2023 UTAH MOVES TRANSPORTATION SURVEY: WEIGHTING METHODOLOGY

July 2025

Prepared for UDOT, UTA, CMPO, Dixie MPO, MAG, and WFRC

Report Title:

2023 Utah Moves Transportation Survey: Weighting Methodology

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Report Prepared for:

The Utah Department of Transportation (UDOT), the Utah Transit Authority (UTA), and Utah's four metropolitan planning organizations: Cache Metropolitan Planning Organization (CMPO), Dixie Metropolitan Planning Organization (Dixie MPO), Mountainland Association of Governments (MAG), and Wasatch Front Regional Council (WFRC)

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EXECUTIVE SUMMARY

This plan documents the weighting and expansion approach used in the Utah Moves Transportation Survey. RSG conducted the Utah Moves Transportation Survey in spring 2023 on behalf of the Utah Department of Transportation (UDOT), the Utah Transit Authority (UTA), and Utah's four metropolitan planning organizations: Cache Metropolitan Planning Organization (CMPO), Dixie Metropolitan Planning Organization (Dixie MPO), Mountainland Association of Governments (MAG), and Wasatch Front Regional Council (WFRC).

The survey aimed to collect complete household data from 8,250 completed households geographically distributed throughout Utah, collected through an address-based sample (ABS). The survey included additional components, including a university supplemental sample with an additional non-ABS target, and a convenience-based sample (CBS) of panel participants.

Following the core travel survey, respondents who agreed to be recontacted were invited to a web-based follow-on survey, including a long-distance travel component. These datasets are weighted separately from the core survey but follow the same methods. Details about sampling approaches can be found in the Sampling Plan.

This document describes the approach to generate weights to expand the survey data to represent Utah's residents across key metrics, such as geography and demographics, that impact travel behavior. The weighting process also corrects for biases related to data collection methods; for example, differences in response due to completing the survey over the phone or on a smartphone app.

The weighting process generates four types of weights:

- **A household-level weight.** The sum of these weights reflects the total households in the survey region.
- **A person-level weight.** The sum of these weights reflects the total persons in the survey region.
- **A day-level weight.** The sum of these weights also reflects the total persons in the survey region (and matches the sum of the person-level weights). The person weights are spread evenly across the number of complete weekdays, so the table represents the sum of one average weekday for each person in the study.
- **A trip-level weight.** The sum of these weights reflects the total trips in the survey region on a typical weekday (i.e., Tuesday, Wednesday, and Thursday).

The survey weighting process includes four primary steps that are covered in more detail throughout this memo:

1) **Initial expansion:** Each household is assigned an initial weight based on its probability of being included in the survey. For example, if 5 households responded in a geography

with 100 total households, each of the 5 households would receive an initial weight of 20 (100 / 5 = 20).

2) **Initial weighting:** After the initial expansion, household weights are adjusted to better fit selected household- and person-level targets, sourced from American Community Survey (ACS) Public Use Microdata Sample (PUMS) data. For example, if 20% of households in the state are one-person households, but 25% of the sample households are one-person households, RSG adjusts the weights to better match the household size distribution of the population. RSG leverages an open-source tool, PopulationSim[1], to match the survey to many demographic targets simultaneously. Initial person weights are derived from the household weights and corrected for the presence of un-surveyed persons (nonrelatives); and, initial day-level weights are derived from person weights and adjusted for the number of days of data collected for each participant.

3) **Reweighting to adjust for non-response bias in day-patterns:** During this step, RSG accounts for survey biases based on the method respondents used to report their travel. RSG uses a model to estimate the number of days with travel to work, school and other locations that would have been captured if all respondents had used the diary platform with the highest reported trip rates (usually smartphone). Along with the original demographic targets, these model estimates are supplied as targets to PopulationSim for a second round of weighting, resulting in new household weights. Person- and day-level weights are re-derived from these household weights as in step 2. These are the final household, person and day weights.

4) **Calculating trip weights:** The final step of weighting is to generate trip weights. Trip weights are first derived from the day weights calculated in step 3 but then are then adjusted with a model that accounts for non-response bias by trip type and survey mode.

TABLE 1 shows how each weight is impacted at each stage in the weighting process.

TABLE 1: WEIGHTS IMPACTED AT EACH STAGE OF WEIGHTING

	Household	Person	Day	Trip
Initial Expansion	x			
Initial Weighting	x	x	x	
Adjusting for Non-Response Bias in Day-Patterns	x	x	x	
Calculating Trip Weights				x

The remainder of this memo expands on the concepts above with specific, practical examples.

[1] https://activitysim.github.io/populationsim/

DATA PREPARATION

This section describes how survey and Census data are processed, made internally consistent, aligned to one another, assigned to relevant geographies, and formatted for expansion and weighting.

SURVEY DATA PREPARATION

Removal of Incomplete Households

RSG removes incomplete households from the survey data for weighting. RSG considered a household complete and eligible for weighting if all members of the household provided complete data on at least one concurrent eligible day of the week. The core dataset uses Tuesday, Wednesday, and Thursday as eligible days. Note that RSG removed additional households for completion based on the quality of their rMove trip traces due to an error with iOS trip tracking during the survey period and households that did not have consistent data for children (proxy data).

Table 2 shows the count of households at every step of data filtering prior to weighting. The initial sample of 11,183 households was reduced to 9,933 households after restricting to households with one complete eligible weekday and removing households with incomplete proxy data for that weekday.

TABLE 2: COUNT OF HOUSEHOLDS AT EACH STAGE OF DATA FILTERING.

SEGMENT TYPE	HOUSEHOLDS UNAFFECTED BY THE IOS TRIP TRACKING BUG	HOUSEHOLDS WITH ONE COMPLETE ELIGIBLE WEEKDAY	HOUSEHOLDS WITH COMPLETE PROXY DATA	HOUSEHOLDS AFTER SAMPLE REASSIGNMENT (SEE BELOW)
Address-Based Sampling	9,676	8,705	8,428	8,454
Convenience-Based Sampling	123	123	123	123
University	1,384	1,382	1,382	1,356
Total	11,183	10,210	9,933	9,933

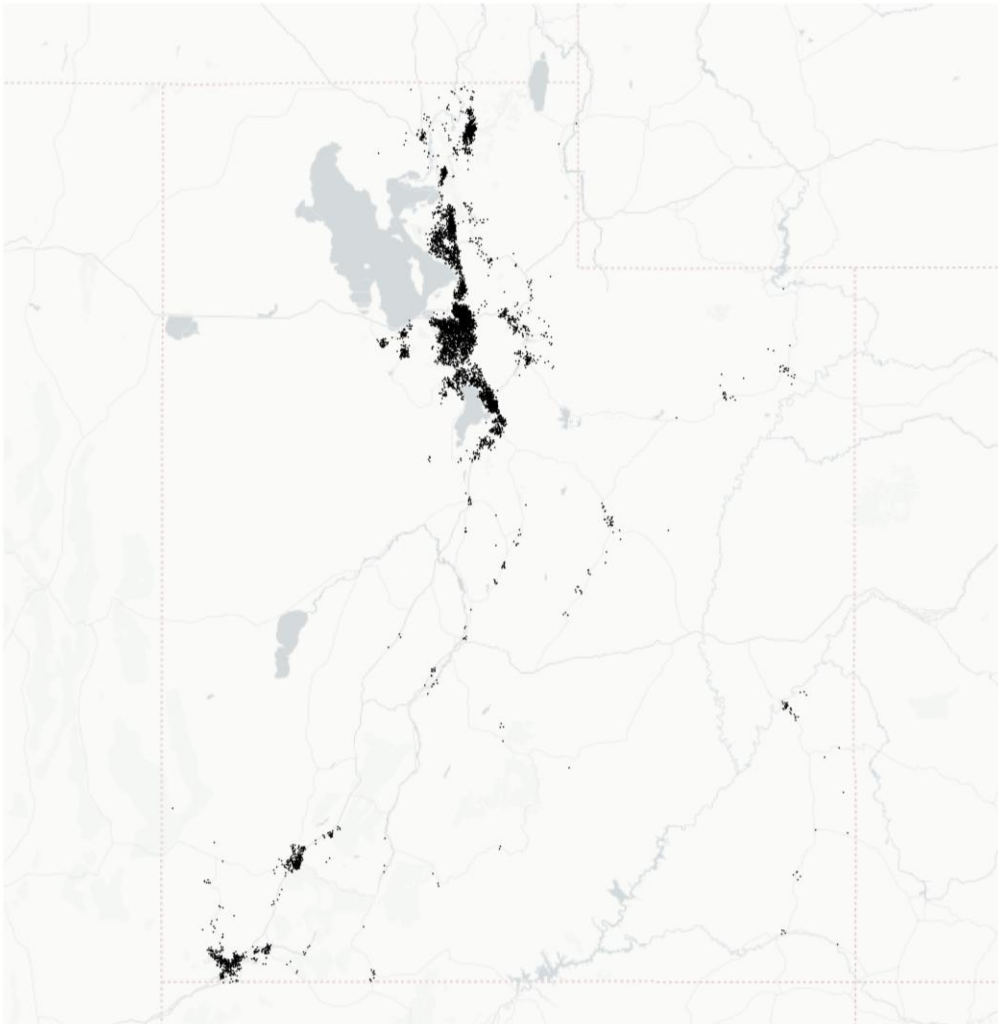
Aligning Household Geographies and Segments to Reported Home Locations

The Utah Moves Transportation Survey used three methods to sample households for data collection:

1. Traditional address-based sampling (ABS) whereby households are invited by mailed invitation.
2. University sampling (UNI) whereby students were invited by email (either from RSG or their college/university).
3. Convenience-based sampling (CBS) whereby residents were invited by email using contact lists from Community Health Workers and UTA.

Household locations are shown in Figure 1. During survey data collection, households are associated with the sampling geography (Figure 2) corresponding to where they received their invitation. The Utah Travel Study used 30 sample segments, each of which was a combination of segment geography (e.g., county) and segment type (Hard-to-Reach, Walk/Bike/Transit, or General). This segment assignment ensures accurate response rate calculations during fieldwork. However, this location does not align with the participant's reported home location for a small share of participants. In the Utah Travel Study, 5.7% of complete ABS households (484 of 8,453 households) reported a home location different from their sampled home location. RSG reassigned these households' home block group and sample segment to their reported home location for weighting (Table 3). RSG also assigned the 123 CBS households to the sample segment that corresponded to their reported home block group (Table 3). This treats the CBS as though they were part of the ABS, which is appropriate given the small share of CBS in the overall sample (1.3% of households). This also satisfies the goal to balance the effects of the ABS and CBS weights.

FIGURE 1: HOUSEHOLD LOCATIONS (JITTERED FOR PRIVACY).



When households were reassigned to their reported home locations, four households ended up in block groups with no Census-recorded households due to users selecting airport addresses as their homes. In such cases, we used the sample home location (the address that received the corresponding invitation) as the home block group instead.

Assigning Households to Weighting Geographies

In addition to a sample segment, households were assigned to their weighting target area. Weighting target areas are regions to which the final survey sample will be expanded and are typically larger than sample segments to ensure sufficient sample size for weighting. Assignment of households to weighting geographies was performed using a simple spatial join.

FIGURE 2: SAMPLE SEGMENT GEOGRAPHIC GROUPINGS (LEFT) AND TYPES (RIGHT).

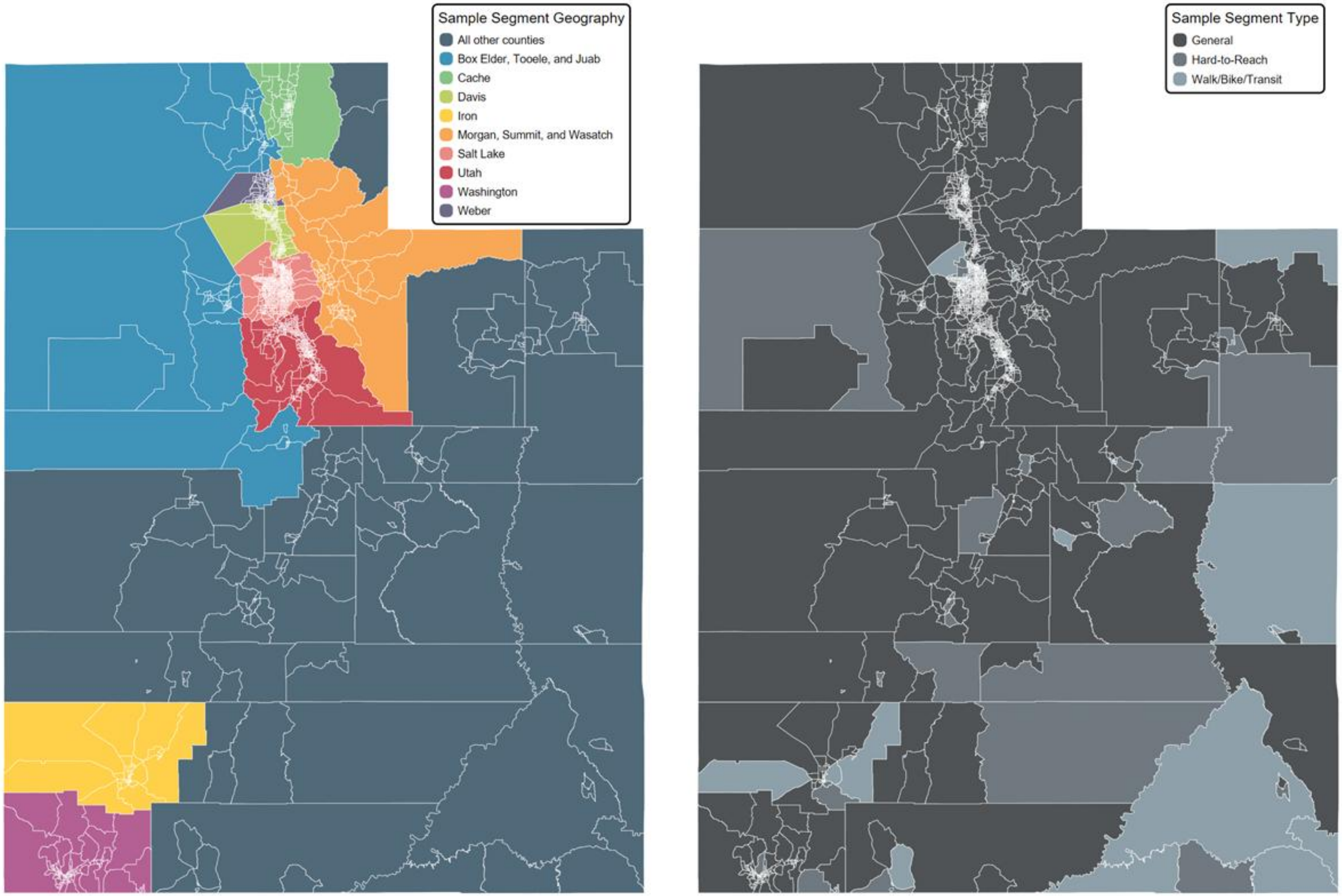
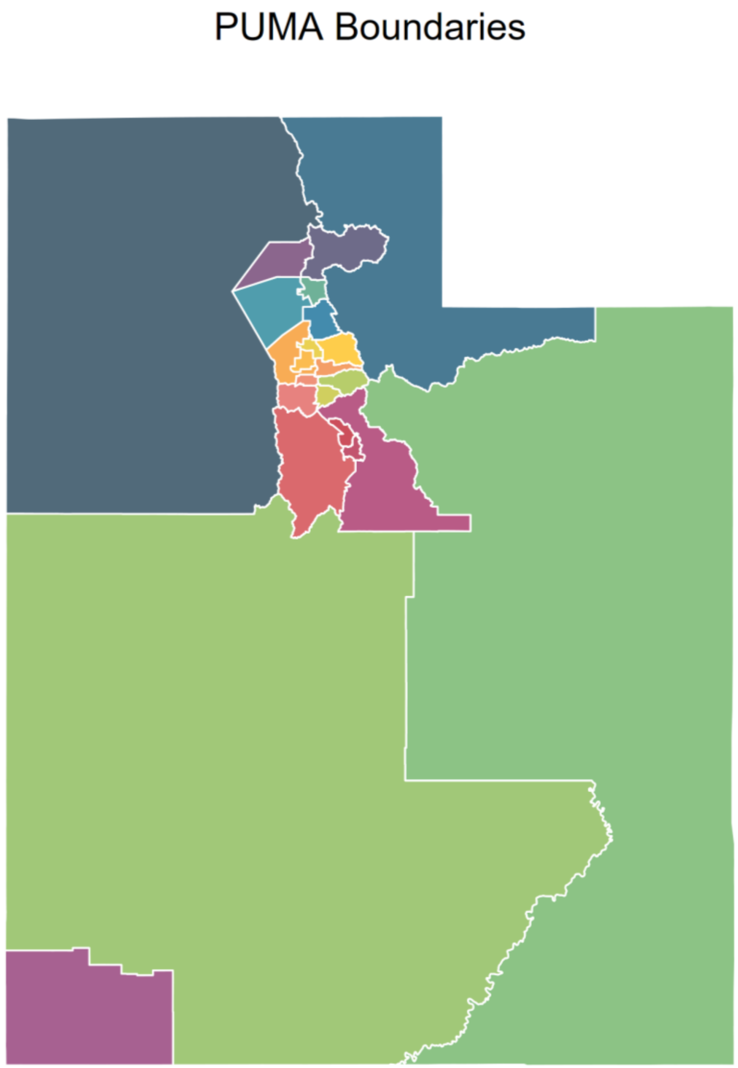


FIGURE 3: PUMA BOUNDARIES (LEFT) AND WEIGHTING GEOGRAPHIES (RIGHT).



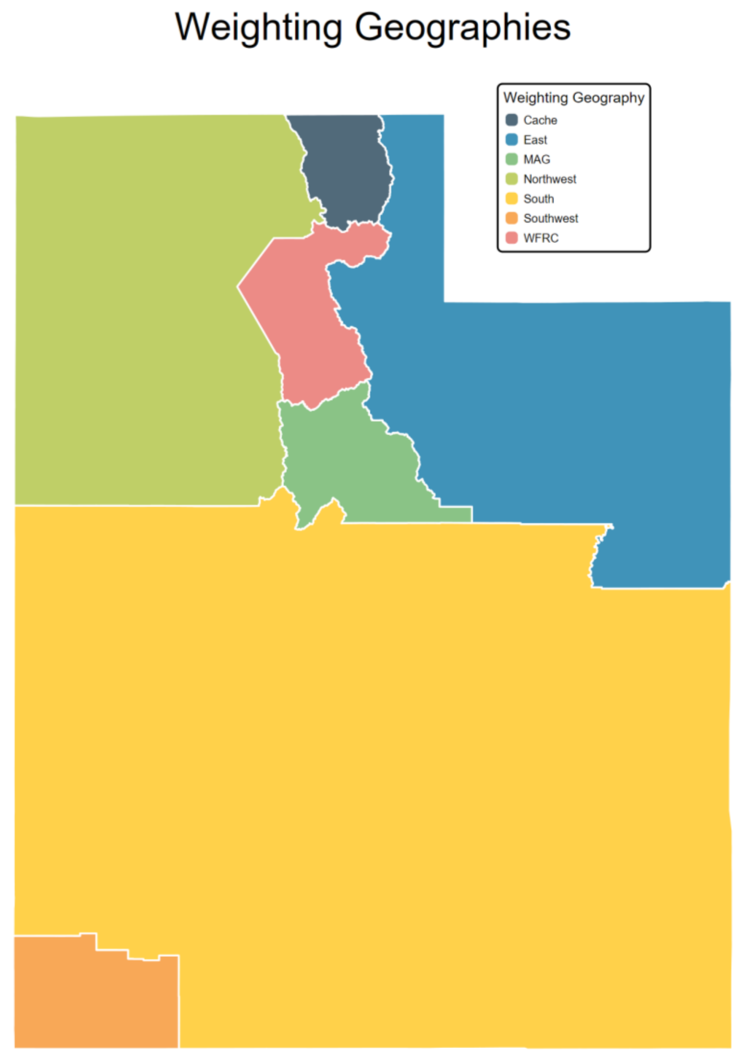


TABLE 3: HOUSEHOLDS BY SEGMENT BEFORE AND AFTER SEGMENT REASSIGNMENT

Geography	Segment Type	Households Before Reassignment	Households After Reassignment
Box Elder, Tooele, and Juab	General	289	305
	Hard-to-Reach	35	35
	Walk/Bike/Transit	64	54
Cache	General	385	383
	Hard-to-Reach	120	122
	Walk/Bike/Transit	170	160
Davis	General	580	610
	Hard-to-Reach	32	33
	Walk/Bike/Transit	96	86
Iron	General	228	215
	Hard-to-Reach	45	53
	Walk/Bike/Transit	56	58
Morgan, Summit, and Wasatch	General	286	281
	Hard-to-Reach	15	17
	Walk/Bike/Transit	18	16
Salt Lake	General	1523	1599
	Hard-to-Reach	656	672
	Walk/Bike/Transit	960	990
Utah	General	987	1011
	Hard-to-Reach	237	221
	Walk/Bike/Transit	234	248
Washington	General	404	404
	Hard-to-Reach	54	56
	Walk/Bike/Transit	92	73
Weber	General	363	384
	Hard-to-Reach	83	73
	Walk/Bike/Transit	202	201
All other counties	General	117	118
	Hard-to-Reach	56	54
	Walk/Bike/Transit	40	44
CBS (Supplemental)*	-	149	
TOTAL		**8,576**	**8,576**

* 26 households signed up via the University recruitment, but had no self-reported University students in them, were moved to the CBS segment for the purposes of weighting.

Selecting University Sample to Be Weighted

Given the project team's goal to create university survey weights that sum to each school's total enrollment, RSG treated the university sample as a person-based survey in weighting. All surveyable[2] university students[3] in the university sample were assigned to the sample segment associated with their invitation (i.e., students who were invited via a Utah State University invitation were assigned to Utah State University). Non-students and non-surveyable household members in university households were retained in the dataset but not weighted. In 26 cases, households were recruited via the University sample but had no self-reported university students within them. For the purposes of weighting, these households were reassigned to the CBS segment (above), then allocated to the appropriate sample segment geography (as described above).

The university sample included respondents from the following schools:

- Brigham Young University
- Snow College
- Southern Utah University
- University of Utah
- Utah State University
- Utah Valley University
- Weber State University
- Westminster College

The project also attempted to survey Salt Lake Community College and Utah Tech but could not collect any responses based on the schools' ability and willingness to participate.

Survey Data Imputation

The income, gender, and ethnicity questions in the survey allowed participants to respond with "prefer not to answer." Additionally, non-related household members (i.e., roommates) were not required to supply their gender, race, or ethnicity; and children were not required to provide their race or ethnicity. To facilitate data weighting, RSG imputed missing values for these variables when a participant was not required to answer or selected "prefer not to answer."

Income Imputation

RSG imputed income using an ordinal regression model. Specifically, we used a proportional odds logistic regression model (POLR), which is designed for predicting ordinal outcomes

[2] Surveyable persons, as with the main survey, were those related to the primary respondent (Person 1).
[3] Respondents who identified as undergraduate or graduate students in their signup survey.

(appropriate for income brackets[4]). The model estimates the probability that an observation falls at or below a particular income bracket, based on the values of the predictor variables.

Missing income was predicted based on a set of independent variables including:

- Income distribution of the block group based on ACS 2023 5-year data, with the median income ($75-100K) used as a reference level.
- Number of non-working adults in the household.
- Number of children in the household.
- Employment status of household members.
- Educational attainment of household members.
- Age of the primary survey respondent.
- Whether the home is owned by the household.
- Whether the household is a single-family home.

The summary of this model is shown below (Table 4). Each coefficient shows the log-odds change of being in a higher income bracket per unit increase in the predictor. A positive coefficient means that as the predictor increases, the household is more likely to fall in higher income brackets. A negative coefficient means it is associated with lower income brackets. Although not all variables were statistically significant (i.e., had large *T*-statistics), they were retained to support the model's predictive performance rather than inference about causal relationships. Variables with the most substantial predictive effects, as suggested by the size and significance of their coefficients, included the household's income distribution within the block group, the number of full-time workers, and home ownership status. The overall fit of the model was modestly strong, with a McFadden's R^2 of 0.187 (McFadden's R^2 values are much lower than traditional R^2 values in linear regression).

[4] https://peopleanalytics-regression-book.org/ord-reg.html

TABLE 4: SUMMARY OF INCOME IMPUTATION MODEL.

Term	Estimate	SE	T STATISTIC	P
Fraction of households in BG earning $0-25K (Census)	-0.19	0.29	-0.65	0.51
Fraction of households in BG earning $25-50K (Census)	-0.09	0.28	-0.33	0.74
Fraction of households in BG earning $50-75K (Census)	-0.02	0.32	-0.07	0.94
Fraction of households in BG earning $100-200K (Census)	1.16	0.27	4.27	<0.01
Fraction of households in BG earning $200K+ (Census)	4.23	0.29	14.77	<0.01
Number of non-working adults in household	0.16	0.03	4.88	<0.01
Number of children in household	0.04	0.02	2.10	<0.01
Number of full-time workers with graduate degree	2.16	0.06	37.50	<0.01
Number of part-time workers with graduate degree	0.77	0.11	7.26	<0.01
Number of full-time workers with bachelor’s degree	1.58	0.05	31.42	<0.01
Number of part-time workers with bachelor’s degree	0.27	0.08	3.57	<0.01
Number of full-time workers without college degree	0.92	0.04	21.72	<0.01
Number of part-time workers without college degree	0.04	0.05	0.77	0.44
Age of primary survey respondent: under 35	-0.25	0.05	-4.98	<0.01
Age of primary survey respondent: over 65	0.22	0.07	3.37	<0.01
Home is owned by household	1.24	0.06	19.93	<0.01
Home is single-family home	0.45	0.06	7.11	<0.01
Under $25,000|$25,000 - $49,999 (Intercept/threshold)	0.53	0.22	2.45	-
$25,000 - $49,999|$50,000 - $74,999 (Intercept/threshold)	2.07	0.22	9.50	-
$50,000 - $74,999|$75,000 - $99,999 (Intercept/threshold)	3.34	0.22	15.21	-
$75,000 - $99,999|$100,000 - $199,999 (Intercept/threshold)	4.43	0.22	19.94	-
$100,000 - $199,999|$200,000 or more (Intercept/threshold)	7.09	0.23	30.65	-

McFadden's R^2: 0.187

Gender Imputation

RSG probabilistically assigned missing gender responses using a Monte Carlo procedure based on the sample data's gender distribution within the respondent's age category. Table 5 provides a summary of the imputation rate for gender across various age categories. The data reveals that post-imputation, there is a higher representation of women than men among adults, but not children. This result stems from using the survey sample to infer gender when the sample itself has a higher proportion of females. Subsequent weighting steps correct for this bias.

TABLE 5: GENDER IMPUTATION RESULTS FOR ADULTS AND CHILDREN IN THE UTAH TRAVEL SURVEY.

Age	Gender	Count before Imputation	Count after imputation	Percent before imputation	Percent after imputation
Children (Under 18)	Female	2,670	2,878	46.5%	50.2%
	Male	2,699	2,858	47.1%	49.8%
	Non-binary	14	0	0.2%	0.0%
	Prefer not to answer	25	0	0.4%	0.0%
	Other/prefer to self-describe	10		0.2%	
	Missing	318	0	5.5%	0.0%
Adults (18 and over)	Female	8,787	9,526	47.6%	51.6%
	Male	8,283	8,925	44.9%	48.4%
	Non-binary	133	0	0.7%	0.0%
	Prefer not to answer	858	0	4.7%	0.0%
	Other/prefer to self-describe	19		0.1%	
	Missing	371	0	2.0%	0.0%

Formatting Survey Data for PopulationSim

The final step in target data preparation is generating survey data tables in PopulationSim input format. Using the processed survey household and person files, RSG tabulates survey data summaries at the level of weighting geographies.

TARGET (CENSUS) DATA PREPARATION

RSG relies on both 5-year ACS estimates and 1-year PUMS ACS data to set weighting targets (Table 6). The 5-year ACS estimates permit a high level of spatial disaggregation (to the block group level), key for both sample planning and creating initial expansion factors (See: Initial Expansion). Complementing the 5-year ACS estimates are 1-year PUMS data which permit detailed crosstabulations by household- and person-level variables. Secondary benefits of the 1-year PUMS data include that the data is more consistent with the survey year(s) and less sensitive to COVID-era distortions.[5] Table 6 below summarizes the source, temporal coverage and purpose of the two types of Census data used in weighting.

TABLE 6: OVERVIEW OF CENSUS DATA USED IN WEIGHTING.

	5-Year ACS Estimates	ACS 1-Year Public Use Microdata Sample (PUMS)
Vintage (Release)	2023	2023
Data Coverage	January 1, 2019 – December 31, 2023	January 1, 2023 – December 31, 2023
General Purpose	Designed for small geographic areas with greater statistical reliability due to cumulative sampling.	Designed for larger geographies, updated population estimates, and detailed, flexible crosstabulations.
Weighting Purpose	Used to spatially allocate the 1-Year PUMS data (right) in alignment with the sample plan, which is constructed at the block group level. This enables initial expansion at the sample segment level.	Used to construct detailed demographic crosstabulations and total population and household estimates suitable for weighting targets.

PUMS Data Preparation

Ahead of weighting, RSG adjusts the ACS PUMS 1-year data used to construct detailed weighting targets. This is performed in a few steps (Table 7).

First, RSG removes group quarters residents from the data, as these were not part of the core survey address-based sampling frame. In the case of the Utah Travel Survey, this adjustment reduced the PUMS-estimated population by 1.62%, from 3,417,734 to 3,362,336 people. The number of households remained the same, because group quarters are not counted as households by the Census.

Next, RSG aligns the PUMS to itself. Importantly, PUMS household and person weights are not self-consistent. That is, the sum of the PUMS household weight times the number of persons (WGTP * NP) is not equal to the sum of the person weights across all persons (PWGTP). This issue is well-known within the Census data users community. To fix this, RSG adjusts the PUMS household weights such that each household in the PUMS file is assigned the average of

[5] https://www2.census.gov/programs-surveys/acs/experimental/2020/documentation/pums/2020AccuracyPUMS.pdf

the person weights of its members. The adjustment tends to be small. For the Utah Travel Survey, this adjustment decreased the PUMS-estimated number of households by 1.47%, from 1,167,589 to 1,150,441 households. The population estimate is not altered by this step.

Allocating PUMS Estimates to Block Groups and Weighting Geographies

The final step of target data preparation is the allocation of PUMS households and persons to (1) sample segments and (2) weighting geographies. The first enables RSG to calculate the initial household expansion factor at the same geographic scale as sampling occurred (see Initial Expansion). The second enables RSG to expand the survey to the geographies used by UTS' modeling team.

Because PUMS and block group boundaries do not align neatly (Figure 3), the process begins with a spatial intersection between the PUMS geographies (Public Use Microdata Areas, or PUMAs) and block group geographies. The fraction of each PUMA that overlaps with each block group is calculated using a spatial crosswalk. This fraction is used to proportionally allocate the PUMS households to each block group. The total number of households is then aggregated to the 30 sample segments (See Table 10). At this stage, small discrepancies can arise due to rounding errors in proportional allocation; in the case of Utah, the sum of the household estimate decreased by 2 households (Table 7).

Next, RSG repeats the process for weighting geographies. This time, both PUMS households and persons are allocated proportionally.

TABLE 7: TOTAL PUMS-ESTIMATED HOUSEHOLDS AND PERSONS AT EACH STEP OF PRE-PROCESSING.

STEP	HOUSEHOLD ESTIMATE (SUM OF WGTP)	POPULATION ESTIMATE (SUM OF PWGTP)
Initial PUMS file	1,167,589	3,417,734
Remove Group Quarters Residents	1,167,589 (no change)	3,362,336 (-1.62%)
Align PUMS to itself	1,150,441 (-1.47%)	3,362,336 (no change)
Allocate PUMS to Sample Segments	1,150,439 (<0.001%)	Not required for initial expansion
Allocate PUMS to Weighting Target Areas	1,150,441 (no change)	3,362,336 (no change)

Weighting Target Summation

Different household and personal attributes affect survey response, which presents bias in unweighted survey data. For example, larger households may be less likely to respond due to the additional time needed to complete the survey questions and travel diaries for each member. To correct these types of biases, RSG selected a variety of household- and person-level target categories as weighting targets.

Total Population Targets

RSG uses a set of total population and household estimates for each weighting geography so that final weighted totals of households and persons match expected population totals. These targets, derived from the adjusted and spatially allocated PUMS data (described above) are shown below (Table 8).

TABLE 8: TOTAL HOUSEHOLDS AND POPULATION TARGETS FOR EACH WEIGHTING GEOGRAPHY.

WEIGHTING GEOGRAPHY	HOUSEHOLDS	PERSONS
Cache	45,873	135,675
East	54,175	154,580
MAG	207,864	704,592
Northwest	45,850	143,927
South	76,583	216,559
Southwest	72,037	199,714
WFRC	648,059	1,807,290
Total	**1,150,441**	**3,362,336**

Demographic Targets

Once RSG set the total population and household targets, the 2023 ACS Public Use Microdata Sample (ACS PUMS) was used to determine the target proportion of each weighting category.

Table 9 shows the weighting categories and estimates for one weighting geography, Cache County, as an example. Note that household-level estimates will always add to 45,873, and the person-level estimates for each target always sum to 135,675, corresponding to those household and population estimates shown above in Table 8.

Formatting Target Data for PopulationSim

The final step in target data preparation is generating a table of targets in PopulationSim's chosen format. Leveraging the processed PUMS household and person files, RSG tabulates targets summaries at the level of weighting target geographies.

TABLE 9: HOUSEHOLD- AND PERSON-LEVEL TARGETS FOR CACHE COUNTY WEIGHTING GEOGRAPHY.

TARGET	TARGET CATEGORY	ESTIMATE	UNIT
Household Size	1 person	7,471	households
	2 persons	15,628	
	3 people	7,931	
	4 people	6,085	
	5+ people	8,757	
Household Income	$0-$24,999	4,210	
	$25,000 - $49,999	7,575	
	$50,000 - $74,999	5,997	
	$75,000 - $99,999	6,177	
	$100,000 - $199,999	14,161	
	$200,000 or more	7,753	
Number of Workers	0 workers	7,645	
	1 worker	14,496	
	2 or more workers	23,732	
Number of Vehicles	None	1,137	
	Fewer vehicles than adults	7,057	
	Vehicles greater than or equal to number of adults	37,678	
Number of Children	0 children	27,945	
	1 or more children	17,927	
Gender	Female	68,955	persons
	Male	66,720	
Age	0 to 4	9,660	
	5 to 15	24,540	
	16 to 17	4,626	
	18 to 24	18,153	
	25 to 44	35,638	
	45 to 64	27,106	
	65 or older	15,953	
Employment	Non-worker	64,742	
	Part-time worker	21,623	
	Full-time worker	49,309	
Commute Mode	Travels to Work (Bike, Walk, Drive, Transit, Other)	55,820	
	Works from Home	13,918	
	None	65,937	
University Student Status	Not a university student	123,381	
	University student	12,294	
Educational Attainment	No college	62,578	
	At least some college	73,097	
Ethnicity	Not Hispanic	120,655	
	Hispanic	15,020	

INITIAL EXPANSION

The first step of the weighting process is to calculate an initial expansion factor for each respondent based on their probability of being included in the final sample. The initial expansion factor serves as a first “guess” for the entropy maximization weighting engine, PopulationSim.

INITIAL EXPANSION OF ABS AND CBS SAMPLE

The address-based and convenience-based (ABS and CBS) initial expansion factor was calculated by taking the inverse of the probability of inclusion in the study. One expansion factor was calculated for each of the 30 Sample Segments (Figure 2).

The probability of inclusion is determined by multiplying the probability of selection by the probability of response.

$$P_{selection} = \frac{m}{H}$$

$$P_{response} = \frac{R}{m}$$

$$P_{inclusion} = P_{selection} \times P_{response} = \frac{m}{H} \times \frac{R}{m} = \frac{R}{H}$$

Where *m* is the number of mailed invites, *R* is the number of responses (complete households), and *H* is the total number of households in the segment (estimated from adjusted 5-year ACS data; see Allocating PUMS Estimates to). Thus, the initial expansion factor calculation for a given segment (IW_s) can be calculated as the total number of households in a segment (H_s) divided by the number of households that complete the survey in the same segment (R_s), or

$$IW_s = \frac{1}{P_{inclusion}} = \frac{H_s}{R_s}$$

For example, if segment A contains 100 households and the survey collected responses from 5 households (H_s), each household in that segment would have an initial weight of 20 (100 / 5 = 20).

Table 10 contains the initial expansion factors RSG developed for each sampling segment.

TABLE 10: INITIAL EXPANSION FACTORS BY SAMPLE SEGMENT (ADDRESS-BASED SAMPLE)

SAMPLE STRATUM	SAMPLED HOUSEHOLDS	TARGET	INITIAL EXPANSION FACTOR
All other counties-General	118	49,434	418.93
All other counties-Hard-to-survey	54	18,571	343.92
All other counties-Walk/Bike/Transit	44	6,522	148.23
Box Elder, Tooele, and Juab-General	305	42,316	138.74
Box Elder, Tooele, and Juab-Hard-to-survey	35	3,941	112.61
Box Elder, Tooele, and Juab-Walk/Bike/Transit	54	3,431	63.53
Cache-General	383	32,831	85.72
Cache-Hard-to-survey	122	6,260	51.31
Cache-Walk/Bike/Transit	160	6,781	42.38
Davis-General	610	106,159	174.03
Davis-Hard-to-survey	33	4,201	127.3
Davis-Walk/Bike/Transit	86	8,828	102.65
Iron-General	215	13,051	60.7
Iron-Hard-to-survey	53	4,002	75.51
Iron-Walk/Bike/Transit	58	2,808	48.41
Morgan, Summit, and Wasatch-General	281	33,223	118.23
Morgan, Summit, and Wasatch-Hard-to-survey	17	1,278	75.15
Morgan, Summit, and Wasatch-Walk/Bike/Transit	16	1,270	79.35
Salt Lake-General	1,599	270,729	169.31
Salt Lake-Hard-to-survey	672	88,065	131.05
Salt Lake-Walk/Bike/Transit	990	74,444	75.2
Utah-General	1,011	174,455	172.56
Utah-Hard-to-survey	221	17,614	79.7
Utah-Walk/Bike/Transit	248	15,795	63.69
Washington-General	404	60,993	150.97
Washington-Hard-to-survey	56	5,930	105.9
Washington-Walk/Bike/Transit	73	5,114	70.05
Weber-General	384	68,192	177.58
Weber-Hard-to-survey	73	11,594	158.82
Weber-Walk/Bike/Transit	201	12,607	62.72
Total	**8,576**	**1,150,439**	

EXPANSION OF UNIVERSITY SAMPLE

RSG calculated targets for the university sample separately from the main survey because data for these students were not available at the same level of detail as the PUMS data for ABS and CBS. The university sample targets (Table 11) were based on enrollment figures provided by the schools or as reported online (if schools did not provide enrollment figures directly). For each school in the university sample, RSG calculated the respondents' person-weight as the school student enrollment divided by the number of surveyed students among university respondents.

$$\textit{University Weight}_{school} = \frac{\textit{Enrollment}_{school}}{\textit{Responses}_{school}}.$$

For example, if a university has an enrollment of 1,000 students, and the survey collected responses from 100 students from that university, then each person for that university would have a person weight of 10 (1,000 / 100 = 10). Note that RSG created two sets of university weights – one set that represents each school individually regardless of sample size and a second that combines schools with small sample sizes to better represent university students throughout the state ("aggregated"). This second set combines Utah Valley University and Weber State University and combines student types within those schools. The second set also combines all student types in Westminster University.

These person-level weights were used to derive household, day and trip weights as follows. For household weight, RSG used the first non-zero person weight among household members. (Because all persons within a household were weighted the same, this could have been an average weight). This means that the total of the household weight for a university segment reflects the estimated number of unique households belonging to that segment. To derive day weights while controlling for multi-day diary data, RSG first applied the person-weight to complete person-days, then divided this day weight by the number of complete person-days in the persons' diary. Trip weights were set equal to their respective day weight.

After this simple expansion, no additional weighting or bias correction was performed on the University sample.

The remainder of this memo deals with the Address-Based and Convenience-Based Samples only.

TABLE 11: UNIVERSITY SAMPLE SIZES, TARGETS AND FINAL WEIGHTS

University	Segment[6]	Unique Households	Surveyable University Students[7]	Other Household Members	Enrollment Target	Person Weight	Enrollment Target Aggregated	Person Weight Aggregated
Brigham Young University	UG On-Campus	78	99	187	6,908	69.78	6,908	69.78
	UG Off-Campus	209	278	356	24,493	88.10	24,493	88.10
	Graduate	53	74	79	3,053	41.26	3,053	41.26
Snow College	UG On-Campus	23	23	39	478	20.78	478	20.78
	UG Off-Campus	55	60	131	2,708	45.13	2,708	45.13
	Graduate	0	0	0	0	N/A	0	N/A
Southern Utah University	UG On-Campus	5	6	14	1,012	168.67	1,012	168.67
	UG Off-Campus	114	134	212	11,637	86.84	11,637	86.84
	Graduate	14	18	16	1,681	93.39	1,681	93.39
University of Utah	UG On-Campus	43	45	34	4,564	101.42	4,564	101.42
	UG Off-Campus	186	221	290	31,481	142.45	31,481	142.45
	Graduate	141	158	186	10,021	63.42	10,021	63.42
Utah State University	UG On-Campus	92	109	167	2,991	27.44	2,991	27.44
	UG Off-Campus	202	244	388	12,500	51.23	12,500	51.23
	Graduate	81	96	114	1,784	18.58	1,784	18.58
Utah Valley University	UG On-Campus	0	0	0	0	N/A	56,118	863.35
	UG Off-Campus	8	12	7	25,424	2,118.67		
	Graduate	2	4	5	780	195.00		
Weber State University	UG On-Campus	3	3	5	1,156	385.33		
	UG Off-Campus	35	43	63	27,747	645.28		
	Graduate	3	3	5	1,011	337.00		
Westminster University	UG On-Campus	3	4	3	307	76.75	1,177	107.00
	UG Off-Campus	6	6	12	590	98.33		
	Graduate	1	1	0	280	280.00		
Total		**1,357**	**1,641**	**2,313**	**172,606**		**172,606**	

[6] UG = Undergraduate
[7] A surveyable person is a household member who is related to person 1

INITIAL WEIGHTING (ABS AND CBS ONLY)

After creating the initial weights to account for each household's likelihood of being sampled, RSG conducted a reweighting process to adjust for non-response bias across geographies and demographics. Non-response bias refers to biases in the unweighted data that occur because different types of people respond to surveys at different rates.

This step was not performed on the University sample.

INITIAL HOUSEHOLD WEIGHTS

Using the geographies and targets outlined earlier in the memo, RSG adjusted the initial weights using an entropy-maximization (EM)[8] algorithm using PopulationSim. This approach is beneficial because it reduces the variance in the final weights, which in turn reduces the margins of error when using the weighted data. Note the core version of PopulationSim uses a randomization approach to transform fractional data into integers for population synthesis. RSG's weighting method uses a version of PopulationSim that does not transform fractional data into synthetic population counts as integers. Thus, replicate weighting runs will produce identical results.

PopulationSim weighting is performed twice during weighting; at this stage (to retrieve initial weights) then again after adjusting for non-response bias in day-patterns and trip rates (See: Final Weighting).

To demonstrate how this step impacts the weights, consider the example in Table 12. If there were only a single weighting geography with only a single target (e.g., household size), this step would simply adjust the initial weights such that the distribution of the adjusted weights match the distribution of the targets.

In this example, assume each of 5 households has an initial weight of 20.0 and a distribution of household sizes as follows:

- 40% of households have 1 member
- 40% of households have 2 members
- 20% of households have 3 members

The distribution of household sizes in the target population is as follows:

- 20% of households have 1 member

[8] For more information, see Multi-level Population Synthesis Using Entropy Maximization-Based Simultaneous List Balancing by Paul et al. (2018).

- 40% of households have 2 members
- 40% of households have 3 members

The initial weight for households with a size of 1 would be scaled down to match the targets, and initial weights for households with a size of 3 would be scaled up to match the targets.

The maximum entropy method achieves a similar outcome but addresses multiple targets at once.

TABLE 12: EXAMPLE WEIGHTS AFTER REWEIGHTING

	Household Size	Initial Household Weight	Household Weight After Reweighting
Household 1	1	20.0	10.0
Household 2	2	20.0	20.0
Household 3	1	20.0	10.0
Household 4	2	20.0	20.0
Household 5	3	20.0	40.0

Optimizing Weighting Constraints

There is no one “correct” weighting solution, but rather a balance between two (sometimes competing) goals:

1. Fit the survey data as closely as possible to the Census target data.
2. Minimize variance in the weights to avoid overly high, low, or skewed weights.

In addition to these goals, RSG aimed to use geographic segmentation compatible with the zones required for modeling and demographic targets with as much detail as possible to force the weighted survey population to match the Census on many axes.

To find the optimal solution that met these goals, RSG iteratively adjusted the weighting constraints and targets to find the optimal solution during weighting. These iterations are described below. The team continued further testing on day patterns and trip rate adjustments to ensure robust weights, described in a separate section (See: Adjusting for non-response bias in day-patterns).

Demographic Target Consolidation

RSG started by evaluating the fit of the data to targets and consolidated target categories to help improve fit. RSG prioritized targets and target categories that had low sample size within the survey data or large error margins around the Census target estimates.

RSG made the following changes to demographic targets, in order:

1. Consolidated the number of categories for the number of workers in the household, capping the top category at “2 or more workers” rather than “3 or more workers.”
2. Consolidated categories for household vehicle ownership for one weighting geography (North), where zero-vehicle households were rare in both Census and UTS data.
3. Consolidated income categories in the Cache geography to top-code the highest income bracket at “$100,000 or more” rather than “$200,000 or more.”
4. Consolidated categories for commute mode in geographies other than WFRC and MAG. Low sample size in both Census and UTS data for modes of transportation to work other than driving resulted in wide error margins on the Census estimates and poor fit to targets in Cache, East, Northwest, South, and Southwest geographies. In the Cache weighting geography, walk, bike and transit were consolidated into a single “nonmotorized” commute mode category. In East, Northwest, South, and Southwest weighting geographies, commute mode categories were consolidated even further to does not work, works from home, and travels to work (akin to worker type variable).
5. Targets for race were first consolidated to “White” and “Non-White.” When this still resulted in extreme uncertainty around the Census estimates and poor fit to targets, RSG set race as a statewide target rather than fitting targets for each weighting geography. When this still did not result in a satisfactory fit, targets for race were altogether removed. Targets for ethnicity (Hispanic / Not Hispanic) were retained.

Though in some cases demographic targets could be further grouped to improve the measured fit to targets, RSG advises against reduction for two primary reasons:

- No further grouping would be logical given the intended use of the data (e.g., it may not be useful to group “walk” with “transit”).
- Further grouping would not change the underlying weights and therefore could present a false impression of fit where data users should instead exercise caution (e.g., understanding the limitations of certain analyses).

TABLE 13: CENSUS TARGETS, BEFORE AND AFTER CONSOLIDATION.

UNIT	CENSUS TARGET VARIABLE	INITIAL TARGET CATEGORIES	FINAL TARGET CATEGORIES
Household	**Household Size**	1-person 2-person 3-person 4-person 5-person or more	1-person 2-person 3-person 4-person 5-person or more *(no change)*
	Income ***(Imputed if non-response)***	Under $25,000 $25,000–$49,999 $50,000–$74,999 $75,000–$99,999 $100,000–$199,999 $200,000 or more	*Cache:* Under $25,000 $25,000–$49,999 $50,000–$74,999 $75,000–$99,999 $100,000 or more *(consolidated categories)* *All other target areas:* *No change*
	Workers	0 workers 1 worker 2 workers 3 or more workers	0 workers 1 worker 2 or more workers *(reduced categories)*
	Vehicles	No vehicles Fewer vehicles than drivers Vehicles greater than or equal to drivers	*North weighting geographic area:* No vehicles or fewer vehicles than drivers Vehicles greater than or equal to drivers *All other weighting geographic areas:* *No change*
	Presence of Children	0 children 1 or more children	0 children 1 or more children *(no change)*
Person	**Gender** ***(Imputed if non-response)***	Male Female	Male Female *(no change)*
	Age	Under 5 5–15 years 16–17 years 18–24 years 25–44 years 45–64 years 65 years or older	Under 5 5–15 years 16–17 years 18–24 years 25–44 years 45–64 years 65 years or older *(no change)*
	Worker Status	Full-time worker Part-time worker Non-worker	Full-time worker Part-time worker Non-worker *(no change)*
	Commute Mode	Work from home Walk Bike Transit Drive or Other Not applicable	*East, Northwest, South, Southwest:* Work from home Travels to work (all modes) Not applicable *(reduced categories)* *Cache:* Works from Home Walk, Bike, Transit Drive or other Not applicable *(reduced categories)* *MAG and WFRC:* *No change*

University Student Status	University student Not a university student	University student Not a university student *(no change)*
Educational Attainment	Some college education No college education	Some college education No college education *(no change)*
Race ***(Imputed if non-response)***	African American Asian/Pacific White Other	*Dropped target variable*
Ethnicity ***(Imputed if non-response)***	Hispanic Non-Hispanic	Hispanic Non-Hispanic *(no change)*

Sensitivity Analysis: Maximum Expansion Factor and Maximum Weight

After consolidating or removing demographic targets with poor sample size and/or fit, RSG searched for the optimum constraints to put on PopulationSim, namely, the maximum expansion factor (the ratio between the initial expansion factor and initial weight) and the maximum weight cap (the absolute maximum weight). RSG performed a sensitivity analysis by re-running initial weighting with maximum expansion factors between 2 and 8 (in increments of 1) and maximum weight caps between 400 and 800 (in increments of 100). For each run, the corresponding minimum expansion factor was set as the reciprocal of the maximum expansion factor (1/2 to 1/16).

RSG evaluated the resulting weights across all 35 runs for their fit to targets, the variance of the weights, and the distribution of the weights.

For a measure of variance, RSG used the coefficient of variation (CV), which provides a normalized, scale-free measure of how much the weights vary relative to their means:

$$CV = \frac{Standard\ Deviation\ of\ Weights}{Mean\ of\ Weights} x\ 100$$

As a measure of fit to target, RSG evaluate the Mean Absolute Percentage Error (MAPE), which represents the represents the average relative error between the weighted estimates and the target values across all target variables:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Weighted\ Estimate_i}{Target_i}\right| \times 100$$

To evaluate the distribution of the weights, RSG used both visual inspection of the weight distributions and Hartigan's Dip Statistic (*D*), a nonparametric measure of unimodality that quantifies the extent to which a distribution deviates from having a single peak. In the context of weight diagnostics, a higher dip statistic indicates potential clumping or multimodality in the weight distribution (usually at the upper and lower bounds enforced by the minimum/maximum expansion factors and absolute bounds). Lower values suggest a smoother, more unimodal distribution, which is desirable for reducing variance and ensuring stable population estimates. A *D*-value greater than 0.10 suggests strong multi-modality.

Figure 4 illustrates the trade-offs involved in selecting maximum expansion factors and weight caps within the PopulationSim weighting process. Three diagnostics are shown: target fit (MAPE), weight variability (coefficient of variation, CV), and distribution modality (Dip Statistic ×100). Each diagnostic is plotted against maximum expansion factor, with separate lines representing different maximum weight caps.

The first panel shows that fit error (MAPE) declines sharply as the maximum expansion factor increases from 2 to approximately 5, across all weight caps. Beyond expansion factor 5, improvements in fit become marginal, as indicated by the flattening of the curves. Weight caps exert a clear influence: lower caps (e.g., 400) consistently produce higher MAPE, indicating poorer fit due to tighter restrictions on weight magnitude. Conversely, higher caps (e.g., 800) permit lower MAPE, as they allow more flexibility in matching the control totals.

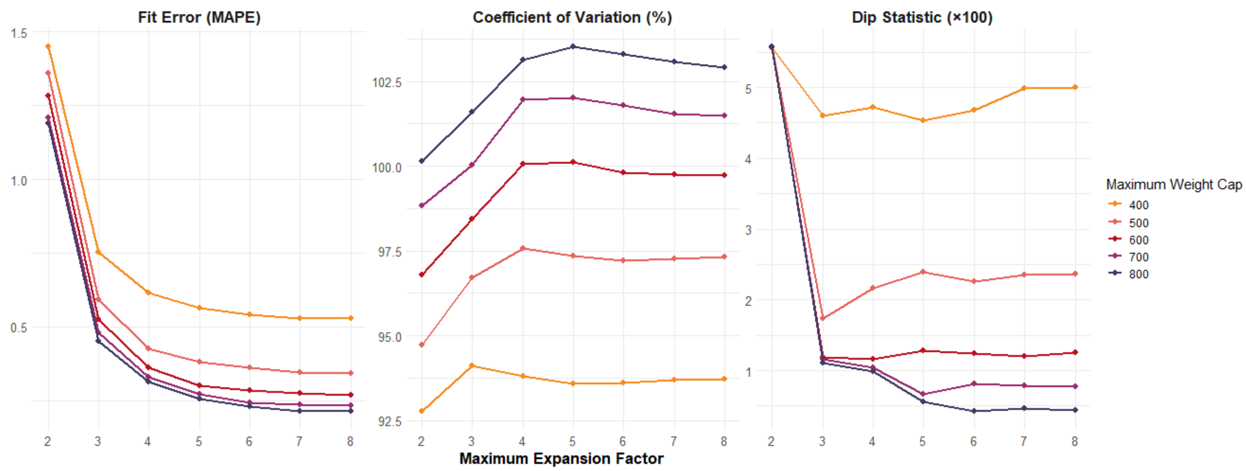
The second panel depicts the coefficient of variation (CV) of household weights. CV rises rapidly with increasing expansion factor between factors 2 and 4, then stabilizes. Higher weight caps consistently result in higher CV levels, reflecting greater variability in the resulting weights. Notably, CV values are already high (above 90%) even at lower expansion factors, suggesting substantial weight dispersion across all scenarios. This indicates that achieving low variability is difficult without severely compromising fit.

The third panel presents the Dip Statistic, measuring modality of the weight distribution. High Dip Statistic values at low expansion factors suggest multimodal or irregular weight distributions. These values fall sharply after expansion factor 3 and remain low beyond that point, indicating that the weight distributions stabilize into unimodal forms at moderate-to-high expansion factors. Weight cap levels appear to have minimal influence once the expansion factor exceeds 3.

In combination, these results reveal clear bias–variance trade-offs in weight calibration. Increasing the expansion factor improves fit but exacerbates weight variability. Similarly, loosening the weight cap permits better fit but introduces greater variability. The modality of weights (as assessed by the Dip Statistic) improves consistently with higher expansion factors, stabilizing early in the process.

Considering all diagnostics, expansion factors in the range of 4 to 5 appear to offer a reasonable balance between fit and variance. At these levels, MAPE is sufficiently low, weight variability begins to stabilize, and unimodal weight distributions are consistently achieved. Choices around weight cap depend on tolerance for high weights: higher caps improve fit but at the cost of greater weight concentration.

FIGURE 4: FIT ERROR (MAPE) VARIANCE (CV) AND MULTIMODALITY (DIP STATISTIC) OF WEIGHTS BY MAXIMUM EXPANSION FACTOR AND MAXIMUM WEIGHT CAP



In addition to the diagnostics summarized above, Figure 5 provide insights into the distribution of household weights across different weighting geographies. Each panel represents a weighting geography, and within each, household weight distributions are displayed for varying maximum weight caps. These plots highlight how both the capping strategy and geographic zone influence weight dispersion and concentration.

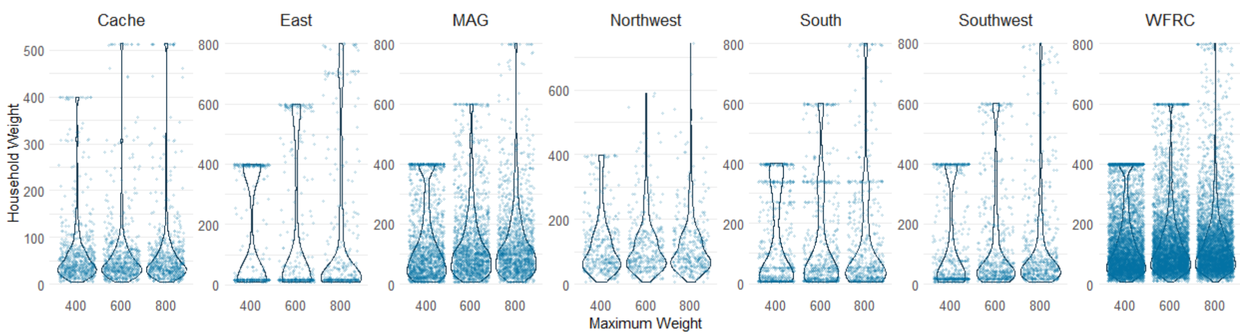
Across most regions, a characteristic pattern emerges: at lower weight caps (e.g., 400), weights are tightly clustered around lower values, with relatively few extreme weights. However, as the maximum cap increases to 800, distributions broaden substantially, with long upper tails evident in some regions (such as MAG, WFRC, and Northwest). This indicates that permitting higher caps results in a small number of very large weights, which drives up both the coefficient of variation and the concentration of survey influence among a few households.

The plots also reveal regional variation in how weights respond to capping strategies. In zones like Cache and Northwest, the distributions remain relatively narrow and evenly distributed across all caps, suggesting that population control targets can be met without resorting to extreme weights. Conversely, in areas with lower sample size or poorer survey sample representativeness like East, South, or Southwest, lower weight caps result in a strongly bimodal distribution of weights as a handful of observations attempt to represent a larger and larger share of the population.

Together, these distributional insights reinforce the earlier findings. While loosening caps allows PopulationSim to improve target fit (as indicated by reduced MAPE), it does so by permitting the creation of large outlier weights in certain regions. Conversely, when caps are set too low, PopulationSim lacks the flexibility to adjust weights sufficiently to align the survey sample with control totals. As a result, the model is forced to assign many households the same constrained weight, limiting its ability to represent population diversity. This manifests as inflated fit errors

(MAPE) and narrow weight distributions concentrated at the cap boundary, as seen in the violin plots for lower cap scenarios. Effectively, restrictive caps prevent the model from utilizing available sample information to meet population controls, leading to underfitting and potential bias in downstream estimates. Balancing flexibility (higher caps) with control (limiting extreme weights) is thus critical to preserving the representativeness and analytical value of the weighted survey data.

FIGURE 5: DISTRIBUTION OF INITIAL HOUSEHOLD WEIGHTS BY WEIGHTING GEOGRAPHY FOR MAXIMUM WEIGHTS OF 400, 600 AND 800 AT A MAXIMUM EXPANSION FACTOR OF 4.

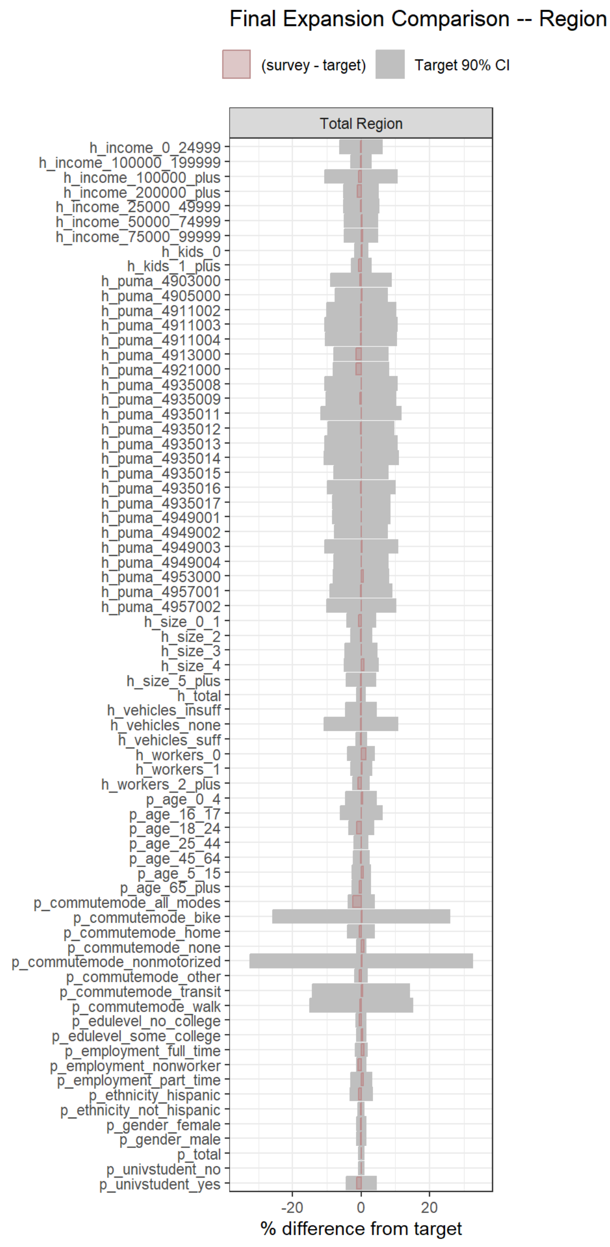


Considering the tradeoffs between variance, fit, and weight distributions, RSG ultimately selected a maximum weight cap of 600 and a maximum expansion factor of 4.

Results of Initial Weighting

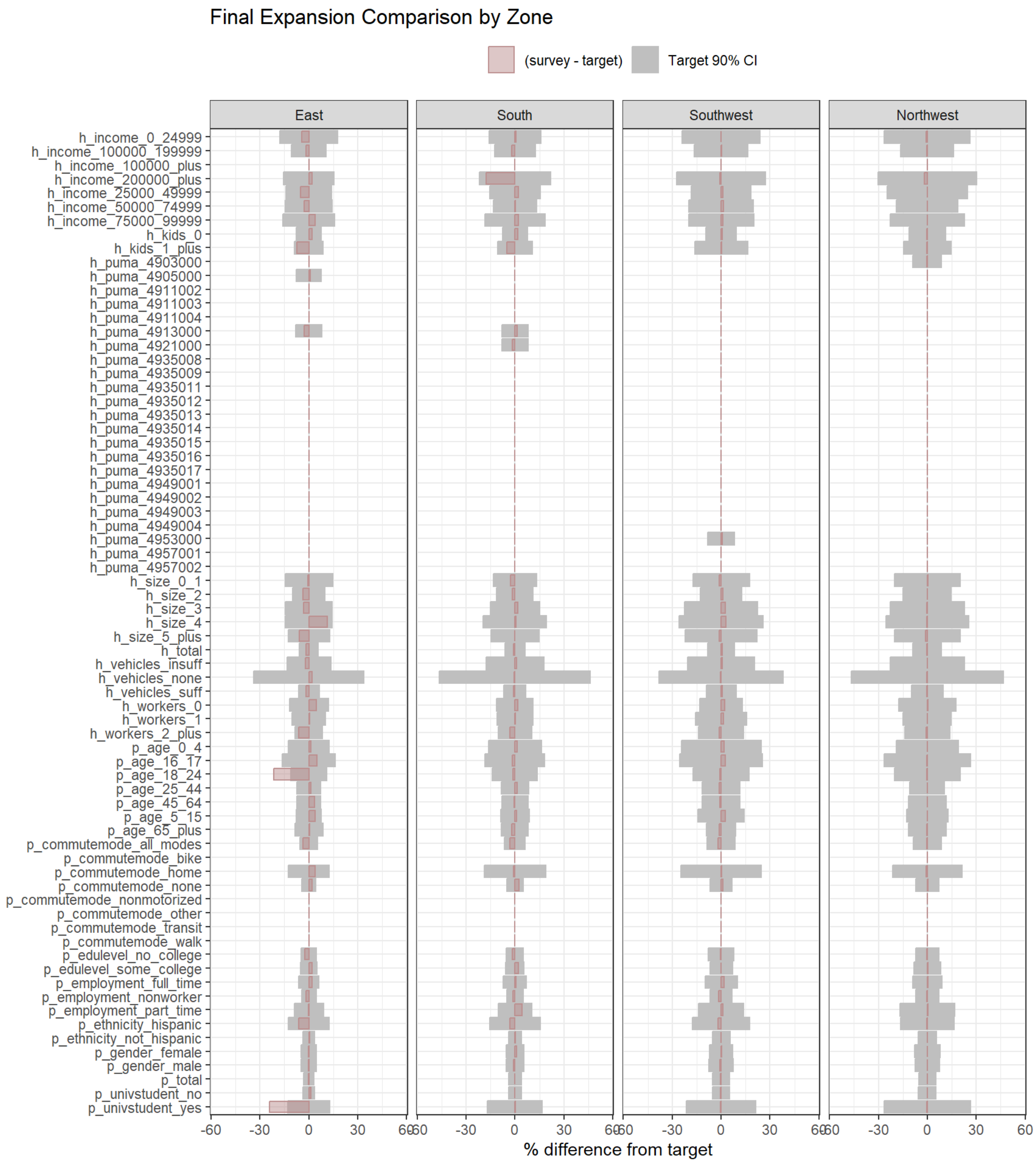
Figure 6 shows the fit between the weighted survey totals and the Census targets after initial weighting for the entire state. Each row in the figure represents a separate weighting target. Gray rectangles represent the 90% confidence interval around the target, expressed as a percentage of the target itself. Red rectangles represent the difference between the Census target and the survey estimate after weighting. When weighted survey totals were less than Census estimates, they appear as negative red bars in the figure. For the entire state, weighted estimates were well within acceptable bounds, falling within the Census' own 90% confidence intervals around target estimates.

FIGURE 6: FIT TO TARGETS AFTER INITIAL WEIGHTING, ENTIRE STATE



Fit to targets in for the East weighting geography were slightly poorer than other weighting geographies (Figure 7). Relative to the Census targets, 18- to 24-year-olds and university students were under-represented in the final weighted sample (Figure 7). However, the error was still within acceptable margins for such a small sample size (323 households).

FIGURE 7: FIT TO TARGETS AFTER INITIAL WEIGHTING FOR EAST, SOUTH, SOUTHWEST, AND NORTHWEST GEOGRAPHIES



The fit to targets for Cache, MAG, and WFRC geographies were all well within acceptable margins (Figure 8).

FIGURE 8: FIT TO TARGETS FOR CACHE, MAG AND WFRC WEIGHTING GEOGRAPHIES

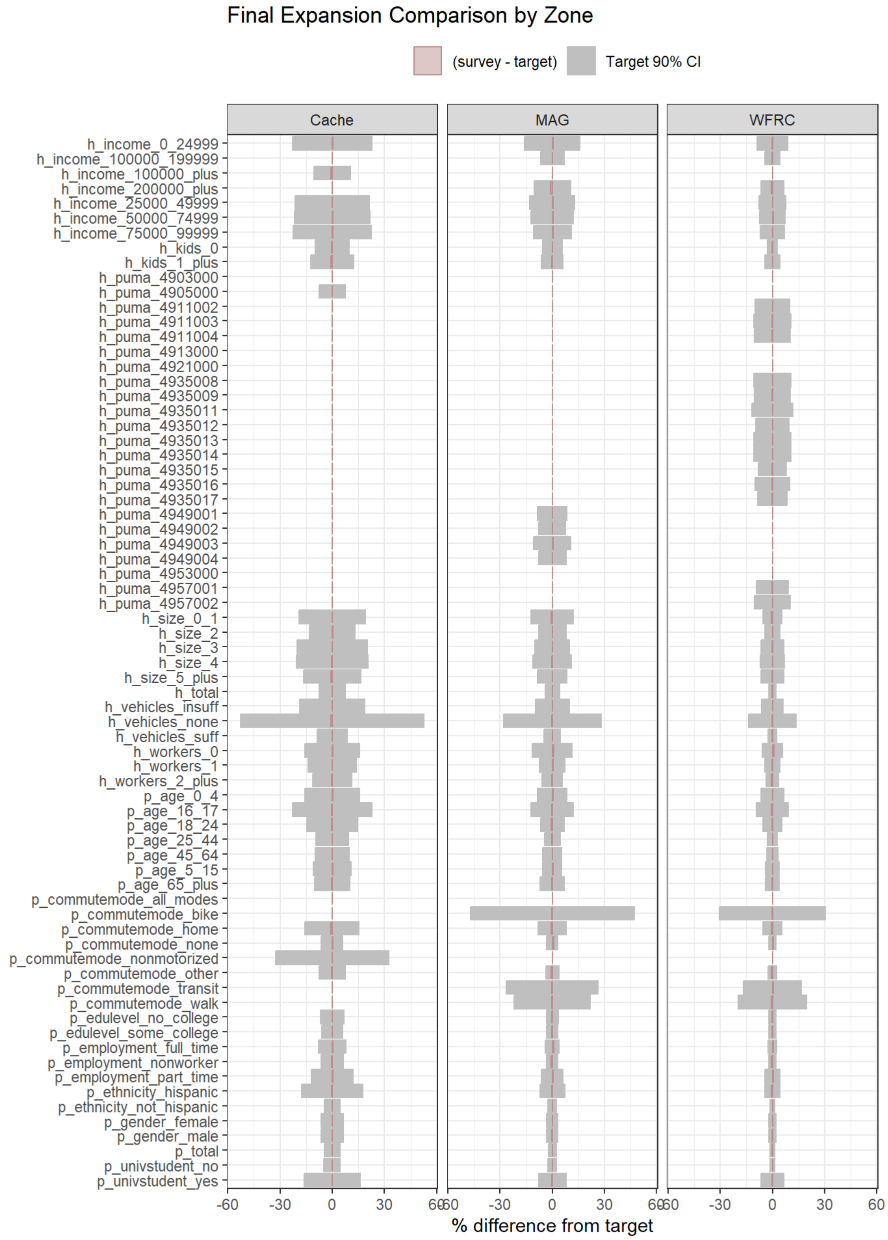


Table 14 provides the distribution of the initial weights RSG calculated for each weighting geography. For the sample overall, the median (88.88) was well below the mean (134.01), corresponding to a mild skew towards high weights at the extremes. Metrics for East, South and Southwest suggest that small sample size, combined with the constraints placed on weighting, led to extremely high skew in these areas (Figure 9).

TABLE 14: SUMMARY OF INITIAL WEIGHTS

Weighting Geography	N Households	Min	Mean	Median	Max	SD
East	323	1.00	165.03	12.44	599.40	218.91
South	521	1.00	145.89	73.92	599.45	177.51
Southwest	533	1.00	136.04	59.84	599.19	173.21
Northwest	374	5.49	122.21	91.33	537.59	97.50
Cache	665	1.66	68.89	45.94	342.25	67.95
MAG	1,480	1.01	140.51	98.14	599.76	134.07
WFRC	4,680	1.77	138.45	99.51	599.81	122.15
Total	8,576	1.00	134.01	88.88	599.81	134.10

In the East geography in particular, most sampled households have very small weights, and a few have extremely large weights to make up for population under-coverage (Figure 9). These geographies would be good candidates for consolidation with others to improve model fit; however, if the goal is to achieve weighted population estimates in alignment with travel model needs, the data may need to be left as is but analyzed with caution (i.e., by calculating confidence intervals around weighted estimates and suppressing estimates with small sample size). The other geographies showed a more even distribution of weights (Figure 9).

FIGURE 9: DISTRIBUTION OF INITIAL WEIGHTS BY WEIGHTING GEOGRAPHY.

Table 15 summarizes the ratio of the initial weight to the initial expansion factor. The average ratio for the sample as a whole, 1.02, is indicative of a modest (on average) post-stratification adjustment, and the SD (0.94) is low suggesting relatively even effects of PopulationSim weighting across the sample. For East and South geographies, however, weighting made much larger on average corrections (mean ratio 1.16 and 1.33, respectively) with a large skew (SD 1.61 and 1.46), indicative of aggressive adjustments in these geographies to meet targets.

TABLE 15: RATIO OF INITIAL WEIGHT TO INITIAL EXPANSION FACTOR

Weighting Geography	min	mean	median	max	sd
East	0.00	1.16	0.11	4.00	1.61
South	0.00	1.33	0.66	3.75	1.46
Southwest	0.01	1.01	0.44	3.99	1.25
Northwest	0.05	0.99	0.78	3.87	0.77
Cache	0.04	0.96	0.68	3.99	0.81
MAG	0.01	0.99	0.70	4.00	0.87
WFRC	0.01	0.99	0.76	4.00	0.79
Total	0.00	1.02	0.72	4.00	0.94

INITIAL PERSON WEIGHTS

RSG created initial person weights by copying the household weight to the associated person records, with one exception, for households with nonrelatives (described below).

Correcting for households with nonrelatives

Based on feedback from recent household travel survey respondents, the project team decided not to collect travel diaries from unrelated household members in respondent households. This decision was driven by a desire to improve the response rates for larger households in particular while also protecting respondents' data privacy.

In households with unrelated members, each unrelated member receives a weight of zero and the value of their weight is split evenly among the remaining household members (see example in Table 16). This step ensures that the full person table still represents the total number of people in the region while avoiding downstream interference when analyzing household- and person-level trip rates.

TABLE 16: EXAMPLE RELATED AND NOT RELATED PERSON WEIGHTS

	Household Weight	Person Number & Relation	Person Weight
Household 3	10.0	1 (Related)	10.0

Household 4	20.0	1 (Related)	20.0
Household 4	20.0	2 (Related)	20.0
Household 5	30.0	1 (Related)	45.0
Household 5	30.0	2 (Related)	45.0
Household 5	30.0	3 (Not Related)	0.0

In the UTS, 4.0% of persons in the survey were unrelated to the primary respondent, comprising 1.9% of the total person-weight (Table 17). Their person weight was reallocated to persons related to the central respondent (Table 17).

TABLE 17: PERSON WEIGHT ALLOCATED TO RELATIVES AND NON-RELATIVES OF THE PRIMARY RESPONDENT BEFORE AND AFTER ADJUSTMENT

	UNWEIGHTED TOTALS		WEIGHTED TOTALS BEFORE ADJUSTMENT		WEIGHTED TOTALS AFTER ADJUSTMENT	
	Count of Persons	**Percent of Persons**	**Sum of Person Weight**	**Percent of Person Weight**	**Sum of Person Weight**	**Percent of Person Weight**
Related to Primary Respondent	20,857	96.0%	3,298,799	98.1%	3,362,278	100%
Not Related to Primary Respondent	860	4.0%	63,478	1.9%	0	0%
Total	**21,717**	**100.0%**	**3,362,278**	**100%**	**3,362,278**	**100%**

INITIAL DAY WEIGHTS

The Utah Moves Transportation Survey collected multiple days of travel from smartphone households, while web and call center households only reported a single day of travel. For this reason, it was important to consider how to combine the multi-day and single-day data using a consistent method without overrepresenting smartphone households. RSG applied the following approach to develop the day-level weights.

After creating person-level weights, RSG applied these weights to the day-level table. RSG assigned households with *only one complete day* the same day weight as person weight. RSG assigned households with *more than one complete day* a day weight that equaled their person weight divided by the number of complete days. For example, if a household had person weights of 30.0 and 3 complete days, each complete day would have a day weight of 10.0 (30 / 3 = 10). Table 18 shows an example.

TABLE 18: EXAMPLE DAY WEIGHTS BY NUMBER OF COMPLETE DAYS

	Household Weight	Person Number & Relation	Person Weight	Complete Household Days	Day Weight
Household 3	10.0	1 (Related)	40.0	1	10.0
Household 4	20.0	1 (Related)	20.0	2	10.0
Household 4	20.0	2 (Related)	20.0	2	10.0
Household 5	30.0	1 (Related)	45.0	3	15.0
Household 5	30.0	2 (Related)	45.0	3	15.0
Household 5	30.0	3 (Not Related)	0.0	N/A	0.0

ADJUSTING FOR NON-RESPONSE BIAS IN DAY-PATTERNS (ABS AND CBS ONLY)

RSG has found over many HTS projects that travel data collected via smartphone app typically exhibits higher trip rates compared to data collected via web or call center travel diary methods. There are three main reasons for this trend.

- Households that own smartphones have different socio-demographic characteristics than households that do not own smartphones. These characteristics can correspond to higher trip-making activity.
- Households that report their travel by smartphone tend to report fewer "stay at home" days. This may be due to the lower burden to recall trips when an app is tracking travel as it occurs.
- On days with reported trips, households that report by smartphone tend to report an average higher number of trips for the reasons previously stated.

These three factors are interrelated and therefore must be isolated in any analysis and weighting adjustments. RSG applied a two-stage approach to address differences in trip reporting across diary methods:

1. First, RSG adjusted weights at the person-day level to account for biases in day-pattern types. Day-level adjustments were adjusted through additional weighting targets instead of simply adjusting the household weights ensures that weight sums are consistent within households and within the region.
2. After adjusting for day-pattern response bias, RSG adjusted weights at the trip level (See page 52).

These steps were not performed for the University sample, both because the share of university students who completed the travel diary via rMove was small, and because the university segment was not weighted with PopulationSim procedure (both of which are prerequisites for these adjustments).

DAY PATTERN MODEL

RSG classified person-days into three mutually exclusive and exhaustive day-type categories:

- Made no trips: The person made no trips on the day.
- Made mandatory trips: The person made trips to or from "work," "work-related," "school" or "school-related" activities.

- Made non-mandatory trips only: The person made one or more trips, but none were to or from “work,” “work-related,” “school” or “school-related” activities.

RSG used a multinomial log-linear model (“choice model”) to estimate the probability of each day type (no trips, made mandatory trips, made non-mandatory trips) for each person-day. This model was estimated using person-day data from:

- Adults only, given that children’s trips are reported via proxy.
- Households and household-days that were “complete”
- Weighted travel days (Tuesday, Wednesday and Thursday)

To account for multi-day travel diary data, avoid over-representation of rMove data in the model estimation, and ensure the model estimates reflected population behavior (rather than the behavior of the sample), the model was estimated with weighted data using initial day weights scaled (divided) by the mean of the day weight across all days in the estimation dataset.

The model dependent variable was day-type. In addition to diary type, predictor variables included demographic variables so that reporting bias by mode type could be estimated while controlling for the effects of demographics on travel behavior. Dependent variables were:

- household income (categorical variable)
- whether the household had zero vehicles (binary, yes/no variable)
- person’s employment status (binary)
- person’s student status (binary)
- age (under 35 or over 65, both as binary variables)
- diary type (call center or online, both as binary variables)
- diary type interacted with age variables (under 35 or over 65).

Table 19 shows the model results. The overall fit of the model was modestly strong, with a McFadden’s R^2 of 0.140 (McFadden’s R^2 values are much lower than traditional R^2 values). The results show that employment status is the strongest predictor of making mandatory trips, with students also significantly more likely to do so. Individuals in zero-vehicle households and those over age 65 are less likely to make mandatory trips, while younger individuals under 35 are slightly more likely to do so. Non-mandatory trip-making is negatively associated with being in a zero-vehicle household or earning under $100,000, though employment and student status have modest positive effects. Diary mode effects were notable: online diary respondents are more likely to report mandatory trips but less likely to report non-mandatory trips, especially among younger respondents. Call center respondents are less likely to report non-mandatory trips overall, but older adults using the call center were significantly more likely to report such trips.

TABLE 19: DAY PATTERN MODEL SUMMARY

Alternative	Parameter	Estimate	Standard Error	T	P
Makes mandatory trips	Intercept	-1.235	0.085	-14.603	<0.001
	Zero Vehicle Household	-0.849	0.142	-5.981	<0.001
	Income over $200,000	-0.212	0.064	-3.302	0.001
	Income $25,000 - $49,999	-0.120	0.067	-1.789	0.074
	Income $50,000-$74,999	0.044	0.063	0.704	0.482
	Income $75,000 – income $99,999	0.027	0.064	0.431	0.666
	Income under $25,000	-0.123	0.091	-1.353	0.176
	Age < 35 year	0.060	0.090	0.665	0.506
	Age > 65 years	-0.321	0.072	-4.461	<0.001
	Employed full/part/self	2.731	0.062	44.248	<0.001
	Full or part-time student	0.915	0.079	11.546	<0.001
	Online diary data	0.014	0.063	0.221	0.825
	Call center diary data	-0.783	0.202	-3.882	<0.001
	Online diary data x age	-0.122	0.101	-1.208	0.227
	Call center diary data/age	-0.130	0.370	-0.351	0.726
Makes non-mandatory trips	Intercept	1.155	0.068	16.977	<0.001
	Zero vehicle household	-0.321	0.113	-2.831	0.005
	Income over $200,000	0.038	0.063	0.597	0.551
	Income $25,000 - $49,999	-0.391	0.064	-6.120	<0.001
	Income $50,000 - $74,999	-0.008	0.060	-0.126	0.900
	Income $75,000 - $99,999	0.030	0.063	0.487	0.626
	Income under $25,000	-0.054	0.080	-0.682	0.495
	Age < 35 years	-0.080	0.087	-0.918	0.359
	Age > 65 years	0.044	0.056	0.793	0.428
	Employed full/part/self	-0.027	0.045	-0.593	0.553
	Full or part-time student	0.001	0.083	0.010	0.992
	Online diary data	-0.398	0.058	-6.811	<0.001
	Call center diary data	-1.353	0.211	-6.409	<0.001
	Online diary data x age	-0.190	0.098	-1.934	0.053
	Call center diary data x age	1.217	0.260	4.684	<0.001

McFadden's rho-squared: 0.140

"No Travel" is the reference alternative and does not report coefficients

DAY-PATTERN TARGETS

RSG then used the model to predict the probability of each day-type, for each person-day in the study as if everyone had reported their travel using the smartphone app (i.e., the diary type coefficients were set to zero when generating predictions). These probabilities were then summed by weighting geography to calculate the total number of person-days expected to fall within each day-pattern type, for each weighting geography. The summed probabilities served as a new set of targets for PopulationSim (Table 20). The un-adjusted weighted total of children's travel days were also summed for each weighting geography and supplied as a target to PopulationSim to ensure that the targets by day-pattern type sum to person totals.

TABLE 20: DAY-PATTERN TARGETS BY WEIGHTING GEOGRAPHY.

Weighting Geography	No Travel Days	Mandatory Travel Days	Non-Mandatory Travel Days	Children's Travel Days (Unadjusted)	Total Persons
Cache	14,241	41,368	41,240	38,826	**135,675**
East	17,631	40,872	51,776	44,300	**154,580**
MAG	69,334	211,436	200,329	223,494	**704,592**
Northwest	15,444	39,154	44,866	44,464	**143,927**
South	25,569	58,448	72,744	59,797	**216,559**
Southwest	25,569	52,768	73,110	48,267	**199,714**
WRFC	200,275	550,639	583,976	472,400	**1,807,290**
Total	**368,062**	**994,684**	**1,068,040**	**931,548**	**3,362,336**

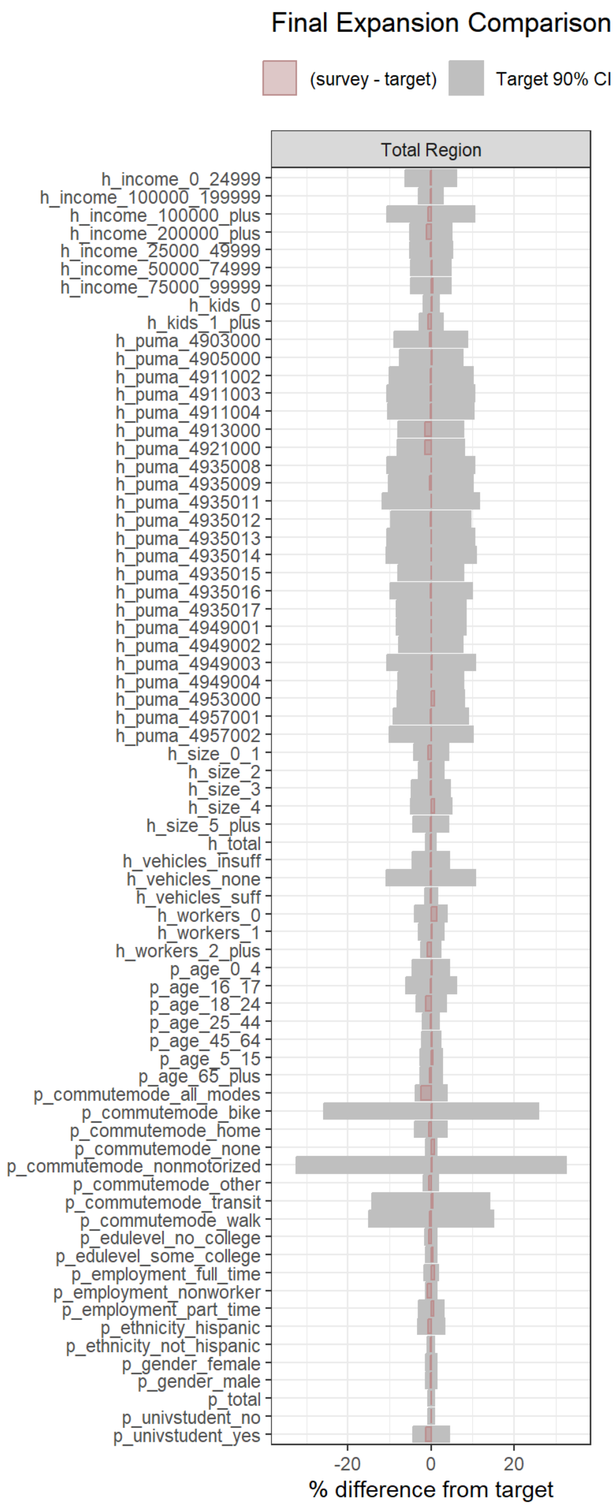
FINAL WEIGHTING WITH DAY-PATTERN TARGETS

RSG then reran the weighting process in PopulationSim with these new day-pattern targets to create the final household weights. Person and day weights were created in the same manner as before, correcting for multi-day travel data and nonrelated persons (See: Initial Person Weights, Initial Day Weights).

Figure 10 shows the fit between the weighted survey totals and the Census targets after final weighting for the entire state. Each row represents a separate target. Gray rectangles represent the 90% confidence interval around the target, expressed as a percentage of the target itself.

Red rectangles represent the difference between the Census target and the survey estimate after weighting. When weighted survey totals were less than Census estimates, they appear as negative red bars in the figure. For the entire state, weighted estimates were well within acceptable bounds, always falling within the Census’ own 90% confidence intervals around target estimates.

FIGURE 10: FIT TO TARGETS AFTER FINAL WEIGHTING, ENTIRE STATE.



Looking to individual weighting geographies, nearly all geographies had very good fit to target and were well within the acceptable error margin across all dimensions (Figure 11 and Figure 12). The East geography, which had a small sample size, fits less well to targets. The fit to targets could be improved by relaxing caps or consolidating geographies, but this would increase the variance in the weights and/or be less useful for modeling purposes. RSG recommends leaving as-is considering this implication.

FIGURE 11: FIT TO TARGETS AFTER FINAL WEIGHTING FOR EAST, SOUTH, SOUTHWEST, AND CACHE GEOGRAPHIES.

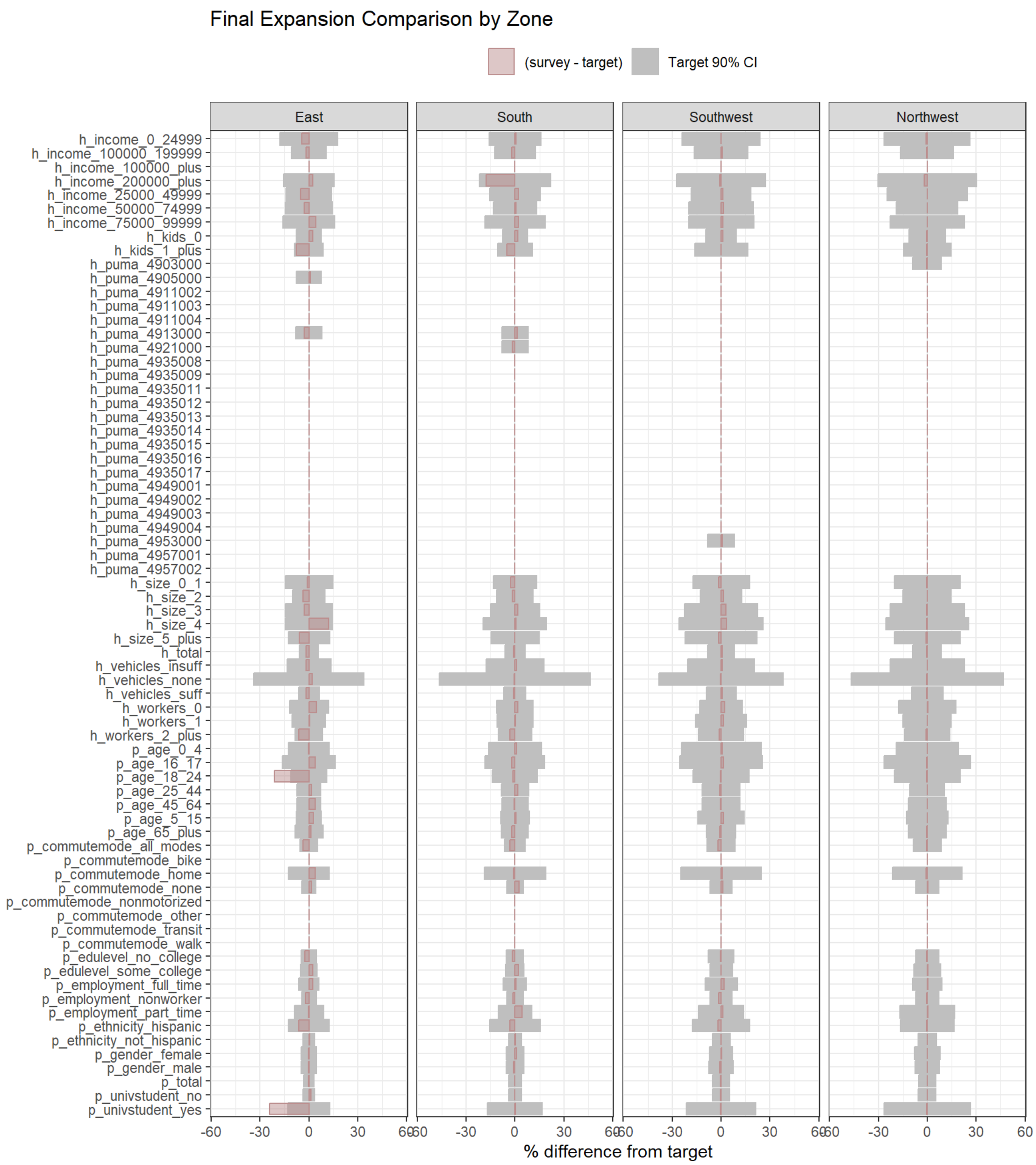
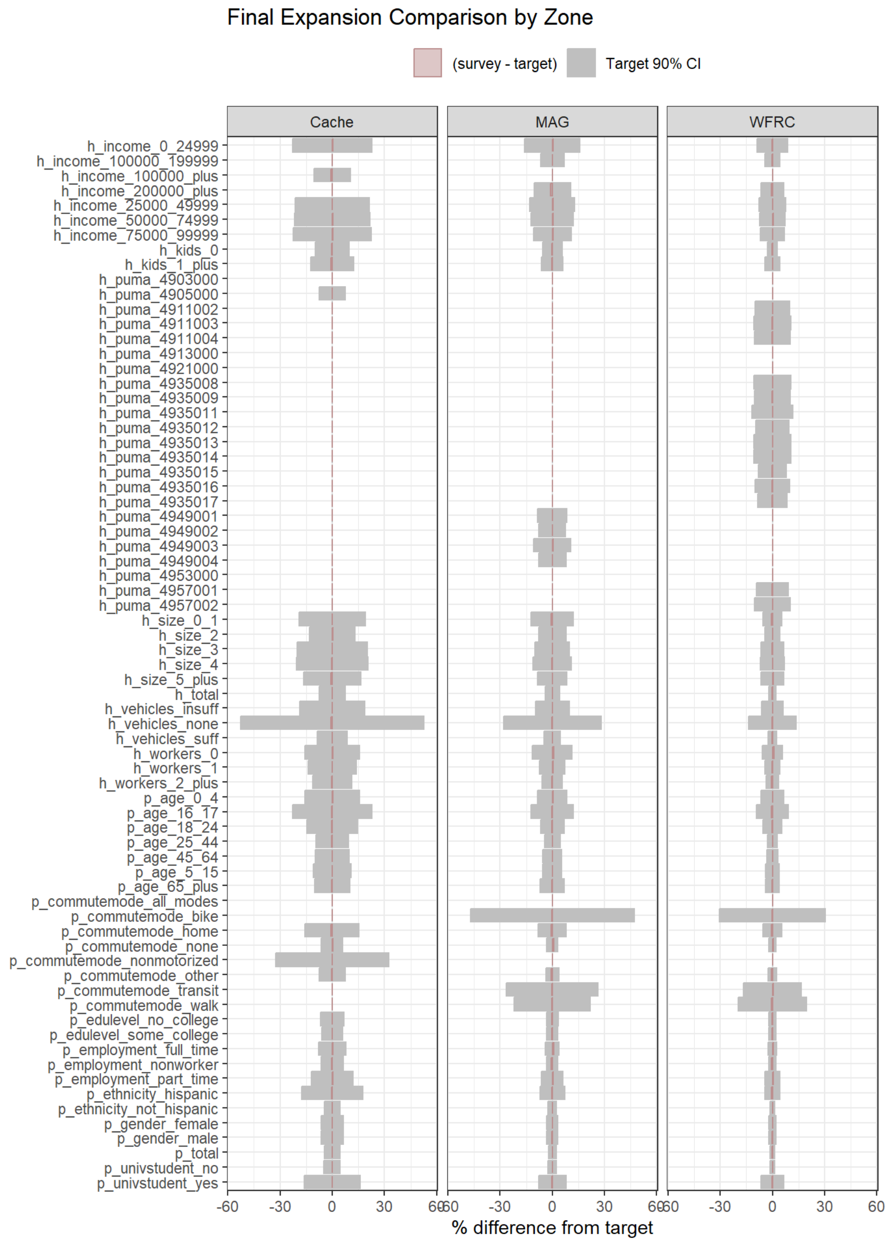


FIGURE 12: FIT TO TARGETS AFTER FINAL WEIGHTING FOR NORTHWEST, MAG AND WFRC WEIGHTING GEOGRAPHIES.



DISTRIBUTION OF WEIGHTS

Table 21 provides the distribution of the final weights RSG calculated for each weighting geography. For the sample overall, the median (88.88) was well below the mean (134.02), corresponding to a mild skew towards high weights at the extremes, as was the case after initial weighting. Figure 13 shows the distribution of final weights by weighting geography after day pattern adjustments. Compared to Figure 9, the distribution is similar, which indicates that the day pattern adjustments did not perturb the weights notably from initial weighting.

TABLE 21: SUMMARY OF FINAL WEIGHTS

Weighting Geography	N Households	Min	Mean	Median	Max	SD
East	323	1.00	165.13	13.51	599.17	219.42
South	521	1.00	145.90	71.98	599.46	177.70
Southwest	533	1.00	136.13	56.48	599.09	174.64
Northwest	374	5.21	122.21	90.88	537.67	97.50
Cache	665	1.66	68.88	45.93	342.66	67.98
MAG	1,480	1.01	140.52	98.07	599.87	134.10
WFRC	4,680	1.79	138.45	99.47	599.79	122.12
Total	8,576	1.00	134.02	88.88	599.87	134.25

FIGURE 13: DISTRIBUTION OF FINAL WEIGHTS BY WEIGHTING GEOGRAPHY

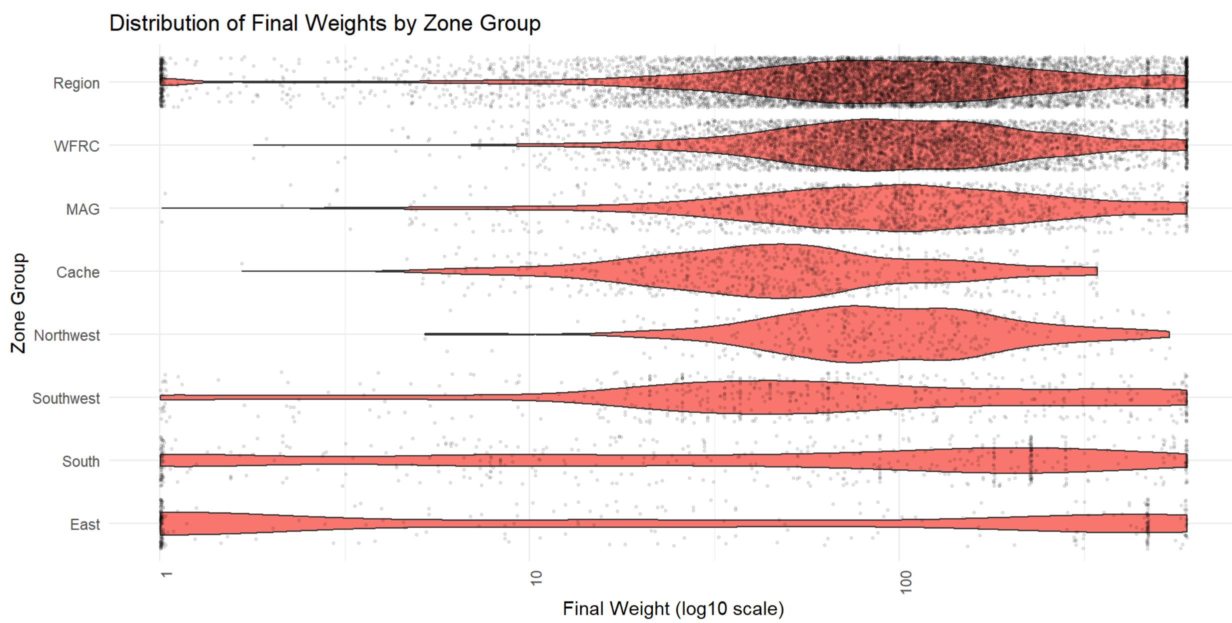


Table 22 summarizes the ratio of the final weight to the initial expansion. The average ratio for the sample as a whole, 1.02. For East and South geographies, however, weighting made much larger on average corrections (mean ratio 1.16 and 1.33, respectively) with a large skew (SD 1.61 and 1.46), indicative of aggressive adjustments in these geographies to meet targets.

TABLE 22: RATIO OF FINAL WEIGHT TO INITIAL EXPANSION

Weighting Geography	Min	Mean	Median	Max	SD
East	0.00	1.16	0.11	4.00	1.61
South	0.00	1.33	0.66	3.75	1.46
Southwest	0.01	1.02	0.43	4.00	1.26
Cache	0.05	0.99	0.77	3.88	0.77
Northwest	0.04	0.96	0.68	4.00	0.81
MAG	0.01	0.99	0.69	4.00	0.87
WFRC	0.01	0.99	0.76	4.00	0.79
Total	0.00	1.02	0.72	4.00	0.94

CALCULATING TRIP WEIGHTS (ABS AND CBS ONLY)

After finalizing the day-level weights, RSG applied these weights to the trip table to create the initial trip weights. Next, RSG adjusted the trip weights to account for difference between survey modes by analyzing person-day trip rates by purpose and person type.

We calculate trip rates for five trip purposes:

- Home-based work (HBW) trips: trips with one trip end (origin or destination) at home and the other trip end at “work” or “work-related.”
- Home-based school (HBS) trips: trips with one trip end (origin or destination) at home and the other trip end at “school” or “school-related.”
- Home-based other (HBO) trips: trips with one trip end (origin or destination) at home and the other end at a purpose other than “work”, “work-related”, “school”, or “school-related.”
- Non-home-based work (NHBW) trips: trips with one trip end (origin or destination) at “work” or “work-related,” and the other trip end at any destination other than home.
- Non-home-based other (NHBO): all other trips.

These four trip categories are mutually exclusive and cover all possible trip types except for change mode trips and ‘loop’ trips which were excluded from the trip adjustment analysis. Loop trips are typically made for walking the dog or exercise and are not typically modeled. They also tend to be represented more in rMove data than in other survey modes and therefore would obfuscate the trip adjustment procedure if included.

The person type categories used in the adjustment are as follows:

- Full-time worker: Assigned if the person reports full-time employment or being self-employed.
- Part-time worker: Assigned if the person reports part-time work or being a volunteer, but only if they are at or above driving age (students below that are not considered workers).
- University/College student: Assigned if the person is attending College, Graduate School, or Technical School, based on their self-reported school type.
- Non-Working Adult: Assigned if the person is an adult but not employed, and not a student.
- K12 student: Any person attending Elementary, Middle, or High School.

- Preschool age child: Assigned if the person is enrolled in Preschool or Daycare, or their age is under 5 years old.

These person type categories are coded according to the order shown above and are exhaustive. We then calculate weighted trip rates from all person-days of travel (Tuesday, Wednesday, and Thursday) from complete households only, segmented by trip purpose, person type, survey mode. We do not include non-related household members in the denominator since we do not collect travel data from them.

To calculate trip rate adjustments, we first designate a canonical survey mode for each person type. We assume rMove is the canonical source of trip rates for all person types except for children (K12 students and preschool-age children), where we assume that browser is the canonical data source for trip rates. We make this assumption because the school and school-related reporting tends to be better for browser data than for rMove data. It is important to have one canonical source for each person type because otherwise trip rates can get unreasonably large. For example, if the browser has the max trip rate for HBS trips for k12 students, we do not want to then also use a maximum trip rate from rMove for HBO trips because it implies that students are spending time both going to school and engaging in other travel that might conflict with going to school. Using one canonical source for each person type ensures consistency in their daily activity schedule.

We calculate the ratio of each survey mode's trip rate to the person-day trip rate for the canonical data source to estimate the trip rate adjustment factor. Because of very low work and work-related trips for any person type other than full-time and part-time workers, we only adjust HBW and NHBW trip purposes for those two person types. Similarly, because there are very low numbers of school and school-related trips for person types other than university students, K12 students, and preschool age children, we only adjust the HBS trips for those three person types. Finally, we cap the adjustments at 2.0 to prevent extreme weights.

We summarize the trip rate adjustment for each purpose below in Table 23 through

Table 27. Total person-day trip rates are shown in

Table 28. Adjusting the trip rates increases total average weekday (Tuesday through Thursday) trips in the state from approximately 12.9M to 14.5M, or 12.4%.

TABLE 23: UNADJUSTED HBW WEIGHTED TRIP RATE, HBW ADJUSTMENT FACTOR, AND FINAL ADJUSTED HBW TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Trip Adjustment Factor			Final Trip Rate		
	browser	call	rMove	browser	call	rMove	browser	call	rMove
Full-time worker	0.52	0.32	0.79	1.52	2.00	1.00	0.79	0.64	0.79
Part-time worker	0.38	0.81	0.66	1.74	0.81	1.00	0.66	0.66	0.66

TABLE 24: UNADJUSTED HBS WEIGHTED TRIP RATE, HBS ADJUSTMENT FACTOR, AND FINAL ADJUSTED HBS TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Trip Adjustment Factor			Final Trip Rate		
	browser	call	rMove	browser	call	rMove	browser	call	rMove
University student	0.26	0.36	0.48	1.85	1.33	1.00	0.48	0.48	0.48
K12 student	2.00	1.57	1.77	1.00	1.00	1.00	2.00	1.57	1.77
Preschool age child	0.72	0.28	0.66	1.00	2.00	1.09	0.72	0.55	0.72

TABLE 25: UNADJUSTED HBO WEIGHTED TRIP RATE, HBO ADJUSTMENT FACTOR, AND FINAL ADJUSTED HBO TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Trip Adjustment Factor			Final Trip Rate		
	browser	call	rMove	browser	call	rMove	browser	call	rMove
Full-time worker	0.96	0.80	1.93	2.00	2.00	1.00	1.92	1.61	1.93
Part-time worker	1.35	1.20	2.51	1.86	2.00	1.00	2.51	2.40	2.51
University student	1.03	0.46	1.57	1.52	2.00	1.00	1.57	0.92	1.57
Non-working adult	1.61	0.57	2.81	1.75	2.00	1.00	2.80	1.15	2.81
Retired	1.11	1.17	1.90	1.71	1.62	1.00	1.90	1.90	1.90
K12 student	0.81	0.44	1.35	1.00	1.84	0.60	0.81	0.81	0.81
Preschool age child	1.11	1.17	1.90	1.71	1.62	1.00	1.90	1.90	1.90

TABLE 26: UNADJUSTED NBHW WEIGHTED TRIP RATE, NBHW ADJUSTMENT FACTOR, AND FINAL ADJUSTED NBHW TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Trip Adjustment Factor			Final Trip Rate		
	browser	call	rMove	browser	call	rMove	browser	call	rMove
Full-time worker	0.97	0.69	1.16	1.20	1.68	1.00	1.17	1.15	1.16
Part-time worker	0.65	0.52	0.65	1.00	1.25	1.00	0.65	0.65	0.65

TABLE 27: UNADJUSTED NBHO WEIGHTED TRIP RATE, NBHO ADJUSTMENT FACTOR, AND FINAL ADJUSTED NBHO TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Trip Adjustment Factor			Final Trip Rate		
	browser	call	rMove	browser	call	rMove	browser	call	rMove
Full-time worker	0.74	1.18	1.02	1.38	0.86	1.00	1.01	1.02	1.02
Part-time worker	1.35	1.30	0.71	1.00	1.04	1.90	1.35	1.35	1.36
University student	1.47	1.07	1.46	0.99	1.36	1.00	1.46	1.45	1.46
Non-working adult	1.16	1.42	1.30	1.12	0.92	1.00	1.30	1.30	1.30
Retired	1.31	0.86	1.04	1.00	1.52	1.26	1.31	1.31	1.31
K12 student	1.54	1.49	1.44	0.94	0.97	1.00	1.44	1.44	1.44
Preschool age child	1.02	0.55	1.42	1.39	2.00	1.00	1.42	1.10	1.42

TABLE 28: UNADJUSTED TOTAL WEIGHTED TRIP RATE AND FINAL ADJUSTED TOTAL TRIP RATE BY PERSON TYPE AND SURVEY MODE

Person Type	Unadjusted Trip Rate			Final Trip Rate		
	browser	call	rMove	browser	call	rMove
Full-time worker	3.27	3.04	5.37	4.97	4.47	5.37
Part-time worker	3.69	4.11	5.59	5.28	5.17	5.59
University student	3.61	2.27	5.78	4.77	3.4	5.78
Non-working adult	3.24	1.78	4.78	4.43	2.74	4.78
Retired	2.77	2.84	3.71	3.46	3.52	3.71
K12 student	4.31	3.31	4.11	4.31	3.73	4.22
Preschool age child	3.16	4.86	4.01	3.16	2.93	3.33

APPENDIX A. SUMMARY OF FOLLOW-ON AND LONG-DISTANCE SURVEY WEIGHTING METHODS

To weight the follow-on and long-distance survey, RSG first created new household and person weights using the methods described earlier in this memo. Given the smaller sample size, RSG collapsed the target geographies to four zones: Cache County, the MAG region, the WFRC region, and all other regions ("combined outer"). RSG also collapsed the sample strata into three groups (General, Hard-to-Survey, and Walk/Bike/Transit) and collapsed the demographic targets to better align with the sample size and key attributes. The final targets and fit to targets are shown in Figure 14.

RSG then calculated the long-distance trip weights as $trip\_weight = (number\ of\ trips\ /\ 28\ days) * person\ weight$. This created weights that represent the number of trips per person per day for similar people statewide. RSG divided the number of trips by 28 based on the long-distance travel period of 28 days.

FIGURE 14: FINAL HOUSEHOLD AND PERSON EXPANSION BY ZONE