out-of-home activities is usually considered in the context of telecommuting and teleshopping, although it could also apply to other activities like social interactions via the internet, exercising at home, and watching Netflix rather than going to the theater, among others. In AB models, time scheduled at home is what is left over after scheduling out-of-home activities, so the trade-offs are modeled indirectly rather than directly. More explicit modeling of these trade-offs may be desirable for future models.

RP data. The core travel survey identifies when people are at home and when they are away from home, and what they are doing when away from home. The survey can include questions to elicit answers to amount of time spent working at home, and perhaps shopping from home, during the day. The recent California statewide survey went further by asking about up to three different activities (and their duration) for each time the person was at home. However, these questions add respondent burden and can seem invasive; they are also subject to respondent recall error and much nonreporting (perhaps due to privacy concerns), so care should be taken in deciding to include them.

SP and attitudinal data. Questions could measure a person's relative attraction toward performing various types of activities in-home versus out-of-home, but it is not obvious how such data would fit into an AB modeling framework for long-term forecasting. The relative attractiveness of in-home activities is likely to change over time as wireless and virtual technologies become more advanced, but there may also be a "satiation point" for spending too much time at home.

The Effects of Auto Route Guidance Information

Over time, more drivers are using in-vehicle navigation systems and smartphones to select a route. These systems are more likely to influence infrequent trips, although real-time information about traffic delays can also influence routes to frequent destinations.

RP data. A possible survey question could relate to frequency of use of in-vehicle navigation technology. RSG has included such questions in the US Department of Transportation Volpe Center panel survey project.

SP and attitudinal data. It is not obvious what types of questions would be asked to study the effects of auto route guidance information, or how they would be used for modeling.

Understanding Destination Choice Behavior

Destination choice models remain a weak link in travel demand models in terms of their ability to predict choices. This is partially attributable to myriad destinations to choose from, but also partly due to a relatively poor understanding of how people select destinations. This is particularly relevant in a tour-based model to understand how people chain trips together.

RP data. As an example, the 2006 PSRC survey included some extra questions asking why people chose their destinations. These data did not provide useful information for modeling, however. It might be possible to improve such questions to make such data more informative.

SP and attitudinal data. In-depth survey questions could probe respondents' "mental maps" and their habitual destinations and reasons for choosing them. It is not obvious how such data could be incorporated into practical model development, however, so this topic might be more appropriate for academic research.

Environmental Justice/Equity Analysis

Current AB models like the H-GAC TourCast model are useful for analyzing the expected "winners and losers" in future scenarios because the output provides great socioeconomic and geographic detail. Correspondingly, this can put more emphasis on forecasting the socioeconomic inputs to the model—what are the assumptions about which types of households will be living in which neighborhoods in the future? It is often not possible to give well-grounded answers to such questions, which could support a land-use scenario approach for future-year policy analysis.

RP data. For equity analysis, it is important that the preferences of all sociodemographic groups be reflected in the models. Thus, it is important that the sampling plan include adequate representation of low-income households and perhaps other types of disadvantaged or "hard-to-reach" households like single-parent families or specific racial/ethnic groups. (Even if race/ethnicity is not used to define explicit variables in the choice models to explain differences in travel behavior, then it can still be included as a variable in the synthetic population and included as a variable in the model output.)

SP and attitudinal data. In some cases, it may be useful to not only model the differences in policy effects in terms of consumer surplus or other economic benefit measures, but also to know if different socioeconomic groups have different policy attitudes or opinions (e.g., road pricing options). An HTS or follow-on survey can specifically ask these questions.

Modeling Weekend Travel

Data to model weekend travel and activity patterns would not necessarily require any changes or additions to the core survey; it only requires assigning weekend travel days to enough respondents. This may be most feasible using a multiday GPS-based survey so that an adequate sample size will remain to also model weekday travel. Travel patterns on Saturdays are much different than travel patterns on Sundays; a separate modeling would be required for the two days. For descriptive analysis or model calibration, the survey data may also need to be weighted separately for each weekend day to include only those households who provided complete data for a Saturday or a Sunday, respectively.

Implementation Costs

Costs for HTSs varies based on several factors such as sample size, mix of methods (call center, paper, online, smartphone), duration of data collection (1 month, 6 months, 12 months), frequency of data collection (once every 10 years vs. biennial), the definition used for complete sample, and the expenses for public outreach, translations, and oversampling of hard-to-reach populations. Additionally, the larger the sample size, the more economies of scale will benefit the project for fixed expenses like postage or print cost per address.

To illustrate, the NHTS cost $175 per household in 2008–2009 and cost $225 per household for the current data collection effort (2016–2017). Most regions can expect to pay a similar cost per household or a modestly lower cost per household for an implementation approach that is the same as or similar to the NHTS. Regions would also benefit from additional customization options.

Costs for smartphone studies also vary based on the factors mentioned and other factors like the portion of the overall sample (e.g., 10% or 70%) that is smartphone and whether smartphones are distributed to households without them. Distributing smartphones is costly and—as mentioned elsewhere—faces challenges that affect data quality (e.g., participants who are unfamiliar with smartphones are more likely to forget to carry them). On studies that include smartphone sample, but that do not distribute smartphones, costs per household are currently modestly higher than a traditional approach and are coming down in cost quickly. The smartphone cost will be closer to the traditional approach cost as the practice becomes more standard.

Importantly, a smartphone sample costs *less per day of data* because selected households provide many more days of data (e.g., seven consecutive days vs. one day). As a point of comparison, the approach used over the previous decade of issuing a GPS device to households (mentioned above) typically cost between $300 to $500 per household, and smartphone data collection costs are already at or below the lower cost figure. Over time as These costs will continue to stabilize as the technology matures and as more US adults acquire smartphones.

Opportunities for Data Integration

Household survey data are typically integrated with several other types of data while using it for model calibration or estimation:

- Geolocation data for geocoding home, work, and trip end locations.
- Census/ACS data for survey weighting.
- Zonal data and network data for attaching travel times and distances.
- Transit route data for identifying transit services used.
- Transit OD or farebox data for expanding survey transit trips or validating transit forecasts.
- Auto traffic count or speed data for validating highway forecasts.

A more recent opportunity is the use of passive data (see Section B.2) to provide more complete information on trip OD patterns. In a region with a zone system of 5,000 zones, there are 25 million possible trip OD pairs, so a HTS by itself will never be able to provide complete coverage of the actual OD patterns across the region. One solution is to obtain passive data to uncover more complete OD information and integrate it with the HTS data in analysis. Currently, the most complete and affordable type of data on regional OD patterns is cell-based data (AirSage), although some of the other LBS data sources described in Section B.2 may soon be competitive in terms of price and coverage while providing greater locational accuracy. The price and quality of passive data may change substantially over the next two or three years, so the future opportunities for data integration should be monitored closely.

One of the weaknesses of any current passive data sources is that they have little or no information on traveler socio-demographics or trip details such as travel mode or purpose. For model calibration, the most common use of the data is to compare the data against district-to-district trip OD flows by TOD predicted by a model. Some passive data providers impute home and work locations. These providers can provide separate work and nonwork trip OD matrices; however, for validating/calibrating home to work OD flows, the ACS/CTPP commute data may prove to be a more accurate data source.

RSG recently completed one of the first examples of using AirSage data to calibrate an AB model in the Chattanooga, Tennessee, region.[10] The project necessitated use of data sources like ATRI and ACS to net out the truck trips and commute trips, but the AirSage data did seem to provide better calibration of the overall OD patterns than could have been done without it. In the Chattanooga region, most trips over one mile are by auto, so the lack of mode information in the data was not a major issue. In regions with a substantial transit share, it would be much more difficult to use passive data to validate/calibrate OD patterns for a single mode, although it could still be used to calibrate total OD patterns across modes. Accurate transit user OD data (discussed in the next section) could also be used to "net out" the transit trips to provide an estimate of auto trip OD patterns.

TRANSIT USER INTERCEPT/OD SURVEYS

In-Practice Methods

Transit rider surveys have long been used to gather information on the characteristics of transit users and their trip-making patterns. Transit rider surveys are frequently conducted while customers are traveling on buses or trains—also called on-board transit surveys. However, similar information can be gathered by interviewing passengers at transit stations or bus stops or even by recruiting survey-takers online.

Useful OD data comes from a subset of transit rider surveys that are designed to capture information on origin and destination location, other trip characteristics, and traveler characteristics. These surveys also require carefully collected information on total trip-making that serve as the basis for expanding sample data to represent the total population.

Because a survey intended for developing OD information requires complete information on both traveler/trip characteristics and on total trip-making, many survey efforts are separated into two key elements:

- **Transit OD Survey**. This element of the survey effort involves a paper-based or computerized survey questionnaire in which the traveler is asked to describe the trip they are making and to provide additional information about their own personal characteristics (e.g., sociodemographics).
- **Transit Control Data Gathering**. This element of the survey effort involves collecting information on the characteristics of the total population of travelers and is used to expand (weight) the results of the OD survey to represent total travel. The best form of survey control is a count of travelers for each combination of boarding and alighting station/stop pairs for each transit route. This information can come from fare gate information or from a specialized on-to-off count. If full on-to-off data cannot be collected, less robust information such as trip boardings and alightings by route segment, TOD, and direction may be sufficient for use as a basis for OD weighting.

[10] To read the abstract and download a Transportation Research Board presentation, please visit: https://www.trbappcon.org/2017conf/PresentationDetails.aspx?abstractid=79

Typical transit OD surveys involve asking transit passengers to respond to a series of questions that ask them to describe the characteristics of their trip and to provide information on individual and household characteristics. To generate a useful database of origin-to-destination travel, these questionnaires must gather information on the following:

- Trip characteristics
  - Origin and destination locations at a level of detail sufficient to understand the origin and destination TAZs. If possible, origins and destinations should be geocoded to latitude and longitude (to within 1/10,000 of a degree) to allow assignment to alternative systems of TAZs that may be defined at some later date.
  - Access mode used to travel from the trip origin to the first boarding location.
  - Egress mode used to travel from the last alighting location to the trip destination.
  - Boarding and alighting stop identification and route identification for the current unlinked trip (i.e., the specific bus or train segment where the passenger is surveyed). If possible, boarding stop, alighting stop, and route identification for all trip segments should be collected.
  - Number of unlinked trips that make up the current origin-to-destination linked trip.
  - Purpose of the trip and identification of whether the trip origin or destination is home, the workplace, school, shopping, or other kind of place.
- Traveler/household characteristics
  - Household income classification.
  - Number of operable vehicles owned by the household.
  - Number of working adults in the household.

Transit Rider Survey Types

These questionnaires can be administered in several ways. The most recent successes have been through having trained interviewers ask travelers verbally about trip and household characteristics and record the answers immediately in a tablet-based data entry form. The use of interviewers helps to improve the quality of the data collection since they can help explain the questionnaire if respondents are confused and can intercept responses that appear erroneous. Survey interviewers can also assist respondents with the tablet-based procedures that identify trip origin and destination locations—often, these are the most difficult-to-answer questions encountered on these surveys. Finally, one of the biggest benefits of in-person interviews is that a response rate (the percent of randomly approached people who provide complete information) greater than 70% is often achieved. Experience has shown that few riders decline to take a survey when asked face-to-face by an interviewer who has been properly trained, which reduces—but does not eliminate—the impact of a nonresponse bias. This is important, as other survey methods tend to have much higher nonresponse, which can raise concerns that survey results are not representative of the characteristics of the full population of transit riders.

Although interview-based questionnaires are generally the most accurate, some agencies may object to cost or the lack of consistency with past, successful surveys. In such cases, surveys may be collected with traditional paper-based surveys. These forms can be distributed in large quantities by a small number of staff, reducing the expense of fielding a survey. However, this approach can also result in lower response rates and more incomplete or inaccurate responses. Unlike answers entered in real time into a tablet, paper-based responses are not checked in real time as the passenger answers each question. As a result, many more survey responses will be judged to be unusable and eliminated from the final survey database.

The final approach for collecting transit rider surveys involves providing a URL for an online survey questionnaire and asking each traveler to log on to a survey website and answer questions about their trip later. This approach has the advantage of providing real-time logic-checking but also suffers from lower response rates and possible memory lapses regarding the trip being recorded. This technique can also result in a skewed response (e.g., higher-income riders might respond in greater proportion). It requires that the transit agency have many e-mail addresses for its ridership base.

In some cases, two or more of these survey administration techniques can be combined to provide a convenient array of options for travelers and increase overall response rates.

An important consideration for any of these survey techniques concerns the number of records required to generate a useful dataset. General guidance suggests that a 10% sample is sufficient in most cases to generate a useful sample. This guidance is not based on statistical tests but—instead—comes from experience that a 10% sample is sufficient to develop an OD transit trip table at the TAZ level of detail that is helpful to support travel forecasting model development and application. One problem with a simple 10% rule is that it might involve collecting more information than is needed for uninteresting situations while collecting insufficient data for more relevant travel.

Transit Control Data

All data collection efforts that attempt to use a sample to represent an entire population must also develop a means for scaling the sample information up to represent all users. For transit rider surveys, this is usually accomplished by attaching a weight to each record that indicates how many trips in the population are represented by that record. Separate weights are usually defined to scale the record to match unlinked trips (i.e., each boarding) and linked trips (i.e., the overall journey from the trip origin to the trip destination). These weights must account for the fact that the fraction of all passengers that successfully respond to a survey are not proportionately distributed over the entire system. For instance, travelers making short trips on crowded transit vehicles have a lower chance of being approached by a surveyor and—when they are—they may not have adequate time to complete the survey before they alight from the transit vehicle. Some groups of travelers may be likely to respond to surveys depending on their trust of governmental institutions, level of education, and other factors. To the extent possible, survey weighting should correct for these response biases so that the weighted surveys represent the full traveling population as accurately as possible.

One way to improve the survey representation of the transit population is to expand the survey to match the observed number of trips for each combination of on-stop and off-stop. This count is more than just how many riders get on or off at Stop 1 or 4, but rather, how many riders make a trip from Stop 1 to Stop 4 on a transit vehicle as it proceeds along its route.

This information is most commonly obtained a separate on-to-off count[11]. This type of survey is typically conducted for approximately 20% of all scheduled transit vehicle trips. On each sampled vehicle trip, a short survey card is distributed to all boarding passengers and then collected when each passenger disembarks. The survey card may have just two questions (where did you board and where did you alight?). Alternately, the survey may be barcoded and is scanned by members of the survey crew at the time of boarding and at the time of alighting. These times can be converted to latitudes and longitudes using information on bus/train location from an Automatic Vehicle Location system. Because the survey is easy to complete, on-to-off count response rates are usually quite high, often 90% or more.

These boarding and alighting pairs for sampled trips are then weighted up to the total number of riders at each stop on each route using count information obtained from Automatic Passenger Counting (APC) systems by weekday TOD based on an average of APC data over multiple weekdays

Factoring is typically accomplished using an IPF algorithm. With this method, on-to-off count results are used as an initial “seed” matrix. Stop-level APC provide the overall row and column control totals. Rows and columns are iteratively factored to match row and column totals until both rows and columns match the desired control totals.

If an on-to-off count is not feasible, then a fallback position for survey control is to collect rider counts stratified by route, direction, TOD, and (if possible) by boarding/alighting counts by stop and route.

Data Validation and Weighting

Before being used to develop an OD database, survey responses must be reviewed for accuracy and completeness and unusable records culled from the dataset. Data validation checks include:

- Valid response for key fields including origin location, destination location, boarding stop, alighting stop, route(s) used, trip purpose, home location, and socioeconomic characteristics.
- Consistency of origin/destination location with bus routes and access/egress modes.

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[11] If a system uses fare cards to control system entrances and exits, fare data may also be used to create an estimate of on-to-off ridership.

- Check against incorrect round-trip reporting.

The exact form of the survey weighting to expand questionnaire responses (a sample) to represent the entire population depends on both the sampling plan and the availability of control data. The basic process involves weighting in two stages:

- Expand survey results to represent unlinked trips on the vehicle where the survey was conducted. The exact nature of this calculation depends on whether on-to-off counts are available or whether data are only available at the route level (stratified by direction and TOD) or boarding or alighting location. In any case, the expansion factor (weight) is equal to counted trips for the expansion frame divided by the number of survey responses. Similar procedures are employed if the survey is conducted on a station platform except that the control is by station boarding rather than route[12].
- Convert unlinked trip weights to linked trip weights. The unlinked trip weights are next converted to linked trips by dividing by the number of boardings (number of transfers plus one) made during the entire linked trip. The linked trip weight is used for development of the OD dataset.

Additional survey processing may be required prior to development of an OD database. One of the first steps is dependent on whether the table should be organized in terms of OD table or whether the table should be organized as productions and attractions (PA table). In this context, the production location is the origin or destination location that corresponds to the traveler’s home. The attraction location is the other end of the trip. In the case of non-home-based trips, productions are assumed to equal origins and attractions are assumed to equal destinations.

As an illustration of the meaning of OD and PA tables, imagine a worker traveling from home in the suburbs to a job in the city and then returning home in the evening. The trip would result the following records:

- OD Table Structure:
  - One work trip from the suburban location to the city location.
  - One work trip from the city location to the suburban location.
- PA Table Structure:
  - Two work trips from the suburban location to the city location

Most transit analysis is conducted with PA tables since it keeps the home end of the trip separate from the nonhome end. This concept allows models to properly associate the surveyed trip with characteristics associated with the residential location (e.g., household income, availability of a car for access) and the work location (e.g., employment type).

[12] Occasionally, trips exist in the control data for a given boarding/alighting pair but do not exist on the O-D survey data set. When this happens, adjacent stops should be combined into groups of stops and the survey expansion should be conducted for stop-to-stop groups rather than for individual stop-to-stop pairs.

If a PA table is desired, additional survey processing is required. This involves determining whether the destination end of the trip is the traveler's home. If it is, then all the characteristics associated with the destination (destination location, destination type, and egress mode) are stored in the production fields and all the characteristics of the trip origin (origin location, origin type, access mode) are stored in the attraction fields. If not, then the reverse is true—all the characteristics associated with the origin are stored in the production fields, and all the characteristics of the trip destination are stored in the attraction fields.

Supplemental processing may also be required to classify mode of access, trip purpose, socioeconomic characteristics, and path according to the desired (often model-specified) definitions. This step involves converting whatever fields were defined in the survey to the definitions defined for modeling or analysis purposes. Typical fields are defined as follows:

- Mode of access (production end):
  - Walk.
  - Kiss-and-ride.
  - Park-and-ride.
- Trip purpose:
  - HBW.
  - Home-based other (may be further subdivided into shop, school, social-recreation, and other).
  - Non-home-based.
- Socioeconomic classification:
  - 0, 1, 2 or more household cars.
  - Household income group.
  - Measure of automobile sufficiency.
- Transit path:
  - Commuter rail.
  - Urban rail.
  - Bus.

OD databases are prepared by accumulating linked transit trip weights across all survey records for each combination of production zone, attraction zone, trip purpose, socioeconomic class, access mode, and transit path.

Data for Potential Areas for Future Model Development

Development/Calibration of Conventional Travel Demand Models

One key use of transit OD information is to help develop and calibrate conventional travel demand forecasting models.

For example, an assignment of transit survey data to transit networks can be used to simultaneously check the validity of the OD data and the networks that are used to represent transit supply. This is accomplished by converting transit OD data (in PA table format) into travel model-type trip tables. These trip tables are then assigned to the transit network using the transit assignment procedures of the local model. These assignment procedures generate a listing of modeled (from the survey in this case) station boardings, alightings, and route ridership that can be compared to independent count data. If the assigned survey volumes match ridership counts well, then the analyst can have confidence in the survey, the transit networks, and the path processing procedures. If assignment results do not closely match counts, then each step must be reviewed to determine what actions must be taken to improve the representation of how travelers utilize the existing supply.

After the transit trip table is successfully assigned to transit networks and the accuracy of the trip tables and transit supply are established, the survey OD tables can be used to assess the validity of the demand elements of the model. This is done by comparing the transit person trips generated by the mode split model to the survey trips. This comparison should be performed separately for each production district (aggregation of TAZs), attraction district, socioeconomic class (auto ownership, income, or auto sufficiency), trip purpose, access mode, and transit submode. If mismatches are found between the mode split model output and the survey data, then the analyst must examine both the mode choice model itself and key precursor models including trip generation and distribution. Often this process involves proposing a theory for the root cause of the mismatch, testing a solution and comparing updated transit model results to the survey. Given the unknown nature of many problems, this investigation cycle may need to be repeated multiple times before an acceptable solution is found.

Direct Application in Incremental Models

Some types of transit models can use transit OD tables directly as an input. These models are known as incremental models because they focus on representing the change (“increment”) in demand that results from a change to the transit system. One recent example of this type of model is the FTA’s Simplified Trips-on-Project Software (STOPS).

Incremental models work by using the transit OD survey as the basis for all computations. If the existing transit service is the same as that operated at the time of the survey, then the transit trip table is simply equal to the result of the survey effort. If that table and the underlying transit networks and path processing procedures generate a realistic portrait of transit boardings, alightings, and route ridership, then the model is calibrated.

When changes are made to the transit supply, zone-to-zone transit travel times will change and the incremental model will predict a proportional change to the number of trips made by transit.

In many cases, incremental models are much quicker to calibrate than conventional models. That is because incremental models skip the process of calibrating the trip generation, trip distribution, and mode choice model components; often the hardest steps associated with conventional transit model calibration. Although testing of the survey trip table, transit networks, and path procedures must still be done (and possibly revised), these elements are, typically, more straightforward than calibration of the demand modeling portions of travel models.

Other Planning Analyses

Lastly, transit survey data has considerable utility for nonmodel planning analyses. Quantitative transit analysts often use information on trip locations, trip characteristics, and traveler characteristics as part of service planning, mobility, and social equity analyses.

The fundamental advantage of transit rider survey data and the resulting OD flows is that these data represent transit trip-making patterns using characteristics of each trip as reported by the travelers themselves. Expansion procedures have been devised to minimize nonresponse bias. The process of converting these data to assignable trip tables and then comparing assignment results to counts confirms the accuracy of all steps in the process—survey data processing, transit network coding, and path-building. When these review steps are successful, users can have high confidence in the accuracy of the OD database.

Implementation Costs

A proper survey of a large transit operator can take over a year to accomplish and require considerable financial resources. To date, the most useful surveys have collected system-wide samples of 10% of their customers. For H-GAC with an average of about 280,000 weekday riders in 2017[13], this could result in more than 28,000 survey responses and cost upwards of $20/rider if both an on-board OD and an on-to-off count are conducted.

Opportunities for Data Integration

As described above, transit OD data and control data are typically used to expand HTS data or to validate models based on HTS data. It can also be used to improve and calibrate transit network data and network path-building methods.

Currently, there is limited potential for integrating passive OD data with transit user OD data because the passive data cannot identify transit trips separately from trips by other modes. However, one use of accurate transit OD information may be to subtract it from the aggregate passive OD information so that the remaining trips more accurately reflect auto trips only (if ATRI data are also used to subtract the truck trips).

In the future, passive data sources may be able to more accurate identify transit trips separately from other modes. Such data would still not be as rich as transit on-board survey data, however, as they do not provide data on traveler characteristics or trip purposes. Also, the passive OD information would likely be less accurate than transit system control data.

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[13] METRO Ridership Reports (http://www.ridemetro.org/Pages/RidershipReport.aspx) accessed July 12, 2017.

UNIVERSITY SURVEYS

In-Practice Methods

University travel surveys are typically conducted by e-mailing students using their e-mail address. Students are invited to participate via e-mail to their university e-mail address. Depending on permissions with the university, e-mails are either distributed by the university itself or by the survey consultant. Similarly, depending on permissions, e-mail reminders are either distributed to all e-mails or only to those who have not yet completed the survey. This requires coordination and buy-in by university administration (including IT department) to obtain the e-mail list or have the university forward the invitation and follow-up e-mails.

Given the demographics of student populations, these surveys are either administered via an online survey or via a smartphone app. Additionally, to minimize burden for the respondent, these surveys are typically programmed to combine the recruit and travel diary into one experience and generate a travel date. For example, typically an online survey will generate a travel date for the previous weekday based on the timestamp that the respondent begins the survey. Students with a smartphone would be directed to download the app before their travel date.

The timing of a university survey is extremely important. Most universities have schedules for their own internal surveys and sometimes will have prescriptive timetables for when to administer the university special generator survey. Additionally, these surveys are best conducted during semester, but also avoiding periods such as breaks, exams, and add/drop windows for classes. As such it is important to have realistic expectations and ensure permissions are in place prior to fielding the survey and setting the schedule.

Since many college students live in group quarters or other nonfamily households, their travel behavior tends to be highly independent from roommates and other household members. Therefore, for purposes of surveying, the RSG team recommends recruiting individual students to participate as opposed to the entire household. Although multiple members of a household could potentially participate in the survey, each member would be recruited independently, and their travel days are scheduled independently of each other.

Given the high rate of GPS smartphone ownership among university students, it is likely that the entire survey can be conducted using smartphone technology; a web-based option is only necessary if the web option is made available as part of a household survey as well.

Two types of university student travel surveys are currently in use. University surveys are typically either conducted as stand-alone surveys (unrelated to a household travel diary) or as an integrated part of a HTS—either simultaneous or as a supplemental follow-on survey – both of which utilize the core HTS design.

An example stand-alone web-based survey was administered to University of Oregon students in two phases over the 2011-12 academic year (Lane Council of Governments 2012). The survey was a cooperative survey research project between the Lane Council of Governments, the University of Oregon Department of Campus Planning & Research, and Portland State University. The purpose of the survey was to collect daily travel pattern data on the student, faculty, and staff of the University of Oregon, to build a special generator extension to the regional travel demand model maintained by the Central Lane MPO. The data collection process employed a joint survey approach; an initial recruitment questionnaire, followed by a travel diary log covering all trips on a randomly assigned travel day within the period covered by each period. All members of the University of Oregon (UO) community were assigned randomized survey ID numbers, and then randomly assigned travel dates (all days of the week, including weekends) throughout the survey period. Participants were sent initial e-mails to their UO e-mail address, asking them to complete the preliminary recruitment survey. Once a person completed the recruitment survey, they received an automated e-mail message confirming their enrollment in the survey, along with their assigned travel date, randomized survey ID number, and a log sheet to help them keep track of their travel. Follow-up e-mails consisted of an additional recruitment solicitation two days before the candidate's survey date, and an e-mail one day immediately after their survey date. Those candidates who missed their survey date who still wanted to participate were re-assigned new dates. In total across both phases, approximately 5% of students participated in the survey, yielding 1,244 observations.

A similar online university travel survey was conducted by Virginia Department of Transportation (VDOT); four universities were surveyed in 2009 and another two universities were surveyed in 2010.[14] The survey instrument was based on the NHTS. The second round of surveys were conducted using a shorter survey instrument, and benefited from more usable samples, higher response rates, and approximately 15-20% higher reported trips. The VDOT surveys relied on a stratified sample of students by on and off-campus residence status, undergraduate/graduate status, and full- or part-time student status. Distance learning students were excluded.

In the VDOT surveys, students were first mailed prenotification letters and a hard copy of the travel diary approximately one week prior to receiving their e-mail invitation. All students with a valid e-mail address received an e-mail invitation with the web survey link notifying them about the study one day prior to their original assigned travel day. After five days from the original travel day, follow-up telephone calls were made to inform and remind students about the survey. Students who had not responded two weeks from their original travel day were sent another e-mail giving them a re-assigned travel day which was on the same day of the week as their original travel day and again were invited to participate in the survey. Additional final telephone reminder calls were made during the last week of the study period to those students who had expressed interest in participating in the survey during the initial reminder call but had not yet completed the survey. In the second round of surveys, hard copy travel diary with prenotice was not sent via postal mail. Instead students were e-mailed the survey link and asked to report all trips from the previous day. The final number of students surveyed in the first phase varied between approximately 650 and 800 for each of the four universities participating in the survey. The second phase of the survey was

[14] Wang, Xin, Asad Khattak, and Sanghoon Son. "What can be learned from analyzing university student travel demand?." Transportation Research Record: Journal of the Transportation Research Board 2322. 2012.

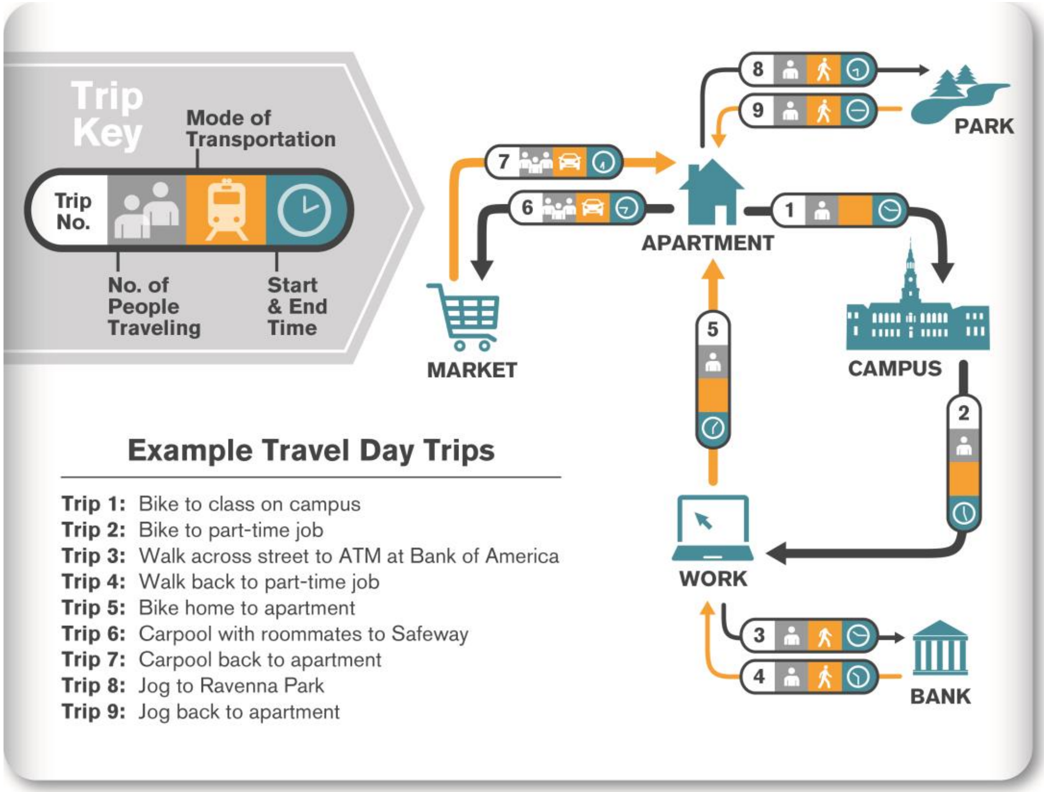
conducted at two of these universities (Virginia Tech and Old Dominion) and resulted in 1,468 and 1,128 participants, respectively.

An additional stand-alone survey was the Maricopa Association of Governments university survey of the Arizona State University (ASU) campuses in 2012. This survey obtained approximately 12,000 responses from the graduate and undergraduate students across ASU's campuses in Arizona. The survey was issued to student e-mails with staggered reminders that varied by day of week and TOD. The travel date was assigned as the most recent weekday based on the timestamp of the time that the student began the survey. Response was encouraged by a variety of campus methods such as in-person in the student activity center and an ad on the campus intranet. A raffle prize of an Apple iPad was offered to encourage response. The survey was only offered online.

The alternative method of surveying university students is to combine the design of the university survey with the design of a parallel or recently completed HTS. This approach is typically less expensive because of the cost of designing and programming the survey is already complete and only needs to be modified for comprehension and other details for the university survey.

For example, PSRC conducted a college travel survey to complement a HTS sample with data from the region's college population in fall 2014. The survey targeted students, faculty, and staff at Bellevue College, Everett Community College, Green River Community College, Seattle Colleges, and the University of Washington. The travel diary format of the Puget Sound College Survey closely resembled that of the 2014 HTS. The primary difference between the College Study and the HTS was that respondents to the College Study answered only for themselves in the survey, rather than reporting travel at a household level. Additionally, rather than recording their travel on an assigned travel date, respondents of the College Study answered travel details about the most recent weekday.

FIGURE 22: EXAMPLE TRAVEL DAY FROM 2014 PSRC UNIVERSITY SURVEY



Undergraduate and graduate students from all colleges were invited, and Everett Community College, Green River Community College, and Seattle Colleges also invited their faculty and staff. The survey was designed to accommodate anyone affiliated with these institutions, including all full- or part-time students, faculty, and staff. After administering the Puget Sound College Survey for approximately one month in fall 2014, data were cleaned and processed, resulting in a final dataset of 4,454, of which 59% were undergraduate students, 22% graduate students, and 13% faculty or staff.

Another example is the State of Utah travel survey which was conducted in 2012 and included both a HTS and a companion university travel diary. Overall, this approach was like that of the PSRC study. Approximately 8,000 students from eight colleges in the greater Salt Lake area completed the university travel diary. The colleges included Dixie State College, LDS Business College, Salt Lake Community College, Utah State University, Utah Valley University, University of Utah, Weber State University, and Westminster College. The survey was particularly important because college students (at the time) comprised more than 20% of the Utah Transit Authority's total transit market.

FIGURE 23: POSTCARD HANDOUT FOR UTAH UNIVERSITY SURVEY

Smaller regions that have a dominant university have also opted in recent years to conduct a college special generator travel diary in conjunction with their household travel diary. South Bend Indiana is an example of this, where the University of Notre Dame plays a huge role in the transportation behavior of the region. This survey was conducted in 2013 for the regional MPO, Michiana Area COG.

The advantage of coupling the university survey with the household survey are obvious; the potential to share administrative costs, and use the same survey instrument for both surveys, is a clear cost advantage. RSG typically recommends that the household survey be fielded first and then closely afterwards the university survey is fielded. For example. PSRC conducted their HTS in spring 2014 and their university survey was then conducted in fall 2014. This ensures that the survey design remains focused on the household travel diary and then efficiently modified for the university survey.

Implementation Costs

The RSG team recommends attempting to collect a minimum of 1,000 student surveys per large university (30k or more students), 750 surveys for medium size universities (15k-30k students) and 500 surveys for small universities (less than 15k students). Less than 500 surveys for a given college or university makes it difficult to draw meaningful insights regarding trip rates, purposes, trip-length distributions, and mode shares.

Implementation costs of university surveys vary depending on whether the survey is a component of a broader HTS or implemented as a stand-alone survey and depends on factors such as the number of universities surveyed, the number of students per university, the ease with which permissions are obtained, and extent of institutional review board approvals required. However, in general, these surveys are notably lower cost per respondent than a traditional household diary because of the ability to obtain and utilize a population e-mail list to invite response. It is reasonable to assume a cost that is safely less than $100 per respondent.

Opportunities for Data Integration

As part of the survey outreach effort, additional data should be collected on the following:

- Residential location of all students by student type (e.g., first-year student on campus, graduate student off campus). Due to privacy issues, university administration is typically unable to provide actual residential address of all students. However, university administration may be willing to provide a summary of number of students by TAZ, Census Tract, ZIP Code or campus location. This data can be used to calibrate a residential location choice model for university students or be used as a segmentation variable in data expansion. Note that the data are often aggregated from mailing addresses, so in some cases the address of the student's parent may be provided instead of the student. Care must be taken when interpreting and using this data.
- Parking supply, utilization, permit system, and price data. Parking supply and utilization data are typically available from the university campus infrastructure department. Parking permit and price data are typically available online.
- Intra- and intercampus shuttle bus route, schedule, and fare data. Campus shuttles often operate between parking lots and campus locations, and are free with a student ID. These routes are sometimes not included in regional travel models but exhibit ridership on-par with other transit routes and play a key role in campus connectivity.

VISITOR SURVEYS

In-Practice Methods

Visitors to the Houston-Galveston region can be characterized in two groups; those who visit the City of Houston and visit for work, conferences, or leisure, and those who visit Galveston Island, primarily for leisure or to attend a conference or convention. Houston received approximately 17.5 million visitors in 2015 and has more than 80,000 hotel rooms with approximately 8,000 located downtown.[15] In 2014, Houston hosted 364 conventions, events, and shows that drew 774,152 attendees to Houston. Galveston Island has more than 5,000 hotel/motel rooms and a 140,000-square-foot convention center,[16] and attracts approximately 5 million annual visitors.[17]

Several options exist to recruit overnight visitors into a travel survey. One way is to pair the survey with an airport ground access survey and recruit at airport departure gates. In this case, either the survey focuses on nonresidents, or the survey is designed to collect airport ground access information on all participants, while nonresidents are asked an additional set

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[15] Greater Houston Convention and Visitors Bureau website (https://www.visithoustontexas.com/about-houston/facts-and-figures/), accessed July 12, 2017.
[16] Galveston Island Convention and Visitors Bureau website (http://www.galveston.com/promoteyourmeeting/) accessed July 12, 2017.
[17] http://www.galvestonislandconventioncenter.com/

of travel questions in addition to information gathered regarding airport-related travel. Since the survey is conducted on site, the last full day of travel in the region is typically collected.

An example of this type of recruitment survey was conducted by OahuMPO (Newmark 2014). Approximately 1,000 participants were surveyed at Honolulu International Airport out of approximately 30,000 daily departing passengers; the survey focused on nonresident travel only. Data was initially expanded by destination and TOD, like other airport surveys (see below). A second round of data expansion adjusted the expansion factors to account for the average number of visitors on Oahu on an average weekday. The advantage of this approach is that the survey can be conducted efficiently; visitors are more willing to take the survey when they are waiting for their flight to board. The disadvantage is that the survey misses visitors who travel by car, bus, train, and sea, though similar types of surveys have also been conducted at bus stations, train stations, and ferry terminals/docks as visitors wait to board their mode of transit. Conducting additional intercept at these types of locations adds cost and requires additional permissions, but it is worth considering.

An alternative approach involves intercepting visitors at key locations such as hotels/motels, campgrounds, and tourist locations throughout the region. The advantage of this approach is that the survey will capture visitors who access travel by modes other than air; the disadvantage is that visitors are less amenable to participating in the survey when they are engaged in tourist activities or checking into or out of their hotel. An example of this type of survey was conducted for Portland (OR) Metro in 2010.[18] The survey consisted of a one-day trip diary and SP survey questionnaire to gather information from visitors who stayed in a hotel either in downtown Portland or in the Lloyd District. The web-based survey collected data on all the trips made during one day of the respondents' visit, presented them with information about mode and station/stop type, and used SP experiments to collect data that were used to quantify visitors' time perception on different types of transit vehicles and at different types of transit stops.

The survey plan focused on contacting and recruiting visitors primarily through the hotel they patronized during their time in Portland. More than 3o hotels in downtown Portland and the Lloyd District were contacted in the months preceding survey administration, nine of which agreed to participate and assist the survey effort. To capture more respondents, postcards with project information and a link to the survey were handed out at Portland International Airport (PDX), the Portland Convention Center, TriMet Transit Centers and Park & Rides, and at a C-TRAN Park & Ride. Additionally, respondents who completed the Portland Metro Stated Preference Travel Study in November 2009 and submitted their e-mail address were asked to invite friends, family, and colleagues who visited Portland to participate in this study. Finally, TravelPortland.com, a resource for visitors to the region, sent out a link to the survey as a part of its monthly e-newsletter. Despite these efforts, only 196 respondents completed the survey, with 40% of these intercepted in-person, 25% from postcards handed out at hotels, 19% via the TravelPortland e-newsletter, and the rest from

[18] Portland Metro Visitor Travel Study Survey Report, By RSG for Portland Metro, March 2010.

other means. Note that this study did not allow incentives, raffles, or any type of gift which likely impacted the low response rate.

A more recent visitor survey was conducted in Chicago in 2014 for the Regional Transportation Authority (RTA). RTA wanted to tailor marketing, fare, and service strategies to better meet the needs of visitors and ideally increase transit ridership among the visitor market. Approximately 3,700 respondents completed the Chicago Visitor Travel Survey and were segmented based as nonregional visitors vs. regional visitors (who lived in the six-county region and made a trip to downtown Chicago). The survey was web-based and about 1,900 respondents were intercepted at key visitor locations in the Chicago area. The rest of the survey sample was recruited via e-mail from the regional transit agencies (Pace, CTA, RTA, Metra).

FIGURE 24: 2014 CHICAGO AREA VISITOR TRAVEL STUDY

One key issue in conducting visitor surveys is that visitors may be less familiar with the region than residents, and therefore may have a harder time identifying actual origin and destination locations. This makes software with automated mapping features an essential tool for visitor surveys, and in-person interviews are preferred to provide assistance to the survey respondent should it be needed.

Implementation Costs

The cost of conducting visitor surveys depends on the selected approach and number of sites and sample size. For example, consultant budget for the visitor survey conducted for

OahuMPO was approximately $110,000. That included survey design, programming, coordination with the airport and Department of Homeland Security, data collection, expansion, and a final report. Consultant budget for Portland visitor survey data collection was approximately $30,000, but that effort was combined with a larger survey effort so administrative costs could be shared between project phases, and the survey suffered from low sample size. The Chicago RTA visitor survey had a budget of approximately $200,000.

Opportunities for Data Integration

AirSage data provides separate trip tables for visitors, based on the most frequently observed "sleeping" or overnight location of the phone. The data are subject to the caveats mentioned above with respect to cellular phone data; it is likely biased toward overrepresentation of longer trips. Furthermore, while trip data for residents can be scaled to account for sample bias based on Census population estimates at the home end of the trip, there would likely be more error associated with visitor data due to the low sample rate for visitors who come from outside of the region. Finally, while AirSage data for the entire region can be adjusted to traffic counts using ODME procedures, such expansion would require assumptions regarding the split of visitor versus nonvisitor traffic for each observation or some other technique to account for the share of visitor versus nonvisitor flows. However, it may be less expensive to purchase visitor trip tables from AirSage or another provider than to conduct a visitor survey by one of the methods suggested above.

AIRPORT SURVEYS

In-Practice Methods

Airport surveys are typically conducted at departing gates and target departing passengers waiting to board their flights. The sample frame is typically constructed based on number of departing flights and seats by destination and TOD. Typically, these surveys are conducted using tablet PCs with the survey instrument programmed on the tablet or accessing a website with the survey instrument. To survey at departure gates, permission must be obtained for each surveyor from Department of Homeland Security. Once collected, the data can be expanded to the actual number of departures by destination group and time period.

Implementation Costs

Costs of airport surveys vary depending on sample size but typically range from approximately $100,000 to $400,000. Factors that affect this cost range include the size of the airport generally, the number of terminals, the length and complexity of the survey, and the complexity associated with permissions to survey. Additionally, project costs are likely to be at the high end of the range or modestly above if the project includes surveying airport employees who themselves can be a segmented population and hard to reach.

Opportunities for Data Integration

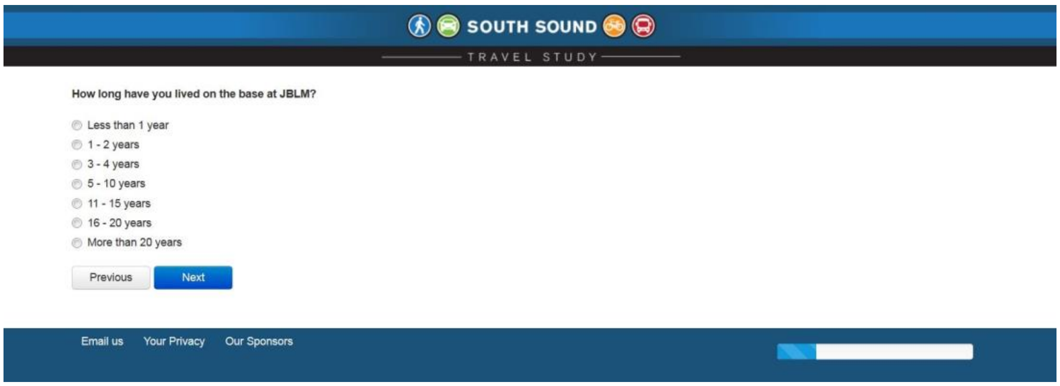
It may be possible to use locational or cell-based data as a point of comparison for airport travel patterns, but such data has limited value for development of airport ground access modeling as mode of arrival, parking location, demographic data, and other vital details are missing.

OTHER SPECIAL GENERATOR SURVEYS

In-Practice Methods

For regions with a large military population that lives in group quarters, it can be efficacious to conduct a military base special generator travel diary in a manner like the college/university special generator surveys mentioned above. As with the university survey, military base surveys are highly reliant on permissions and typically require assistance from the regional agency in obtaining these permissions. Additionally, military surveys require consideration of security or privacy needs—for example, it is more common to not ask about travel on the military base to avoid instances of enlisted military having to report going to secure locations on base. Recent examples of military surveys include one for Joint-Base Lewis-McChord in the Tacoma-Olympia, Washington area and one for SANDAG.

FIGURE 25: TACOMA-OLYMPIA WASHINGTON MILITARY SPECIAL GENERATOR SURVEY



Other special generators include hospitals, parks, special events, major shopping centers, and other unique destinations that are sometimes underrepresented in HTSs. Typically travel behavior associated with these sites is observed by conducting an intercept survey at each site of interest. The survey is structured by creating a sample frame based on-site characteristics (type of establishment, size, or area type/location). The survey consists of the following components:

- An establishment-component (type of business, number of employees, site characteristics).
- An optional worker component (worker characteristics and either a full day of travel for each worker or a survey focused on travel to/from the site as well as all work-related travel including office visits, service calls, deliveries, etc.).
- An optional visitor component that records travel to/from the site and the characteristics of visitors.
- A count of workers, personal vehicles or commercial vehicles and deliveries to the site on an average day (usually a weekday) to estimate magnitude of trip-making (trip

attraction rate estimation) and expansion of worker and visitor travel survey components.

TTI has conducted numerous workplace and special generator surveys over the past several decades, including the majority of the 34 surveys conducted throughout Texas between 2004 and 2014.[19] Throughout the past few decades, sampling methodologies employed in selecting establishments to participate in work place travel surveys have been selected based on quota sampling—wherein establishments are segregated into separate groups depending on specified stratification criteria. The actual establishments to include in the survey are then selected using Monte Carlo simulation, where establishments are disaggregated by employment types, and education establishments are manually separated from the list of service establishments. A random number generator is then used to develop a subsample firms from each employment type. The vendor is instructed to start recruiting businesses from the top of the list and continue until the cell quotas are roughly met. If an establishment refuses to participate, the next establishment on the list is contacted for recruitment. After the establishment agrees to participate, a follow-up meeting is scheduled so that the survey can be explained in greater detail, any questions related to the survey can be answered, and the survey date can be established. Each site must be analyzed to determine the number of surveyors to allocate on the survey day(s) and where to post surveyors to intercept the maximum number of visitors and to correctly expand the survey data.

One of the key advantages of workplace and special generator surveys is that they can provide unbiased estimates of travel patterns to and from each site. However, they are relatively expensive, and therefore only a limited number of establishments can be included. For this reason, agencies are beginning to explore passive data as an alternative to establishment surveys (see below)

Implementation Costs

Military special generator surveys are typically conducted as a follow-on or supplemental travel diary survey like the college/university special generator survey. These surveys require more effort for permissions and to obtain an adequate sample size. Costs are typically \$50–\$400 per respondent and based entirely on how successful the recruitment method is and the type of permission the military base provides.

The Maricopa Association of Governments recently completed their establishment survey. This survey was conducted on a similar timeframe as the HTS and had an advertised budget of \$1.5 million for 1,100 establishments. The 2009 H-GAC workplace survey cost \$940,000 for a sample size of 500 establishments. The New York Metropolitan Transportation Council conducted a regional establishment survey in 2015–2016 but has not yet published a report documenting the project.

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[19] Improved Trip Generation Data for Texas Using Work Place and Special Generator Survey Data, by Edwin Hard, Chandra Bhat, Byron Chigoy, Lisa Green, Subodh Dubey, David Pearson, Benjamin R. Sperry, Lisa Loftus-Otway Parker C. Moore for Texas Department of Transportation, May 2015.

Opportunities for Data Integration

Several opportunities exist (and more are being developed) to use passive data in addition to, or as a substitute for, conducting establishment surveys. Although cellular phone data may not be accurate enough to home in on travel patterns for specific sites (especially relatively small sites), data derived from LBS that use GPS likely have the positional accuracy to isolate special generators from nearby land uses. This data can be used to obtain OD patterns by TOD, day of week, and represent many more data-points than can be obtained from a one or two-day survey at a specific location. However, using passive data has a few disadvantages. First, the data are biased as described above, and just as with visitor data, it is more challenging to use traffic count ODME techniques to adjust special generator data to account for this bias. Second, the data lacks many of the socioeconomic variables that may be useful for modeling purposes. Finally, LBS data do not reveal magnitude of travel; instead, distributions are provided. Therefore, if passive data are used as a substitute for intercept surveys at special generators, then driveway traffic counts may still be required to expand travel patterns and obtain trip attraction estimates for each site. More specific recommendations for using passive data as an alternative or supplement to establishment surveys will be provided in Task 5.

COMMERCIAL VEHICLE TRAVEL SURVEYS

Collecting data for commercial vehicles requires accommodating multiple complexities and challenges. Most of the CVSs conducted recently in the United States have struggled with low response rates and small sample sizes with excessive costs. Three primary types of CVSs exist, and each has advantages and disadvantages and are useful for different types of modeling or planning activities:

- Intercept surveys are collected at truck stops, WIM stations, ports, transfer terminals, or facilities of interest. These are typically used for corridor or special generator studies, but these can be adapted for freight models. Smartphone data collection is being considered for these surveys. They tend to produce the biggest sample sizes for the least cost.
- Establishment surveys are collected on site or by phone/mail/online methods. These have been used for several different types of freight analysis:
    - *Commodity flow surveys* are used for goods movement and commercial vehicle analysis, national or statewide freight planning or modeling. Data collected typically include commercial vehicle trips by mode, origin and destination, vehicle type, commodity type, transfer facilities, and TOD. These surveys can be used to estimate commodity flow allocation models and mode and shipment-size models. They may also support other model components, depending on the availability of the original survey data.
    - *Commercial surveys* are used for regional freight analysis and modeling. Data collected typically include employer characteristics; number and type of employees and vehicles; and aggregate mode, shipment size, and transfer

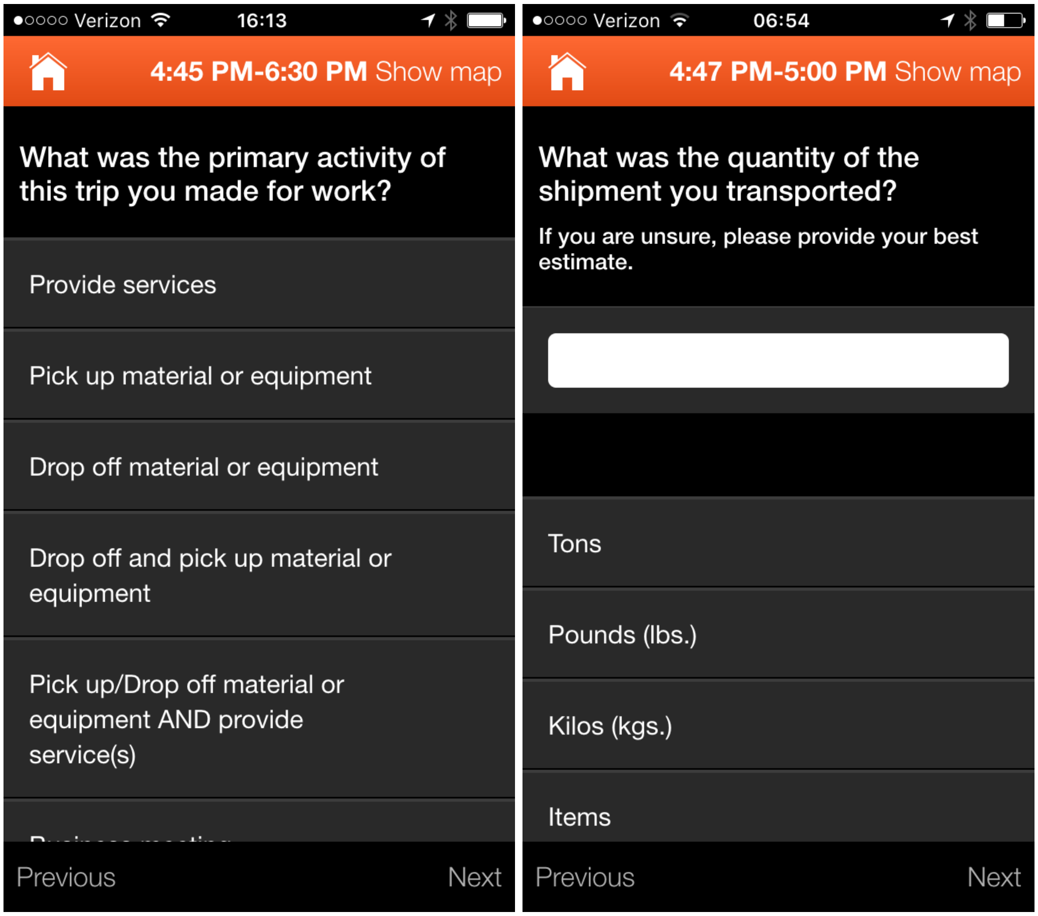
facility data. These surveys can be used to estimate distribution channel and mode or shipment-size model components.

- *Vehicle use surveys* are used for vehicle inventory or air quality analysis and commercial vehicle demand. Data collected includes the characteristics of commercial vehicle fleets. Data collected typically include vehicle age, make, model, leasing status, vehicle characteristics, and use. These surveys can be used to estimate commodity flow allocation models and possibly support other model components. They tend to produce small sample sizes for a medium cost.

- Truck driver surveys are collected on site or by phone/mail/online or smartphone methods. Data collected includes commercial trip origin, destination, start time, stop times, routes, distances, vehicle types, commodity types, and stop characteristics. They are the most comprehensive CVS data available and can support estimation of network flow model components, but they cannot support upper-level models since they are focused on a single mode. Truck driver surveys can be paired with intercept or establishment surveys to recruit drivers. These surveys are the most useful for freight modeling but tend to be expensive with small sample sizes.

A newer method for CVSs is to collect commercial vehicle trip data using GPS, either with a GPS logger or a smartphone. Data collected passively include commercial trip origins, destinations, start times, stop times, routes, and distances. Additional data can be collected using smartphones with notifications to drivers after each trip to collect data on vehicle type, shipment weights, commodities carried, parking or tolls paid, and purpose of stop. Data can be collected for a fleet of trucks over several days using a smartphone (e.g., a week or a month) or longer if GPS loggers are used (e.g., a month or year). The smartphone approach offers the same benefits of traditional GPS loggers with less burden because respondents answer survey questions directly on their phone throughout the day without having to go online to complete a separate survey. The smartphone approach also provides a significant reduction in missed trips or instances of drivers reporting zero trips in a day, as respondents generally have their smartphones with them always but may forget to bring a third-party GPS logger with them.

FIGURE 26: SMARTPHONE COMMERCIAL VEHICLE TRAVEL DIARY SCREENSHOTS



Another advantage of the GPS surveys for commercial vehicles is the ability to pick-up stops for meals, breaks, fuel, or personal business during the day spent picking up and dropping off goods. In addition, service-related commercial vehicles (parcel or mail delivery, plumbers, contractors, home healthcare, insurance claims adjustors, realtors, etc.) are often likely to under-report travel using phone or online survey methods because there are so many trips made in a single day. GPS surveys will pick up these additional trips without the respondent burden involved in other methods.

Recruitment of commercial vehicles to participate in any one of the surveys above is quite challenging. Intercept surveys are the most reliable, especially when they are conducted at locations where commercial vehicles are waiting anyway (e.g., weigh-in-motion stations, truck parking sites, ports). Typically, intercept surveys are conducted in-person and are quite short to ensure that all data are collected while commercial vehicles are waiting or pulled over briefly. Intercept surveys can obtain e-mail addresses or phone numbers for a more comprehensive follow-up survey or can be used as an opportunity to download a smartphone-based GPS travel survey app to collect further data. Establishment and truck driver surveys are much more difficult to recruit participants for because many establishments are concerned about drivers being distracted, confidential data being shared, or respondents taking time during their work day to complete the survey. These surveys can be shorter or longer, depending on the desired use of the data; truck driver surveys are typically the most burdensome. Smartphone-based GPS travel surveys have reduced driver burden significantly, but recruitment remains a challenge.

Implementation Costs

Survey costs vary widely depending on the type of CVS being conducted, the desired sample size and the type of data required. Sample sizes are typically in the 500–2,500 range for establishments, with an expectation of that there will be more than one driver from each establishment in the truck driver surveys. Intercept surveys will typically contain smaller sample sizes, such as 200–500, when the purpose is for a corridor or special generator analysis, and similar sample sizes to establishment surveys when the purpose is to support a broader analysis.

Opportunities for Data Integration

Many opportunities exist for data integration of commercial vehicles:

- Model estimation. GPS data on trucks can be used fused with land-use data to impute industry or commodity type and estimate travel demand for trucks. If the land-use data are spatially detailed, then intermediate stops may also be estimated. Service trips may be difficult to distinguish from goods delivery at many locations. These data can also be used to estimate touring patterns, stop frequency, duration and sequencing models by industry or commodity type as well as route choice models.
- Model calibration. Some GPS data sources include data on vehicle type or industry and these can be used to calibrate truck touring model components such as vehicle type, touring patterns, stop frequency, duration and sequencing, intermediate stop, and route choice models.
- Model validation. All GPS sources can be used for model validation, especially if the vehicle type is known. This is the most common use of these data currently, but model estimation and calibration uses are appealing because of the significant reduction in cost, recognizing the limitations in these GPS sources.

Truck GPS data suffers from many of the same limitations that have been described for other surveys: they are biased; they are lacking crucial data variables such as commodity type or establishment characteristics; and they are difficult to expand to be comprehensive and representative.

OTHER TYPES OF INTERCEPT/OD SURVEYS

In-Practice Methods and Opportunities for Data Integration

In addition to transit riders (section 3.2), intercept/OD surveys may be used to gather data on other specific types of travelers. Specific types of surveys for university students, visitors, airport users, special generators, and commercial vehicles are discussed above in sections 3.4 through 3.8, respectively, and those can range from simple intercept surveys to more complete diary-based surveys that last one or more days. Three other types of intercept/OD surveys that can be considered are discussed in the rest of this section:

- External surveys.
- Bicycle user surveys.
- Toll user surveys.

External Surveys

In the past, common practice for estimating the number of external-external (X-X), internal-external (I-X) and external-internal (X-I) trips between different zones and external station pairs was to conduct roadside intercept OD interviews. As the costs and safety restrictions of roadside interviews have increased, a more common method has been to use LPC and to send a short OD questionnaire to the address associated with the plate registration. This method requires motor vehicle department cooperation and tends to omit out-of-state visitors from the sample. As mentioned in Chapter 2, Bluetooth data capture can now be used as well, although this does not capture all vehicles, does not capture trip purpose, and only captures X-X trips and not internal origin or destination points.

More recently, the use of passive data is obviating the need for external surveys. Even cell-based data such as AirSage is generally deemed accurate enough for the longer trip distances and the reduced spatial accuracy required for external surveys. (I-X and X-I trip OD patterns can be calibrated at a level of geographic detail coarser than TAZs).

Bicycle User Surveys

Bicycle use is of growing policy and public interest in many regions, but the amount of data available on bicyclist travel patterns tends to be limited.

One option for collecting more data on cyclists is to conduct an intercept OD survey, intercepting cyclists at intersections or other points with higher cyclist traffic volumes. These same locations can also be good locations for collecting bicycle count data, which is a useful complement to bicyclist OD data. OD surveys for cyclists can involve short paper-based or tablet-based questionnaires, asking trip origin, destination, and purpose, as well as selected demographic questions.

If conducted in conjunction with a HTS, a bicyclist intercept survey can also provide a means of recruiting cyclists to take part in the household survey, and thus increase the number of bicycle trips likely to be captured in the HTS. (Such intercept "convenience" samples are typically not included in the weighting for household survey data, since they are not part of a probability-based sample, but they can be used to enhance model estimation, which typically does not use weighted data.)

The approach described above was recently used by RSG for the San Diego region HTS. Several sites were chosen for bicycle counts, as well as bicyclist OD intercept interviews carried out on electronic tablets. Cyclists who were interviewed were also given a postcard with an invitation and a web address to take part in the smartphone-based GPS travel survey. Although it is not certain that these recruits will make bicycle trips during the household survey travel days, the fact that they are intercepted making bicycle trips means that they are more likely to also make bicycle trips during the travel survey. The bicycle trips in the HTS is used to improve the mode choice model estimation, while the bicyclist OD intercept data and count data are used to calibrate and validate the resulting models.

Toll User Surveys

Toll user surveys can be carried out for several different purposes. The most recent toll user survey in the Houston region was carried out by Texas A&M Transportation Institute in 2008. Invitations to a web-based survey were distributed at toll booths, and a final sample of 1,144 transponder (EZ Tag) users and 981 cash customers was obtained. The questions asked included several questions about the trip made when intercepted (origin, destination, purpose, frequency), plus many household and person sociodemographic variables. Most of the questions asked users satisfaction and attitudes regarding various aspects of the toll system and potential changes.

For future toll user surveys, there are several options, depending on the main purpose that the survey data are needed for:

- If the main purpose of the survey is to ask similar satisfaction and attitude questions to gauge changes in toll users and their attitudes since 2008, then it would be best to keep the survey and recruitment methods as similar as possible to the 2008 survey. (Some changes could be made to use more up-to-date web-based interview software, using a Google Maps interface for addresses, for example.)
- If the main purpose is to simply identify OD patterns and other trip characteristics for EZ Tag and cash toll trips, then it may be possible to capture that data as part of a HTS, without conducting a separate toll users survey. For example, if a large household survey sample is asked about EZ Tag ownership and asked about toll use for each auto trip recorded during the travel days, then it should be possible to capture OD information for tolled trips with a sample size equal to or greater than the sample size from the 2008 toll users survey—particularly if multiple travel days are collected from each respondent.
- Another option would be to identify toll-using trips during a HTS, as described in the preceding paragraph, and then go back to re-survey certain households with a follow-up survey that asks additional questions about a tolled trip that was reported in the travel diary, perhaps with additional attitudinal or SP questions about toll road options. Using the follow-up approach can greatly reduce recruitment costs compared to conducting a separate toll user intercept survey recruitment and can facilitate a more controlled selection of which tolled trips are used as the basis for the targeted survey.

As discussed in Chapter 2, passive data can be used to calibrate or validate toll user OD data to some extent, particularly if GPS data (TomTom, StreetLight) is used. Cell tower data (e.g. AirSage) is not spatially accurate enough to identify tolled facility users separately from nontolled facility users, particularly if the tolled and nontolled routes run adjacent to each other, such as a high-occupancy toll lane.

B.4 METHODS SUMMARY

Table 9 summarizes the findings for both passive data sources and travel survey methods.

TABLE 9: PASSIVE DATA SOURCES AND TRAVEL SURVEY METHODS

SOURCE	SUMMARY	ADVANTAGES	DISADVANTAGES	COST	INTEGRATION
Bluetooth	• Uses detector locations • Corridor study application • Sample: 4-9% of vehicles on road	• Decent sample of facility or route-level vehicles • Careful placement of detectors leads to spatial precision	• Lack of OD information • Limited route data • No vehicle class information	• More expensive than other passive data • Cheaper than surveys	• Expand to traffic counts
Cell Tower	• Communicate with networks through control channel messages • Locates and tracks cell phones with signals sent between phones/towers • Application for external, long-distance, and visitor travel • Sample: 6-10% of vehicles on road	• Highest sample penetration • Device ID persistence • Filters intermediate trips	• Limited spatial precision • Limited temporal resolution • False imputation of work trip purpose • No vehicle class information • Systematic bias for areas with poor coverage	• Based on population/ number of zones • Cheaper than LBS • Expansion costs	• Expand to traffic counts • Census commute flows for work trip segmentation
GPS Truck	• Derived from onboard vehicle, navigation, or mobile devices • Processed to create aggregate trip OD matrices and travel time metrics • Regional/modeling applications • Sample: 9-12% of vehicles on road	• Truck segmentation • High sample penetration • Good temporal availability • High-fidelity spatial precision	• Requires significant processing • Limited device ID persistence • Systematic bias for long trips	• Low cost for raw data • Additional cost for data processing	• Expand to traffic counts

SOURCE	SUMMARY	ADVANTAGES	DISADVANTAGES	COST	INTEGRATION
GPS Auto	• Derived from onboard vehicle, navigation, or mobile devices • External travel application • Sample: <1% of vehicles on road	• Good spatial precision	• Demographic bias for high income populations • Limited sample penetration • Limited device ID persistence	• Commonly purchased in a package • Additional cost for expansion	• Expand to traffic counts
Location-Based	• Aggregate from smartphone and mobile device applications • Uses GPS, Wi-Fi, or Bluetooth locations or cell tower signaling • Regional/modeling applications • Sample: 5-8% of vehicles on corridor/15% of total population	• Good spatial precision • Good sample penetration • Device ID persistence • Good temporal availability • Truck and nontruck segmentation	• No vehicle class information • Systematic bias for trip length	• Commonly purchased in a package • Based on population/ number of zones • Additional cost for expansion	• Expand to traffic counts
SURVEY METHODS					
Household Travel	• Household, person, vehicle, and trip characteristics • Mode and route data • Smartphone/GPS, online, and phone methods available • Sample based on the size of the study area typically.05-2% of households	• Extremely detailed dataset • Able to oversample populations of importance • Customizable to region’s needs	• Time intensive, projects typically require 4-12 months or more • Burdensome for respondents • Respondents concerned about privacy implications	• Varies based on approach and sample size and several other factors	• Expand to intercept/OD data and to passive OD datasets
Transit User Intercept/OD	• Characteristics of transit users • Trip-making patterns • Interview or paper-based surveys on site or online recall surveys • OD survey and control data gathering • Sample: 10% of total ridership	• High confidence in accuracy • Ability to minimize nonresponse bias with appropriate expansion	• High cost and time intensive e	• Varies based on approach and sample size and several other factors	• Used to expand survey data, compare against passive OD datasets

SOURCE	SUMMARY	ADVANTAGES	DISADVANTAGES	COST	INTEGRATION
University	• Travel pattern data for students/staff • Stand-alone survey or integrated with HTS • Sample based on size of university	• Efficient when design based on HTS • Data specific to university populations	• Can lack attention if conducted with a HTS	• Varies based on approach and sample size	• Residential locations • Parking supply, utilization, price data • Campus shuttles, routes, schedules, fares
Visitor	• Visitors to geography of interest (e.g., city, beach, etc.) • Visitor intercept surveys or integrated with airport ground access survey	• Efficient when coupled with airport survey • Intercept surveys cover all travel modes	• Airport surveys limited to air mode travelers • Limited visitor local locational knowledge • Hotel intercept permissions are difficult to obtain	• Varies based on approach and sample size	• Aggregate passive visitor trip tables
Airport	• At departure and arrival gates • Sample based on number of arriving/departing flights and seats	• Generally short surveys • Travelers complete while waiting for flight	• Intercept staff require security clearance	• Varies based on approach and sample size	• Use passive data for comparison
Other Special Generators	• Intercept surveys at site (hospitals, parks, special events, major shopping centers, unique destinations) • Sample based on-site characteristics	• Unbiased estimated of travel patterns to/from sites	• Limited to a specific site or sites	• Varies based on approach and sample size	• Use passive data for OD patterns
Commercial Vehicle Travel	• Intercept, Establishment, and truck driver surveys	• Truck segmentation	• Low response rates • Limited sample penetration	• Relatively high cost	• Aggregate GPS data for OD patterns
Other Intercept/OD Surveys	• External surveys • Bicycle user surveys • Toll user surveys	• OD data for model calibration • Can recruit into HTS	• Intercept interviews can be expensive	• Relatively high cost	• Use passive data to replace external surveys

APPENDIX C. ATTRACTION RATES: AIRSAGE DATA VS. ESTABLISHMENT SURVEY

C.1 AIRSAGE DATA SUMMARY

The AirSage data used in the analysis includes observed trips made during October 2016 average weekday (Tuesday, Wednesday, and Thursday) and average weekend (Saturday and Sunday). Since the travel demand model typically forecasts average weekday trips, only average weekday trips are used in analysis.

The AirSage trip purposes are defined based on origin purpose (work or nonwork) and destination purpose (work or nonwork), see Table 10. Over 15 million trips are recorded in AirSage data, and 46% of these trips are other purpose to other purpose, which indicates that a significant portion of AirSage trips are short distance.

TABLE 10: AIRSAGE AVERAGE WEEKDAY TRIPS BY PURPOSE

TRIP PURPOSES	REPORTED TRIPS	PERCENTAGE
Home to home (H2H)	2,654,422	17%
Home to other (HO)	1,138,967	7%
Home to work (HW)	607,118	4%
Other to home (OH)	1,144,962	7%
Other to other (OO)	7,324,801	46%
Other to work (OW)	942,354	6%
Work to home (WH)	534,581	3%
Work to other (WO)	1,108,555	7%
Work to work (WW)	442,246	3%
Total	**15,898,006**	**100%**

The AirSage data also distinguishes resident and visitor trips. About 40% of trips are made by visitors and there is not enough data to isolate long-term visitors (who should be counted as residents in demand model) from short-term visitors. For simplification purpose, both resident and visitor trips are used in analysis.

C.2 H-GAC MODEL AND AIRSAGE CORRESPONDENCE

A total of 5,217 internal zones are in H-GAC model, while AirSage only has 172 zones. H-GAC model has larger area and more refine geographic resolution than AirSage. Figure 27 shows the AirSage zones (polygon with red line as zone boundary) and centroids of H-GAC zones (red or blue dots). The red dots are model zones not in AirSage zones, and blue dots are model zones in AirSage zones. AirSage zones mostly include eastern and urban area of H-GAC model.

FIGURE 27: H-GAC MODEL AND AIRSAGE ZONES CORRESPONDENCE

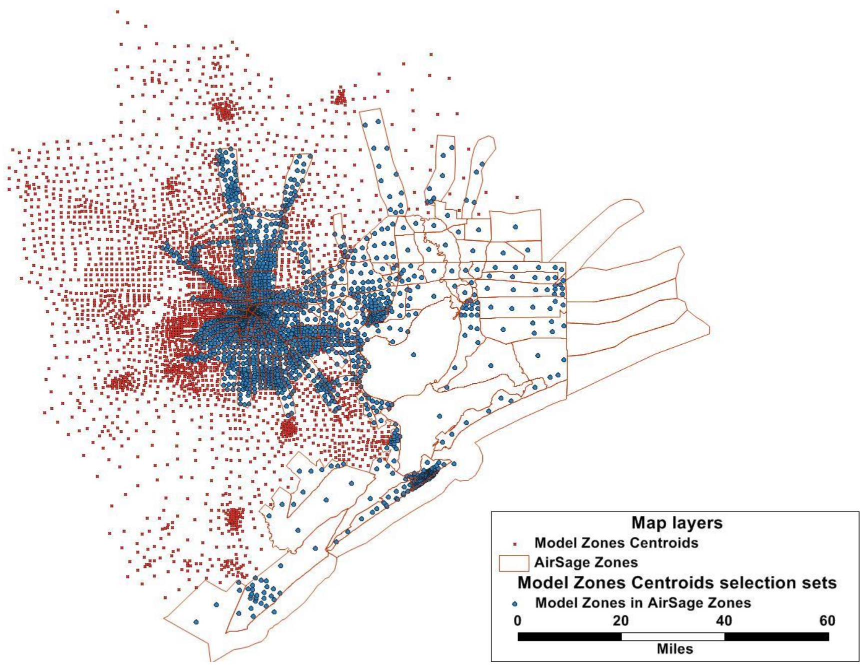


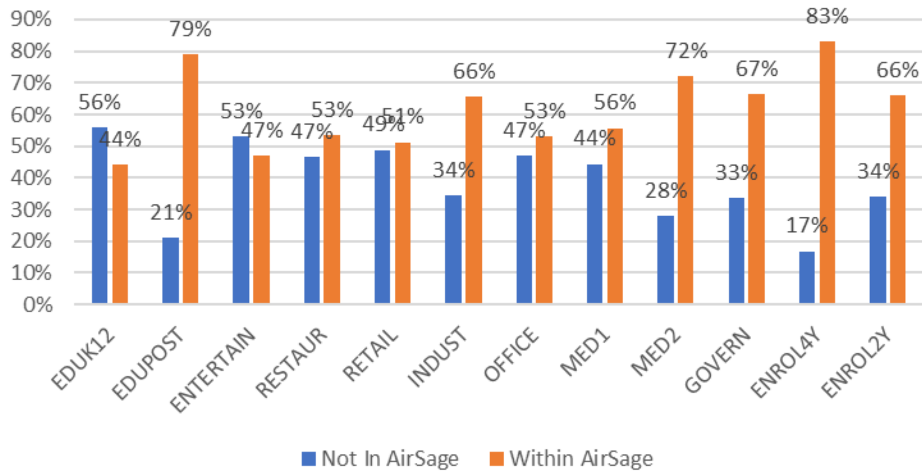
Table 11 shows social-demographic distribution within and outside of AirSage zones. In general, AirSage zones cover more urban areas and less rural areas. About 60% of households and population are not included in AirSage zones and 44% of employment not included in AirSage zones.

TABLE 11: SOCIODEMOGRAPHIC DISTRIBUTION BY AIRSAGE ZONES

	TOTAL HOUSEHOLDS	TOTAL POPULATION	TOTAL EMPLOYMENT
ABSOLUTE NUMBER			
Not in AirSage	1,437,772	3,842,074	1,416,406
Within AirSage	1,016,424	2,606,802	1,810,710
Total H-GAC Model	**2,454,196**	**6,448,876**	**3,227,116**
PERCENTAGE			
Not in AirSage	59%	60%	44%
Within AirSage	41%	40%	56%
Total H-GAC Model	**100%**	**100%**	**100%**

Figure 28 shows the distribution of employment by industry categories within and outside AirSage covered area. In general, college education jobs, industry jobs, medical industry jobs, government, and college campus are more likely to be included in AirSage zones.

FIGURE 28: EMPLOYMENT DISTRIBUTION BY CATEGORIES



C.3 AIRSAGE ATTRACTION RATES VS ESTABLISHMENT SURVEY RATES

To estimate attraction rates from AirSage data, the model sociodemographic data are aggregated to AirSage zones for estimation purpose. The attraction rates are estimated using nonlinear regression package in R with all coefficients constrained as larger than zero. The estimation model is specified as no constant.

The estimation model is specified as:

$$Attractions = f(Household, Employment\ by\ Industry\ Categories, Enrollments)$$

Where:

$Attractions$ variables are total AirSage zone attractions by purposes (HBW, HBO, NHB_Other, NHB_Work). The detail calculation is explained in Table 12.

$Household$ variable is total households in each AirSage zone, aggregated from model zones.

$Employment\ by\ Industry\ Categories$ is total employment by industry categories in each AirSage zone, aggregated from model zones.

$Enrollments$ is college enrollment in each AirSage zone, aggregated from model zones.

As shown in Table 10, AirSage data has trip information as the origin and destination. These trips are aggregated by AirSage origin or destination zones to be used as attractions. The detail calculation is explained in Table 12.

TABLE 12: ATTRACTION CALCULATION

AIRSAGE ZONE ATTRACTIONS	CALCULATION
HBW	Total trips going to the zone (HW) + Total trips from the zone (WH)
HBO	Total trips going to the zone (HO) + Total trips from the zone (OH)
NHB-Other	(Total trips going to the zone (OO) + Total trips from the zone (OO))/2
NHB-Work	(Total trips going to the zone (OW) + Total trips from the zone (OW))/2 + (Total trips going to the zone (WO) + Total trips from the zone (WO))/2 + (Total trips going to the zone (WW) + Total trips from the zone (WW))/2

The model trip purposes are difference from AirSage. The correspondence of trip purposes between AirSage and model is defined in Table 13. When comparing the attraction rates, the rates for HBO from model are sum of rates from all purposes falling into that group.

TABLE 13: AIRSAGE AND MODEL PURPOSES CORRESPONDENCE

AIRSAGE PURPOSE	MODEL PURPOSE	NOTE
HBW	• HBW	• Home-based-work
HBO	• HBNW-ED1 • HBNW-ED1-SB • HBNW-OTHER • HBNW-RETAIL	• Home-based-other
NHB-Other	• NHB-Other	• Non-home-based-other
NHB-Work	• NHB-Work	• Non-home-based-work

Table 14 to Table 17 compare the attraction rates of HBW, HBO, NHB-Other, and NHB-Work estimated from AirSage data with the average attraction rates from model. In general, the two sets do not agree with each other well. A few issues can be identified:

1. The estimated attraction rates from AirSage for some employment categories are zero. For example, attraction rates for medical employment for HBW purpose and office employment for HBO purpose are zero. This is due to that the nonlinear regression with coefficients constrained to be larger than zero. If it is not constrained, the estimated coefficients will fall into negative range.

2. Some estimated attraction rates are much bigger than model attraction rates. For example, the H2H rates for HBW purpose from AirSage is 0.0955 while model is only 0.016. The education employment for noncollege school (EDUK12) from AirSage is 3.2826 while model is only 3.2826.

3. On the contrary to second point, some estimated attraction rates are much smaller than model ones.

The above issues can be explained by following reasons:

1. Aggregation bias. As explained above, there are only 172 AirSage zones while total model zones covered in AirSage data are over 2,500. The aggregation of model zones to AirSage zones makes estimation model lose certain sensitivity (2,500 zones to 172 zones).

2. Selection bias. As shown in Figure 28, AirSage area mostly covers zones with more employment and less population, or more urbanized area. The estimated attraction rates are therefore bias toward the urbanized area while the rates from model are average of whole region. The model does have attraction rates by area type, however, a comparison to those rates cannot be made due to zone aggregation.

3. Trip expansion bias. The trips reported by AirSage need to be processed to be consistent with regional travel, therefore the estimated attraction rates include bias due to using not expanded data. This bias can be remedied to some extent by using weight calculated as total trips generated from AirSage attraction rates divided by trips generated from model attraction rates.

TABLE 14: HBW ATTRACTION RATES

HBW	AIRSAGE	MODEL
H2H	0.0955	0.0160
RETAIL	0.3925	0.1889
ENTERTAIN	0.3925	0.1889
Restaurant	0.3925	0.1889
OFFICE	0.0466	0.2407
INDUST	0.1040	0.1989
GOVERN	4.2240	0.2126
MED1	0.0000	0.1966
MED2	0.0000	0.1966
EDUK12	3.2826	0.2652
EDU2Y	3.1925	0.2557
EDU4Y	0.0000	0.1645

TABLE 15: HBO ATTRACTION RATES

HBO	AIRSAGE	MODEL
H2H	0.0000	0.4440
RETAIL	0.2192	3.6508
ENTERTAIN	0.2192	3.6508
Restaurant	0.2192	3.6508
OFFICE	0.0000	1.6092
INDUST	0.1373	0.6424
GOVERN	4.3028	2.9782
MED1	0.7234	3.7918
MED2	0.7234	3.7918
EDUK12	4.8305	40.7524
ENROL2Y	0.0000	0.5603
ENROL4Y	0.4644	0.5557

TABLE 16: NHB-OTHER ATTRACTION RATES

NHB_OTHER	AIRSAGE	MODEL
H2H	0.6208	1.0289
RETAIL	4.3585	10.3689
ENTERTAIN	4.3585	10.3689
Restaurant	4.3585	10.3689
OFFICE	0.0000	1.3031
INDUST	2.9030	1.3688
GOVERN	5.5850	2.1986
MED1	0.0000	2.2728
MED2	0.0000	2.2728
EDUK12	31.4166	4.5316
EDU2Y	4.6177	1.8666
EDU4Y	1.0056	1.2005

TABLE 17: NHB-WORK ATTRACTION RATES

NHB_WRK	AIRSAGE	MODEL
H2H	0.4405	0.0832
RETAIL	0.9203	0.5942
ENTERTAIN	0.9203	0.5942
Restaurant	0.9203	0.5942
OFFICE	0.0000	0.5472
INDUST	0.2493	0.3466
GOVERN	4.4433	0.2473
MED1	0.0000	0.3820
MED2	0.0000	0.3820
EDUK12	10.5159	0.3229
EDU2Y	3.5762	0.2247
EDU4Y	0.0000	0.1445

C.4 COMPARING ATTRACTION RATES IN HIGH LEVEL

To better access the estimated attraction rates from AirSage data, the estimated rates are compared to the attraction rates reported in Texas trip generation study[20] (referred as TTI report in the following discussion). The TTI report defines attraction rates by four employment categories: basic, service, retail, and education. The AirSage rate is scaled using weight calculated as total trips generated from AirSage attraction rates divided by trips generated from model attraction rates. Then model and AirSage rates are calculated as weighted average to collapse to rates by four employment categories to be consistent with TTI report categories. The correspondence definition is listed in Table 18. Note that number of households as one of attraction factors is not included in TTI report. Also, TTI report does not include college enrollment (ENROL2Y and ENROL4Y).

TABLE 18: EMPLOYMENT CATEGORIES CORRESPONDENCE

AIRSAGE/MODEL	TTI REPORT
H2H	N/A
RETAIL	retail
ENTERTAIN	retail
Restaurant	retail
OFFICE	service
INDUST	basic
GOVERN	service
MED1	service
MED2	service

[20] FHWA Report: Improved Trip Generation Data for Texas Using Work Place and Special Generator Survey Data, May 2015.

AIRSAGE/MODEL	TTI REPORT
EDUK12	education
EDU2Y	education
EDU4Y	education
ENROL2Y	education
ENROL4Y	education

Table 19 has the correlations of attraction rates from H-GAC, TTI, and AirSage. There were differences between AirSage and H-GAC, but the AirSage rates were more closely correlated to the H-GAC rates than the default Texas rates from TTI (for metro areas over 1.2M). The correlation of the H-GAC total rates with the AirSage total rates was 0.97 versus 0.87 with the TTI total rates.

TABLE 19: CORRELATIONS BETWEEN ATTRACTION RATES FROM THREE SOURCES

CORRELATION	TOTAL	HBW	HBI	NHB
AirSage—H-GAC	0.97	0.37	0.72	0.1
AirSage—TTI	0.71	0.37	-0.04	-0.02
H-GAC—TTI	0.85	0.61	0.3	1

Figure 29 to Figure 32 show the comparison of attraction rates from H-GAC model, AirSage and TTI. In terms of total rates, AirSage rates for Retail and Services were low, which is likely related to the systematic trip/activity duration bias in AirSage. This is likely related to the documented systematic trip/activity duration bias in AirSage. It was not possible to correct this as part of this analysis, but it would likely produce higher attraction rates for these categories presuming the expansion of the dataset used for model estimation corrected for this.

FIGURE 29: COMPARISON OF H-GAC, AIRSAGE, AND TTI TOTAL ATTRACTION RATES BY EMPLOYMENT CATEGORIES

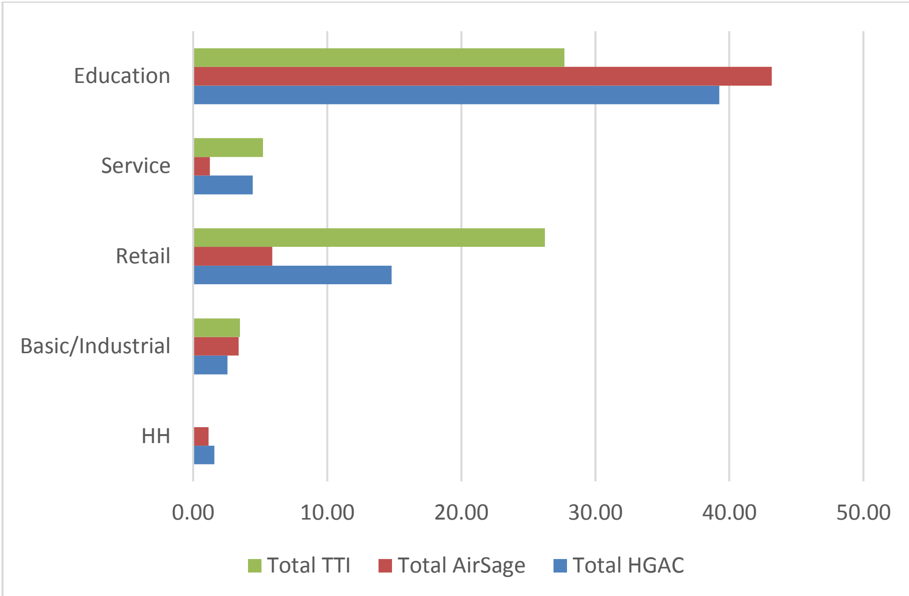


FIGURE 30: COMPARISON OF H-GAC, AIRSAGE, AND TTI HBW ATTRACTION RATES BY EMPLOYMENT CATEGORIES

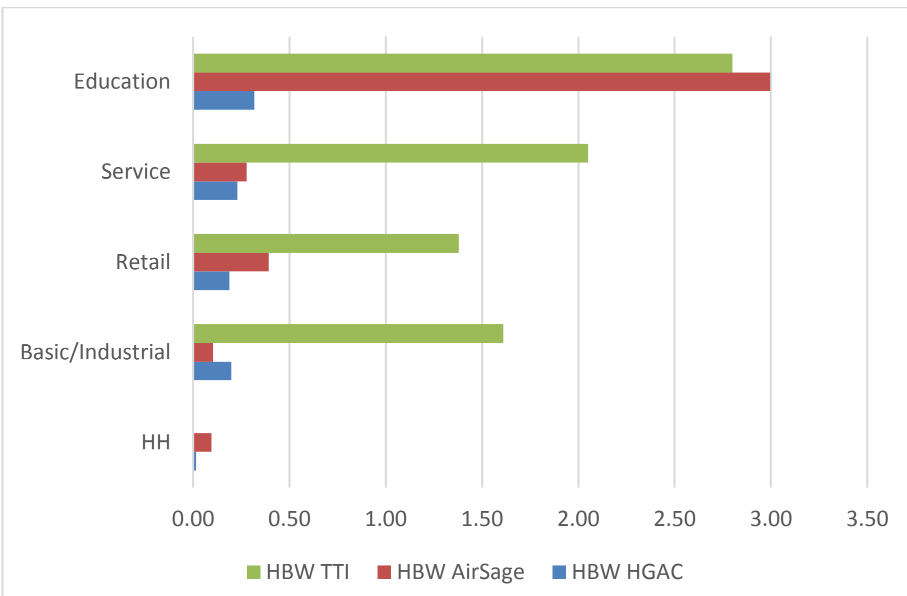


FIGURE 31: COMPARISON OF H-GAC, AIRSAGE, AND TTI HBO ATTRACTION RATES BY EMPLOYMENT CATEGORIES

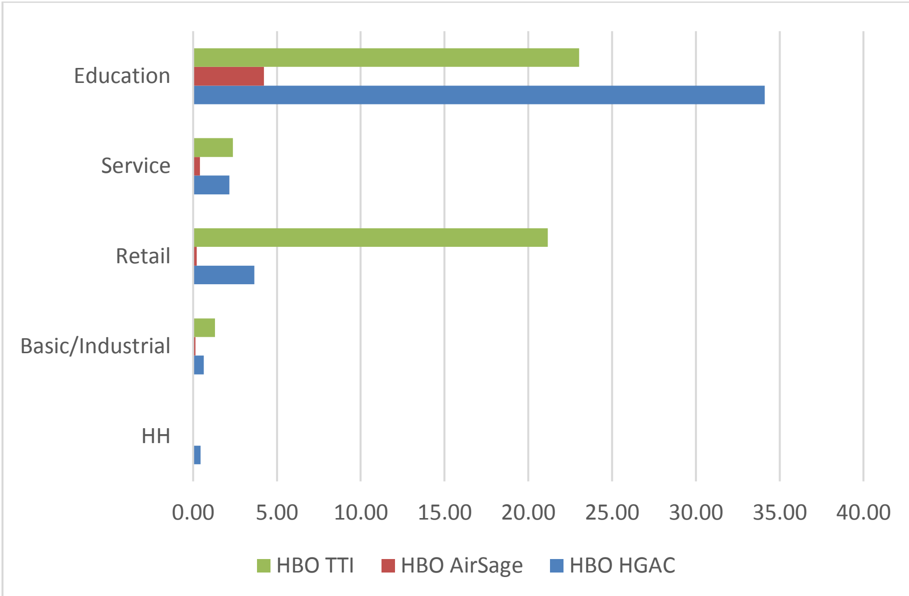
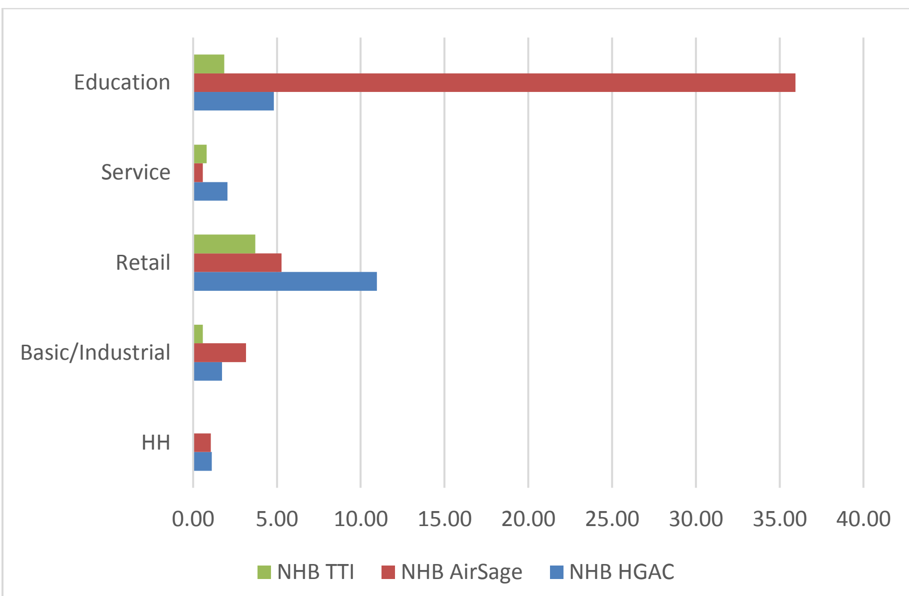


FIGURE 32: COMPARISON OF H-GAC, AIRSAGE, AND TTI NHB ATTRACTION RATES BY EMPLOYMENT CATEGORIES



C.5 CONCLUSION

The analysis points on the on the on hand on the inadequacy of this particular AirSage dataset to provide attraction rates for the H-GAC model, but on the other hand, provides strong evidence that the passive data as from AirSage could support this use.

The particular AirSage dataset available for this analysis was less than ideal in several regards. Most notably, it only covered a (nonrepresentative) portion of the model area and the zone sizes were quite large. Presumably a passive dataset which covered the whole model area with zones closer in size to the model zones would also produce even more accurate results, comparable to the survey. Also, given the limited time and budget available for the analysis, it was necessary to rely on AirSage's simple expansion factors based on market penetration alone. AirSage data has been demonstrated to oversample long trips and under-sample shorter trips and expansion based on market penetration alone does not correct for this sampling bias. Correcting for this bias with a more complete/refined expansion would also be expected to produce more accurate results. Since, for instance, retail establishments are disproportionately associated with shorter stops and trips, correcting for the duration bias in the data would presumably increase the attraction rates for retail which were overall one the largest discrepancies in the datasets.

AirSage's imputed trip purposes also have some issues, which could likely be improved. For instance, it seems likely that many home-school trips are being erroneously identified as non-home-based due to stops (as by a bus to pick up other students) on the way to school.

Despite these issues, the AirSage data correlated better with H-GAC's attraction rates than the TTI rates, and generally produced reasonable patterns and rates. Where there were issues with the rates, they were generally explainable in relation to the foregoing issues with the limitations of this particular dataset/analysis which would not be expected to impact a dataset acquired for purposes of model development. Although the analysis shows some of the technical challenges of estimating attraction rates from passive data, it also shows that the data does capture attraction patterns and a better dataset and more rigorous analysis including refinement of the expansion could produce reasonably good attraction rates at a fraction of the cost of an establishment survey. The evidence is best that the data could support good estimates of total attraction rates. If the data could produce good estimates of total attraction rates, attractions could then be apportioned to trip purposes based a simple model from the household survey (especially if the household survey contained a full seven day sample). Moreover, newer passive LBS datasets offer more precise and less biased data than AirSage's cellular data with similar sample penetration and can be analyzed at more disaggregate levels. These datasets may likely produce even better results for estimation of attraction rates and other purposes.

Finally, while the analysis has evaluated the reasonableness of attraction rates by comparison with survey-based rates, it is possible, that a more representative/properly expanded passive dataset may produce even more accurate attraction rates than surveys, due to the far greater sample size.

APPENDIX D. TXDOT AND TTI COMMENTS AND RSG TEAM RESPONSES

Technical Memorandum
December 09, 2017

Technical Memorandum

To:	Chris VanSlyke, Houston-Galveston Area Council Chi-Ping Lam, Houston-Galveston Area Council
From:	Christeen Pusch, Texas Department of Transportation Janie Temple, Texas Department of Transportation Byron Chigoy, Texas A&M Transportation Institute Ed Hard, Texas A&M Transportation Institute
Subject:	Houston-Galveston Area Council (H-GAC) Travel Survey and Data Collection Plan

The purpose of this memo is to present comments on the findings and recommendations presented in the H-GACs's travel survey and data collection plan for updating the H-GAC regional model.

This technical memorandum is based on TxDOT and TTI's review of the referenced data collection plan as prepared by H-GAC's consultant Resource Systems Group (RSG). This memorandum pertains to technical details of the data collection plan and sampling targets and does not consider funding availability required to meet proposed sampling targets or data purchases. One funding detail to note is that TxDOT cannot provide funding for "incentives" used to facilitate survey participation and completion and that the funding of any such incentives would be the sole responsibility of the data collection vendor.

RSG Response: We have found that the use of incentives dramatically increases response rates, which not only provides a more representative sample, but also substantially reduces the overall recruitment cost. Additionally, the use of incentives is considered standard practice nationally, including the NHTS. For the recent state of Connecticut household travel survey (~8,500 household sample size), RSG conducted a split sample during the pilot to test the effectiveness of incentives. The result (consistent with our work in other regions) was that Connecticut saved more than $300,000 on the project by offering incentives (over not) due to the higher response rates saving on print/postage/invitation costs. We would estimate a similarly higher cost per household due to the increased cost of recruitment in Texas in situations where incentives were not allowed. If H-GAC can find a source of funding that can be used for incentives, that will reduce the overall cost of the

survey. RSG can provide additional information on our past research into the use of incentives.

1. **Household Survey**

   Previous household data surveys for the region consisted of approximately 5,800 households which were sufficient for developing inputs for the H-GAC 4 step trip-based model. The proposed sample of 10,000 surveys may be less than optimum for a statistically robust sample considering the population cohorts of H-GAC's ABM model. However, the sample size is consistent with other recent and ongoing survey efforts including San Diego (6,200 surveys), Atlanta (10,200 surveys) and Phoenix (7,000). The proposal to oversample hard-to reach populations should help to compensate for sample size.

   The proposed use of a smart-phone based survey with a diary based option and multi-day data collection could work well. The use of smart-phones for data collection is becoming state-of- the practice for large regions with complex travel patterns. The recommended use of a diary based option aligns with TxDOT's findings in Texas and other regions across the U.S. where some households could not or did not wish to participate via the use of a smart-phone and needed to be provided the option of a CATI/paper diary and/or web-based option. It is recommended to further explore and research the combinations of options and how the use of smart-phone and web based methods affects participation among differing populations (older, low-income, non-English/non-Spanish speakers).

   The data-collection plan does not include a "fatal-flaw" analysis to identify gaps and deficiencies of the methods being proposed. These might include typical data errors, participation rates over a multi-day period, technological and network issues etc. Given the innovative methods being proposed, the expense of data collection, and other factors, it is recommended that H-GAC and its consultant review similar recent and ongoing data collection efforts in Chicago, Minneapolis, San Diego, Phoenix, Billings and elsewhere for lessons learned and potential improvements.

RSG Response: RSG has now completed three major smartphone-based surveys (San Diego, Columbus, Seattle), and plan to have at least three more in the field in 2018 (Tampa, Minneapolis, Sacramento). Overall, we have collected smartphone sample in more than fifteen regions to date. We continuously test various options during these surveys, so will be able to "explore and research" the types of issues mentioned above. (We are also examining smartphone-based surveys done by others, to the extent that we can do that.) We do not foresee any "fatal flaws", but we are continually examining how we can fine-tune the recruiting, data collection, and data processing methods over time. The smartphone-based method provides additional route trace data that are not provided by non-GPS methods, so a challenge has been how to process and provide this additional data in a format that will be most useful to the agencies, and we expect this to continue to evolve as agencies develop various ways of using of the additional trace data.

2. **Supplemental Surveys**

   Proposed supplemental surveys include university, toll user, bicycle, Ridehailing/Carsharing services or transportation networking companies (TNC), and attitudinal survey regarding

Connected/Autonomous vehicle (CAV) use. Each has its benefits. Any supplemental surveys should consider the policy goals of the region, existing mode share, and their ability to improve a portion of the model and the improvement's impact relative to other surveys. Considering this, it is recommended that the supplemental surveys be prioritized according to the scale of improvements and policy goals. For example, bike mode share in Houston is less than <0.5% of trips while toll road usage is >7% of regional VMT.

An exception to this recommendation is the CAV attitudinal survey. CAV technology and market penetration is a fact of the future; however, its potential impacts are difficult to measure. Most studies rely on a range of assumptions and "scenarios", an attitudinal survey would help to quantify these assumptions and benefit forecasting methods.

RSG Response: Agree on all points, although in some regions, the public/political interest is in how to increase the bike mode share, rather than on what the mode share is currently. We have included a short set of attitudinal questions about autonomous vehicles in household travel surveys in the Seattle and Jacksonville regions.

3. **Special Generator Surveys**

Proposed special generator surveys include airports, malls and medical centers. As with the supplemental surveys, each has its benefits, and implementation should consider the policy goals of the region, existing mode share, and their ability to improve a portion of the model. It is also recommended to consider the regional transportation plan to determining corridors and transit improvements that might significantly impact/benefit major SGs. The recommendations of the airport survey consider mode choice (e.g. transit access and TNC) as a primary reason for conducting a ground access survey. H-GAC should consider preliminary research into whether transit or the impact of TNCs is as important a factor in the region as in other regions (e.g. Boston Logan). An additional reason cited is to determine trip distribution to/from the airport by employees, regional resident travel and visitor travel. For this it is recommended that passive data (either Cellular or LBS) be investigated in greater detail as a less intrusive means to collect this data while also having the ability to be updated with greater frequency. Other regionally specific SGs to consider include the Medical Center and the Port of Houston.

Like the household survey comments, it is recommended that the data collection plan consider a fatal flaw analysis. For example, with special generators, it is notoriously difficult to obtain optimal access, and often extensive coordination with the facilities is required. Even when all appropriate due diligence has been obtained, it is not uncommon for SG's to back out of commitments.

RSG Response: Agree that interviewer access to special generators is a key factor to consider and scope out early. Airports are very interested in how TNCs will affect them, so collecting that data may be a motivator for them to provide survey access (unless they already have a MOU with Uber and/or Lyft to provide them with data). An additional note is that in the instance of a special generator survey for universities, the cost is typically very low per respondent in our experience. We are also aware that SG's can change or

alter commitments having conducted several military base special generator travel diary surveys. We agree with your point that having a multi-pronged plan or a back-up plan is useful in these situations.

4. **Commercial Vehicle Surveys**

The recommendations consider truck roadside intercept surveys, which are currently not permitted at TxDOT due to safety concerns. Additional recommended data collection includes paper diary and establishment surveys. H-GAC is currently developing a new truck model using passive GPS data. It is unclear how the recommended data collection compliments ongoing model development activities. As is, the recommended data collection would provide informative content about regional truck and freight travel. Accordingly, it is recommended that the data collection plan identify how this would serve current truck model development. If they are not to serve that development, it should describe benefits versus existing state and federal resources, such as FAF and TxDOT's Statewide Analysis Model (SAM) which also provide regional commodity flow information.

It is acknowledged that the recommended establishment surveys provide detail needed to support a truck model, such as expansion variables, frequency, type, and size of deliveries and shipments. However, these data are often a very sparse sample with wide variability and thus limited ability to inform robust truck models in their various forms. Additionally, often lacking in these surveys is concentrated focus on major regional distribution, warehousing, intermodal and port centers as well as detailed inter-regional freight activities versus state and county inter-regional freight activities.

With these considerations it is recommended that freight/truck data collection be prioritized in consideration of ongoing truck model development and existing state and federal resources.

RSG Response: The recommended data collection compliments the passive GPS data used for estimating truck models by providing observed characteristics of shipments, firms and destinations. These characteristics are not available in passive GPS data, so model estimation based only on passive GPS data often include synthesized (rather than observed) variables or have explanatory variables that are left out. Collecting observed characteristics allows the truck models to be more responsive to changes in these characteristics and their responses to transportation investments. Accordingly, commercial vehicle surveys can be used to support the current truck model in several ways: in combination with the passive GPS data to improve model estimation and calibration of location choice models or to provide an independent source for calibration.

The commercial vehicle surveys that TxDOT collects are a strong means of addressing the sparse samples and wide variability found in these data by allowing multiple regions to combine surveys to better understand the behavior of goods movement in the state. The advantages of a larger sample outweigh the disadvantages of have data collected in multiple regions. Our recommendation for future commercial vehicle surveys is to ensure that the survey collects data to support future truck touring models as well as current

trip-based truck models so these can be used to improve truck models across the state, as well as in the Houston-Galveston region.

5. **Abandon Establishment Survey**

The establishment survey for TxDOT's trip-based models are used to produce and balance attraction rates to productions from the HH survey for calibration of the trip generation model. As such these surveys are not designed to the specifications for typical destination choice models used in ABM.

It is a misnomer that cellular data is "aggregate." For the data provider it is "disaggregate" but for data privacy and licensing reasons it is only distributed at aggregate resolutions. Critically, cellular and GPS data are LBS data. LBS is ubiquitous throughout any computing that interacts with a network. In this context LBS data is exclusively from one provider, Cuebiq, whose software development kit (SDK) is imbedded in many mobile device applications. Unlike cellular data, Cuebiq LBS is opt in only – using apps with specific location data needs. Some of these apps may only interact with a Wi-Fi signal, while others may interact with cellular GPS depending on the service. The use of LBS data for model development has risk, because its use is not yet vetted and significant questions remain about what the data represents and best practices for use.

Additionally, page 38 of "LBS trace data" implies that LBS data represents a valid trace of a device's movements. Just like GPS and cellular data, it is very likely that LBS has deficiencies. It has not been shown that the range of LBS tracking on a given device are consistently active and to what degree/persistence they interact with regional Wi-Fi and cellular networks. Accordingly, a given device's activity may be sparse or intermittent i.e. missing origins and destinations.

Page 32 of the report mentions RSG comparing attractions rates from the most recent WP survey to those that can be derived from AirSage data. Can the specific methods and results of this compared be shared?

With these considerations it is recommended that additional details of methodology and benefits for LBS versus establishment surveys for current model development be provided.

RSG Response:

RSG has recently completed a study for FHWA's Travel Model Improvement Program (TMIP) examining LBS data from Cuebiq and benchmarking it against high fidelity travel trace data from RSG's rMove smartphone app in Columbus, OH. The study is titled *The Promise and Limitations of Locational App Data for Origin-Destination Analysis: A Case Study* and is currently under final review by FHWA. It should be publicly available in early 2018; if desired it may be possible to obtain a draft prior to that by contacting the TMIP program manager, Sarah Sun. The study is the basis of many of the recommendations regarding LBS data.

Although the Cuebiq dataset, like all datasets, has its limitations, it compares favorably to other available passive datasets in most every way. The TMIP

study found that the Cuebiq data covered over 8% of the local population, a sample penetration rate comparable to cellular, after accounting for data loss which is far greater in cellular datasets. Roughly 70% of the data points were accurate to better than 50 meters and more than third were precise to 10 meters or better (GPS precision). Although sparsity is an issue, as in all passive data sets, the issue appears much better in the Cuebiq dataset than others. The Cuebiq data had a mean of 127 points per device per day. The median time between points was about 2.5 minutes (147 seconds). The Cuebiq data captured a mean of 4.4 trips per day per device, which is roughly 80% of the 5.4 trips per day per device captured by rMove. Hence, the evidence would suggest that this type of LBS dataset is more complete and precise than available alternatives.

As to the estimation of trip attraction rates, it is theoretically superior if these can be estimated as part of the utility (the size term) of the relevant destination choice model. If this is not feasible, or for purposes of validation, rates may be estimated more simply using regression, controlling for accessibility to trip productions.

6. **External and Non-Resident Travel**

Per the comments in Section 5, LBS is an unvetted source with significant questions about data persistence and penetration. However, risks associated with its development for destination choice models is mitigated by the deficiencies and lack of data needed for the ABM modeling framework. With regard to external travel, in urban areas with high Wi-Fi availability and/or app penetration, Cuebiq may have good app penetration as well as tech savvy users. It is unclear how far this penetration goes for many populations, especially in rural areas where the use of LBS for marketing may be less useful and public Wi-Fi may be scarcer. Additionally, it is unclear how data from LBS can be used to track devices on the move – which is critical for identifying long-distance external travel. Cellular data users, however unsafe, regularly interact with the cell network via data, call, and text events.

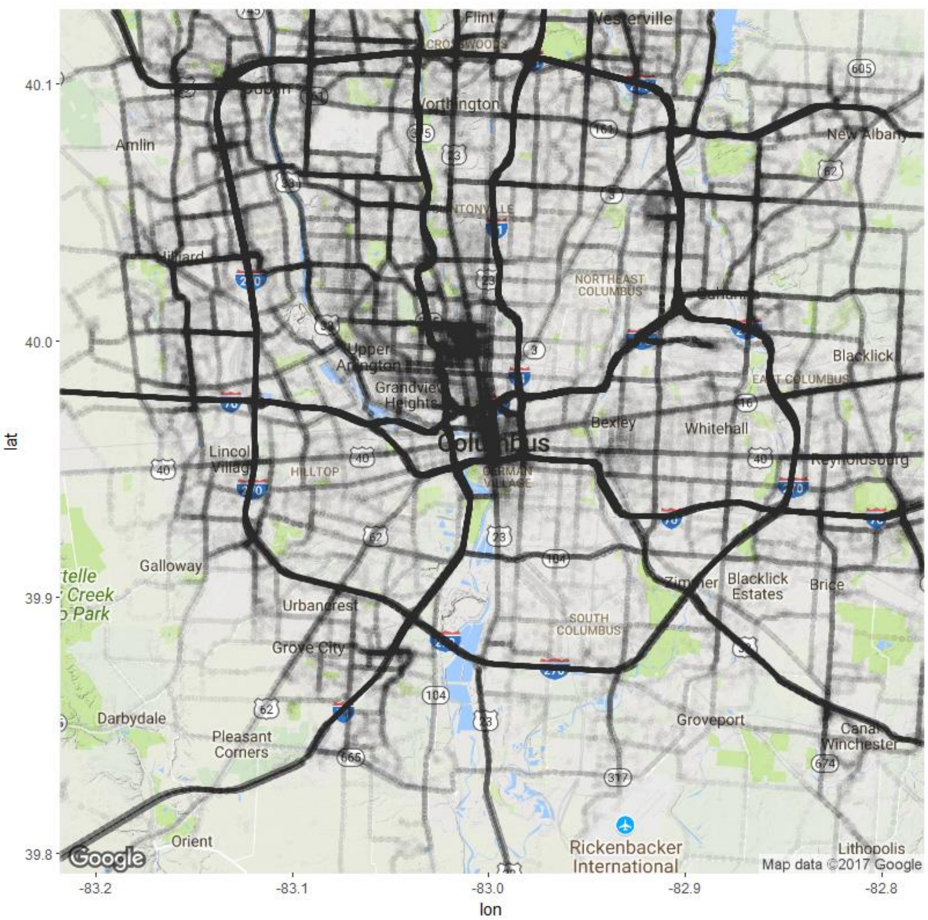
Additionally, the recommendations do not disclose how long a period will be studied using LBS data – is it days, months? What is the proposed external geography? If the main feature of LBS data is its disaggregation will the disaggregate data be provided? For external studies it is critical to locate the travel to appropriate roads of ingress/egress. How does this study propose to do that? Is it based on a simple association of "travel shed/periphery zone" to external roadways?

Based on what is known about current passive data and related products, it appears the current best approach for developing EXT data is using a combination of cell and GPS data – cell for passenger/non-commercial and GPS for commercial/truck. Additionally, this approach develops a detailed geography for the study. This option allows for development of data and matrices on passenger vehicles, several truck categories, resident vs. non-resident travel, visitors, and commuter travel for average week day or weekend and peak periods. It is not known if LBS can develop EXT data for these categories.

Given these considerations it is recommended that H-GAC review the recommendations to use LBS data for external model development and request greater detail of proposed methodologies.

RSG Response:

Comparisons of Cuebiq and INRIX (GPS) external trip patterns by RSG for two MPOs in Indiana showed very high correlation between the two datasets. Moreover, the frequency and precision of observations in the Cuebiq dataset reported above do support tracking devices on the move and allow the identification of trips using particular facilities (at least for the large majority of the dataset, although a less precise subsample may need to be excluded from such analyses). A visualization of a subsample of the Cuebiq dataset for a single day below illustrates the large number of precise location observations of devices en route on facilities. The roadway network is clearly discernable. Given that this is a subset of the data for a single day and analysis would presumably rely on data for at least two weeks if not a month or more, there should be no doubt as to the ability of this dataset to support facility level analyses such as external travel studies (using either well defined catchment zones or pass-through gates on a facility).



The primary advantages of the Cuebiq data being disaggregate are that it allows facility level analyses and disaggregate expansion methodologies. The full disaggregate dataset cannot be provided without adequate privacy protections, but if there it is interest, it may be possible to provide the data in a disaggregate format with some level of spatial aggregation to protect privacy. For instance, origins and destinations may be recorded by census block rather than coordinates and waypoints inside the origin/destination block may be removed.

The Cuebiq data also evidences good ID persistence which allows the imputation of places of residence and work, very much as in cellular datasets, only with more precision. Although there is a significant phenomenon of devices which appear in the dataset for a day or less (e.g., someone downloads an app, uses it once, then deletes it), roughly 75% or better of the devices observed on a particular day persist in the data for multiple weeks, many for multiple months. Thus, the data can support segmentation of external trips by resident/non-resident, and commute/non-commute as well as identify visitor trips by non-residents within the region, just as with cellular data. Truck GPS data is still recommended, however, for developing truck-specific external travel patterns.