THURSTON REGION PLANNING COUNCIL TRAVEL DEMAND MODEL UPDATE

Model Development

Final Report

prepared for

Thurston Region Planning Council

prepared by

Cambridge Systematics, Inc.

with

Clyde Scott and

Jeffrey Newman

February 19, 2016

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report

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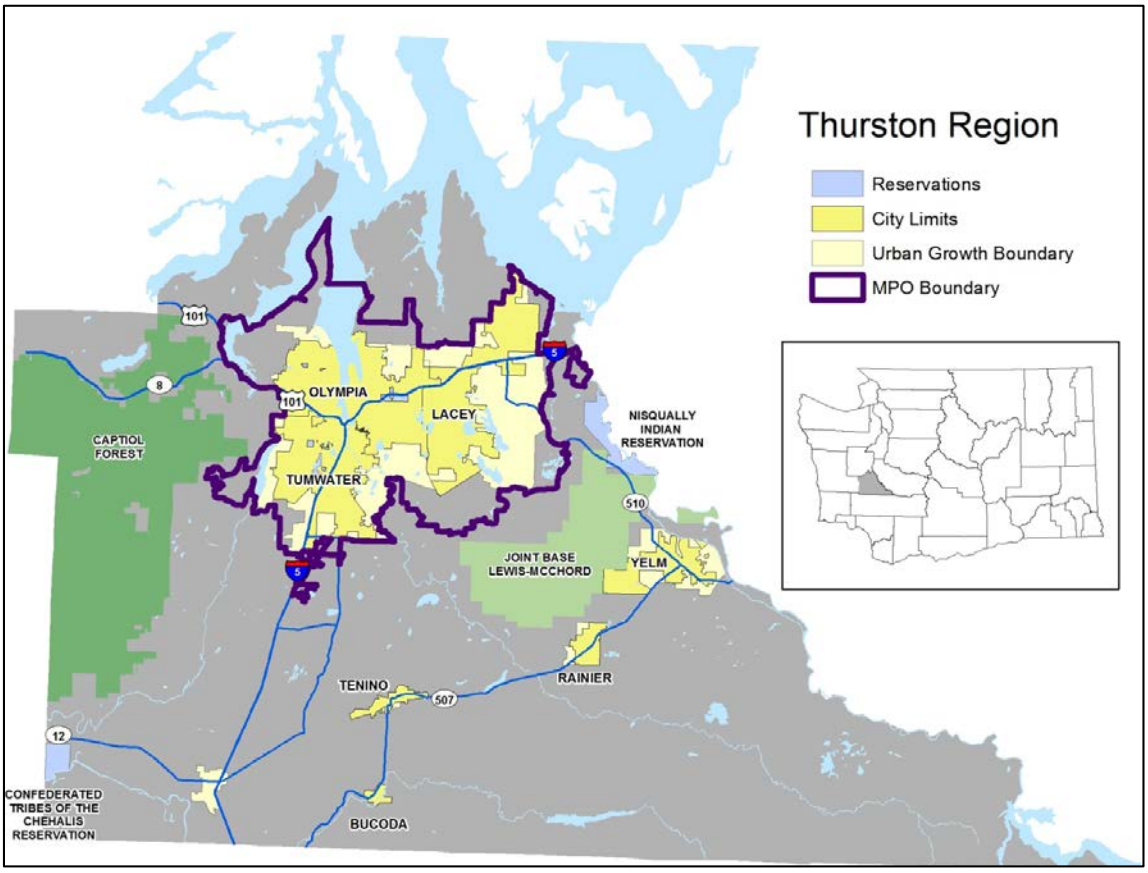
1.0 Introduction

The Thurston Region Planning Council (TRPC) is the federally-designated Metropolitan Planning Organization (MPO) for the Olympia urbanized area and is also the state-designated Regional Transportation Planning Organization (RTPO) for Thurston County.

Thurston County is located at the southern end of Puget Sound on the Interstate 5 (I-5) corridor, about 60 miles south of Seattle. TRPC and the Thurston region have a long standing commitment to integrated transportation and land use planning and development of an integrated multimodal transportation system. The region places a high priority on system efficiency and demand management.

Figure 1.1 TRPC Planning Area



Source: TRPC

I-5 is the largest roadway in the Thurston region, connecting Seattle to Portland, Oregon and California.. US 101 is another major divided highway which carries significant amounts of traffic to and from Mason County and Washington's Olympic peninsula to TRPC's west and northwest. Pierce County to the northeast contains the main part of Joint Base Lewis-McChord (JBLM). JBLM and Pierce County generate large amounts of travel to and from the Thurston region. In addition, the JBLM supports 40,000 active duty personnel, 15,000 civilian workers, 60,000 family members, and 30,000 military retirees living within 50 miles of the base and it is located along the Thurston County/Pierce County boundary.

1.1 Objectives of the TRPC Model Update

TRPC maintains the travel demand model (TRPC model) for the region. The previous model development took place between 1997 and 2000. The model was supported by an I-5 / US 101 external origin-destination survey and the 1998/1999 household travel survey. The model was a traditional four-step model that accounts for peak and off-peak conditions. The model used an 800-zone traffic analysis zone (TAZ) structure that covers the entire Thurston County. The trips produced and attracted outside Thurston County were modeled by external stations. The four steps in the model were trip generation, trip distribution by destination choice modeling, mode choice and multi-modal traffic assignment. The model included three time periods per day (AM Peak, Midday, PM Peak), six trip purposes, and six passenger modes.

The Thurston region has experienced significant growth and demographic changes since the previous model was first developed. Coupled with policies against capacity expansion, and the high traffic volumes and physical constraints near JBLM, TRPC needed to evaluate policies and strategies that manage demand to increase the efficiency of their existing transportation infrastructure. Such strategies include increased use of transit, time of day lane conversion, and managed lanes by designating high-occupancy vehicle lanes or through tolling policies. The structure of the existing travel demand model did not allow the evaluation of such policies.

The new version of the TRPC model incorporated the following characteristics to improve the model sensitivity and policy relevance:

- Expanded geographical coverage to include the entire JBLM and surrounding areas; as well as more detail in the Grays Harbor, Lewis, and Mason Counties
- More reliable procedures to estimate household demographics;
- Explicit coding of transit services;
- More detailed mode choice model structure – drive access transit and exclusive Park and Ride nests;
- Stratified truck model component;
- Travel market segmentation by income;
- Behavioral time of day model; and
- Treatment of JBLM as a special generator.

A new household travel survey was conducted in the fall of 2013 to collect data on the current demographic characteristics and travel behavior in the region. In addition, the survey included sub samples for JBLM residents and Park and Ride users. The model development and validation effort also used recent traffic counts at screen lines.

The 2015 TRPC model was developed as a four-step model with the following characteristics:

- Synthetic population to approximate demographic joint distributions at the TAZ level of detail;
- Trip production rates estimated by household size and income for the following trip purposes;
    - Home based work (HBW),
    - Home based shopping (HBShp),
    - Home based other (HBO),
    - Home based university (HBU), and
    - Non-Home based (NHB) trips.

- A framework to treat JBLM as a special generator
- Home based school purpose segmented by household size and number of school age children
- Destination choice models for HBW, HBO, HBU and NHB purposes partially segmented with income;
- Mode choice models with explicit treatment of transit access modes;
- The HBW and HBO had a separate park and pool (PnP) option; and
- Behavioral time of day post-processing for PM peak period.

These improvements allow the 2015 TRPC model to:

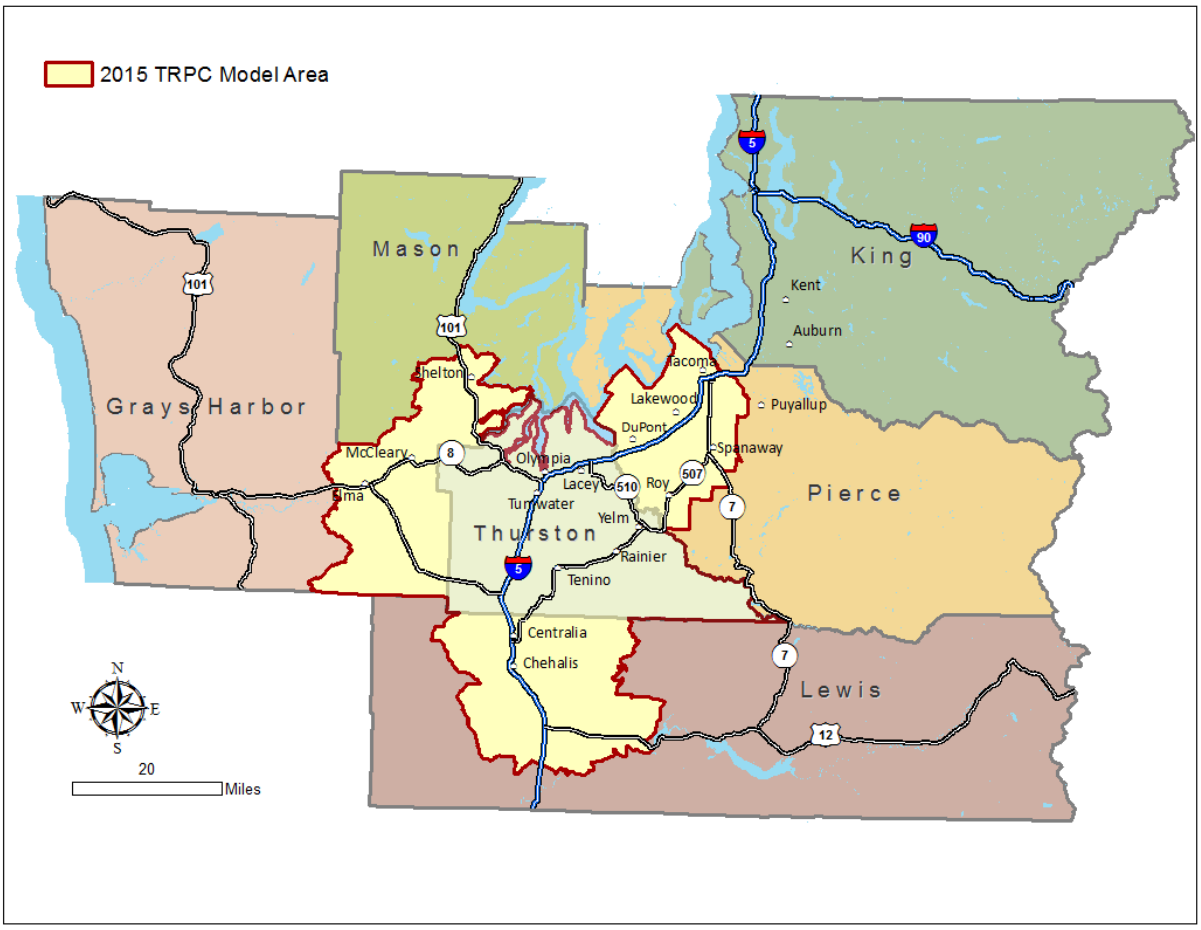
- Incorporate travel patterns involving areas neighboring Thurston County explicitly;
- Use a more flexible and reliable demographic profile in applying model components;
- Address variations in travel behavior across population groups segmented by income;
- Evaluate transit markets by mode of access and analyzing premium transit options;
- Incorporate unique markets such as Park and Ride lot use for ridesharing; and
- Analyze impacts of congestion during the PM peak to address potential shifts to shoulder periods.

This report documents the new updated travel model system for TRPC and is organized in nine chapters. Chapter 2 provides an overview of the expanded model boundaries discussing the zone and district systems used during the study and the updates to the highway and transit networks. Chapter 3 features the post-processing of the household travel survey data and data expansion to reflect the regional population. Chapter 4 summarizes the population synthesis procedures and results. Chapter 5 outlines the land use data available and the trip generation step. Chapters 6 and 7 include mode choice and destination choice model development and validation. Finally, Chapter 8 details the time of day model development.

2.0 Revised Model Boundaries and Zone System

The traffic analysis zone (TAZ) system under went significant revisions that included modifications to existing TAZ boundaries near downtown Olympia and the Capitol Campus area to better represent traffic movements and the addition of 178 new zones expanding the modeling boundaries to neighboring communities. 129 new zones in Pierce County were added, including greater detail for JBLM, the towns of Roy, Lakewood, DuPont, Parkland, and Spanaway, and most of Tacoma. The expanded zone system also included 14 new zones in Mason County, 31 zones in Lewis County, and four in Grays Harbor County. The revised 962-zone 2015 TRPC zone system is shown in **Figure 2.1**.

Figure 2.1 2015 TRPC Model Extent



In addition, both highway and transit networks were expanded and updated to reflect 2010 baseline conditions. The transit network includes routes from the following transit providers: Intercity Transit, Rural and Tribal Transportation, Sound Transit, Twin Transit, Grays Harbor Transit, and Mason Transit with routes serving Thurston County. The external zones were also revised and updated. These revisions and updates were coordinated with Puget Sound Regional Council (PSRC) and other neighboring agencies to ensure compatibility and consistency in the networks. The auto and transit network revision and update were completed by TRPC. Documentation for that effort is available in a supplemental document.

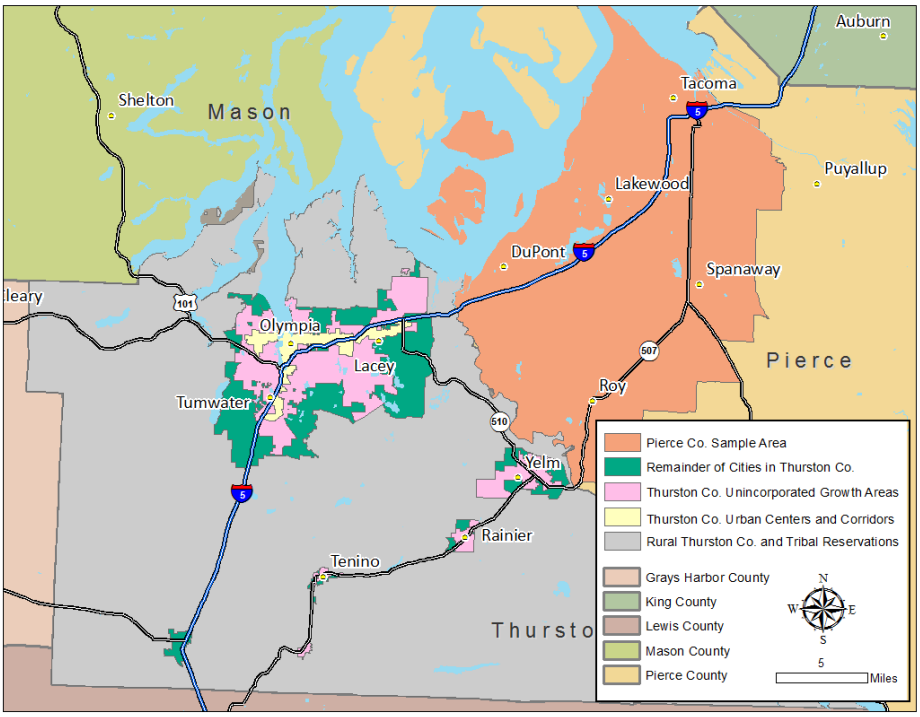
3.0 Household Travel Survey Post Processing and Data Expansion

The sampling frame for the South Sound Travel Study Household Survey (SSTSHS) included all of Thurston County and the portion of the Pierce County that is included in the 2015 TRPC model area. This area included roughly 265,000 households in total with about 100,000 households in Thurston County and 165,000 in the Pierce County area, with a lower sample rate in Pierce County.

The sample stratification effort for the main data collection in the study was based on 2010 Census Blocks instead of Block Groups or Tracts to approximate the areas of interest as precisely as possible. As shown in Figure 3.1, there are five areas of interest specified in the Sample Plan[1]:

1. Thurston County Urban Centers and Corridors
2. Remainder of cities in Thurston County
3. Thurston County unincorporated growth areas
4. Rural Thurston County and Tribal Reservations
5. Pierce County Sample Area

Figure 3.1 South Sound Travel Study Household Survey Sample Regions



The main survey collected valid data from 2,334 households and included 5,119 individuals. The survey included special samples for Vanpool program participants and Park and Ride users, as a well as a sample of JBLM residents and employees. These data components were used without weights in mode choice model estimation and special trip generation analyses.

[1] South Sound Travel Study, Household Survey Report, February 12, 2014, Resource Systems Group.

3.1 Expansion

Household survey expansion is a key step in ensuring that survey data are representative of the overall regional travel behavior. The premise of this effort asserts that the sample obtained is weighted to more accurately reflect the total population in the study area and the distribution of market segments within the study area. This section lays out the key steps that were carried out for the SSTSHS data expansion.

Geographic characteristics. Thurston County is the key area in the sampling plan. Further, portions of Pierce County were sampled, but not at the same rate as Thurston County. Therefore, it was critical to have a geographic element in the survey expansion procedures and to develop separate weights for survey households in Thurston and Pierce Counties.

Sub-Regional Characteristics. It was also necessary to subdivide Thurston County into smaller regions based on density and transportation infrastructure and services. The core portion of the County that provides public transport services was specifically targeted since people in this sub-region have greater transportation options and possibly destinations (more shopping and eating destinations, for instance), and therefore are likely to have different travel characteristics (total trips, mode choice, and travel distances) than the rest of the County.

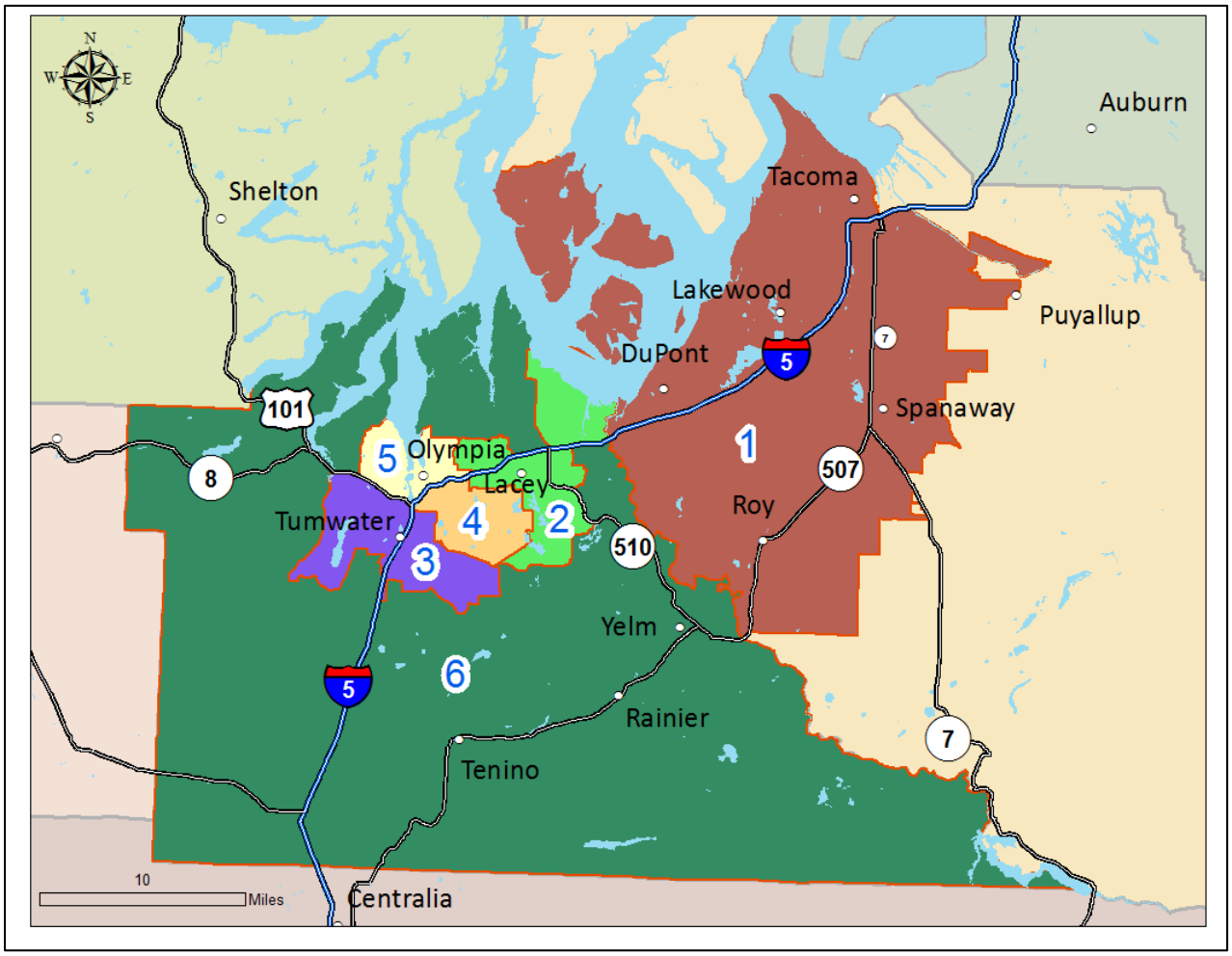
To address these potential variances in behavior by geography, the study area was divided into six sub-regions (Figure 3.2) to perform weighting and expansion. These sub-regions were formed by aggregating Census tracts in the study area. Census tract geography enables the use of three-dimensional American Community Survey (ACS) summary tables for establishing targets and provides more reliable data compared to block groups and Census traffic analysis zones.

- Sub-Region 1 includes the portion of the Pierce County covered by the 2015 TRPC model area;
- Sub-Region 2 covers the urbanized areas (Urban Center and Corridors, Urban Areas and Urban Growth Areas) in the vicinity of Lacey;
- Sub-Region 3 is mainly composed of urbanized areas near Tumwater;
- Sub-Region 4 represents urbanized areas south southeast of Olympia;
- Sub-Region 5 includes Olympia and surrounding urbanized areas; and
- Sub-Region 6 contains the rural Thurston County, Tribal Reservations and the south County urbanized areas including Yelm, Rainer, Tenino, and Bucoda.

Household Characteristics. Travel demand modeling relates trip-making to household characteristics. Therefore, it is critical to include household-level variables into the survey expansion procedure. Typical variables that are used include:

- Household size (one-person, two-people, three-people, and four-or-more-people);
- Household workers (zero, one, two, and three or more workers); and
- Household auto availability (zero, one, two, and three or more autos available).

Figure 3.2 Sub-Regions for Survey Expansion



Personal Characteristics. Personal characteristics are rarely used for survey expansions. However, household surveys typically oversample "older" households whose members are also often retired and have different travel behavior. Therefore, personal characteristics such as age and worker status were included within the expansion process.

The expansion factors developed for the survey were expected to correct for differences in geographic and household characteristics due to variations in sampling and data retrieval. The survey expansion was carried out by using the following six variables:

- Geography (sub-regions as shown in Figure 3.2.),
- Household size,
- Number of workers in the household,
- Number of vehicles in the household,
- Age of individual respondents and,
- Employment status of individual respondents.

Standard Census summary tables are limited to three dimensions. We used the variables listed above by producing a series of "cross-classification" tables to support the expansion. These tables were used as targets in an iterative procedure to ensure that the expansion weights approximated the joint distribution of those variables. This analysis allowed us to match household characteristics along multiple dimensions of interest.

Compilation of Data from National Data Sources to Support Expansion

Household level and person level targets by geography were obtained from the 2007-2011 five-year ACS data at the tract level of detail and were aggregated to the sub-regional geography. Tables 3.1 through 3.3 show the number of households by size and number of vehicles, the number of households by size and number of workers, and the number of individuals by age group. The data are summarized at the sub-region level.

Table 3.1 Number of Households by Size, Number of Vehicles, and District

District	Household Size	No Vehicles	One Vehicle	Two Vehicles	Three or More Vehicles	Total
1	1-person	8,517	32,840	7,120	1,933	50,410
	2-person	2,397	14,004	27,197	11,892	55,490
	3-person	1,179	6,849	10,051	8,053	26,132
	4-or-more-person	886	5,698	16,132	13,219	35,935
2	1-person	806	3,564	1,002	308	5,680
	2-person	246	1,585	4,098	1,718	7,647
	3-person	14	539	1,031	1,228	2,812
	4-or-more-person	61	344	1,821	1,751	3,977
3	1-person	189	2,167	413	120	2,889
	2-person	88	791	2,219	857	3,955
	3-person	105	490	1,019	705	2,319
	4-or-more-person	63	262	563	894	1,782
4	1-person	519	3,625	775	79	4,998
	2-person	144	1,598	4,330	1,289	7,361
	3-person	68	677	1,283	1,056	3,084
	4-or-more-person	84	541	2,323	1,666	4,614
5	1-person	1,030	3,529	419	67	5,045
	2-person	337	1,589	2,429	507	4,862
	3-person	16	809	932	469	2,226
	4-or-more-person	-	316	948	358	1,622
6	1-person	356	4,139	2,169	909	7,573
	2-person	226	1,672	6,936	5,263	14,097
	3-person	83	669	1,970	2,811	5,533
	4-or-more-person	82	725	3,217	4,047	8,071
	Totals	**17,496**	**89,022**	**100,397**	**61,999**	**268,114**

Source: 2007-2011 5-year ACS data.

Table 3.2 Number of Households by Size, Number of Workers, and District

District	Household Size	No Workers	One Worker	Two or More Workers	Total
1	1-person	24,187	26,223	-	50,410
	2-person	15,037	20,734	19,719	55,490
	3-person	3,538	10,532	12,062	26,132
	4-or-more-person	2,864	14,145	18,926	35,935
2	1-person	2,801	2,879	-	5,680
	2-person	1,879	2,724	3,044	7,647
	3-person	260	895	1,657	2,812
	4-or-more-person	238	1,302	2,437	3,977
3	1-person	1,082	1,807	-	2,889
	2-person	1,033	1,401	1,521	3,955
	3-person	123	917	1,279	2,319
	4-or-more-person	189	720	873	1,782
4	1-person	2,456	2,542	-	4,998
	2-person	2,022	2,690	2,649	7,361
	3-person	162	1,325	1,597	3,084
	4-or-more-person	325	1,698	2,591	4,614
5	1-person	2,449	2,596	-	5,045
	2-person	1,030	1,535	2,297	4,862
	3-person	196	793	1,237	2,226
	4-or-more-person	48	587	987	1,622
6	1-person	3,900	3,673	-	7,573
	2-person	4,132	4,866	5,099	14,097
	3-person	850	1,785	2,898	5,533
	4-or-more-person	527	2,929	4,615	8,071
	Totals	**71,328**	**111,298**	**85,488**	**268,114**

Source: 2007-2011 5-year ACS data.

The survey dataset used for weighting included 2,334 households that were geocoded unambiguously and were deemed to have provided all travel behavior information for their travel date. In preparation for survey expansion, the distribution of the sample along the demographic and geographic dimensions of interest was assessed to ensure that enough survey records existed to support robust survey expansion.

The survey data were also tabulated to the same level of detail and some of the cells were aggregated since the sample was not uniformly distributed across all segments and/or responses were too few for particular cells. As a rule of thumb, it is recommended to have at least 30 households in every cell. Cells that do not meet this criterion were combined with other “similar” cells to reduce potential bias in expansion. In certain cases, such as zero-vehicle households, more than one demographic and geographic dimension was merged into a single market segment and cell value.

Table 3.3 Number of Individuals Older than 16 by Age Group and Employment Status

District	Age Groups	Employed	Unemployed/ Not in Labor Force	Total
1	16 -17 years	1,665	10,037	11,702
	18-24 years	32,342	20,647	52,989
	25-34 years	48,621	18,669	67,290
	35-64 years	114,715	50,272	164,987
	65+ years	5,963	44,143	50,106
2	16 -17 years	194	1,015	1,209
	18-24 years	2,791	1,758	4,549
	25-34 years	5,988	1,640	7,628
	35-64 years	14,409	4,867	19,276
	65+ years	698	5,909	6,607
3	16 -17 years	144	494	638
	18-24 years	1,289	882	2,171
	25-34 years	2,948	797	3,745
	35-64 years	8,534	2,651	11,185
	65+ years	489	2,915	3,404
4	16 -17 years	378	1,264	1,642
	18-24 years	2,343	1,498	3,841
	25-34 years	5,372	1,833	7,205
	35-64 years	15,414	4,618	20,032
	65+ years	665	6,327	6,992
5	16 -17 years	87	371	458
	18-24 years	2,536	1,825	4,361
	25-34 years	3,993	730	4,723
	35-64 years	8,726	2,863	11,589
	65+ years	471	3,041	3,512
6	16 -17 years	512	2,610	3,122
	18-24 years	3,945	3,984	7,929
	25-34 years	6,926	2,635	9,561
	35-64 years	29,401	12,120	41,521
	65+ years	1,601	9,678	11,279
	Totals	**323,160**	**222,093**	**545,253**

Table 3.4 shows the aggregation patterns and targets used when considering household size and number of vehicles available. We used 55 cells in expansion for these two dimensions out of a total of 96 potential combinations. For cells that had a fairly proportional distribution in the sample compared to the ACS data, aggregation was not implemented while in other cases the cells were merged. Appendix A provides a detailed presentation of the dimensions and aggregation patterns used in expansion for the six expansion variables.

Table 3.4 Survey Expansion Targets and Aggregation Patterns for Household Size and Vehicle Ownership

		ACS Distribution					SSHTS Sample Distribution				
Districts	Household Size	No vehicle HH	1 vehicle HH	2 vehicles HH	3 or more vehicles HH	Total	No vehicle HH	1 vehicle HH	2 vehicles HH	3 or more vehicles HH	Total
1	1-person	12,979			41,893	50,410	16			99	110
	2-person		14,004	27,197	11892	55,490		24	66	33	126
	3-person			16,900	8,053	26,132			24	13	38
	4-or-more-person		5,698	16,132	13,219	35,935		6	28	24	59
2	1-person	3,134			4,874	5,680	23			96	102
	2-person		1,585	4,098	1,718	7,647		27	106	43	179
	3-person			1,570	1,228	2,812			31	24	55
	4-or-more-person			2,165	1,751	3,977			29	29	58
3	1-person				2,700	2,889				74	81
	2-person		791	2,219	857	3,955		19	70	28	118
	3-person			1,509	705	2,319			17	12	29
	4-or-more-person			825	894	1,782			18	11	30
4	1-person		3,625		854	4,998		105		25	131
	2-person		1,598	4,330	1,289	7,361		36	98	46	181
	3-person		1,218	1,283	1,056	3,084		24	26	23	63
	4-or-more-person			2,323	1,666	4,614			40	30	80
6	1-person		4,139		3,078	7,573		62		32	97
	2-person		1,672	6,936	5,263	14,097		25	103	95	223
	3-person			2,639	2,811	5,533			27	36	63
	4-or-more-person			3,942	4,047	8,071			32	47	79
5	1-person	1,383			4,015	5,045	38			143	174
	2-person		1,589	2,429	507	4,862		37	94	28	164
	3-person			1,741	469	2,226			35	13	49
	4-or-more-person			1,264	358	1,622			32	12	45
	Total	**17,496**	**89,022**	**100,397**	**61,169**	**268,114**	**77**	**1,022**	**688**	**547**	**2,334**

Iterative Proportional Fitting

Survey weights are estimated to account for oversampling and under sampling of specific market segments. All the survey observations with a specific characteristic are factored by the ratio of the sum of the actual households with the characteristic (taken from ACS-based estimates) to the sum of survey records with the same characteristic. However, when multiple characteristics are considered, the weighting for each characteristic changes the weighting for previous characteristics considered. Consequently, a raking procedure that implemented the iterative proportional fitting (IPF) technique was used to establish weights for each characteristic in an iterative fashion.

The IPF approach can be problematic if there are no records or very few records in the survey data for a particular control variable category or if there are one or more records in the survey data with a particular control variable category, but there are no corresponding records in the corresponding ACS estimates. The aggregation schemes as discussed in the previous subsection and as shown in Appendix A also help with reducing the matrix size for more robust IPF application.

The ACS sources, factored to the number of households in the survey sample, were used to establish control matrices for the survey expansion variable categories. The household survey data were tabulated by the control variable categories, and provided an initial estimate of the joint distribution. The joint distribution cells were factored so that they matched the ACS estimates for the first set of cross-classified variables.

The adjusted survey database was then compared against cross-classification tables for the next set of variables and a similar adjustment procedure was employed. Once all the variables were included in this adjustment process, one round of the expansion procedure was completed. Then, a second iteration using the same steps was repeated. This iterative process continued until all the adjustment factors converged to one and there was no meaningful difference observed between the results of one round to the next. We used a range of ± 0.05 for convergence due to the multi-level household and person expansion which typically introduces more fluctuations than a single level expansion.

Expansion Weights

The raking procedure converged after 42 iterations. Both household and person level weights ranged between 0.08 and 79.0 reflecting the variation and imbalances in the survey sampling rates across the region and across socioeconomic segments compared to the population patterns observed in the ACS data. Table 3.5 shows a set of key descriptive statistics for the household and person level weights. For expansion, household weights are multiplied by 114.87, and person weights are multiplied by 122.88.

Table 3.5 Descriptive Statistics for Household and Person Level Weights

Statistic	Household Level Weights	Person Level Weights
Mean	1.000	1.095
Standard Error	0.052	0.036
Median	0.368	0.428
Standard Deviation	2.50	2.58
Confidence Level (95.0%)	0.102	0.071
Sample Variance	6.27	6.67
Minimum	0.08	0.08
Maximum	79.03	78.97
Sum	2,334	5,606
Count	2,334	5,119

Tables 3.6 and 3.7 show the average weights for each population group defined by geography, household size, number of vehicles and number of workers, respectively. Since the Pierce County (District 1) portion of the study area was sampled at a lower rate, the procedure assigned larger adjustment weights. For the Olympia area (District 5), the sampling rate was higher than average and those cells were adjusted downward. The sample also included fewer responses and more missing observations from zero-vehicle households as seen by the larger weights in Table 3.6. Similar issues were found for zero-worker households in Table 3.7.

Table 3.6 Means of Household Weights by Household Size, Number of Vehicles, and District

District	Household Size	No vehicle available	1 vehicle available	2 vehicles available	3 or more vehicles available	Means
1	1-person HH	6.41	3.86	3.40	3.68	4.04
	2-person HH	7.47	5.15	3.63	3.17	3.89
	3-person HH	10.83	13.60	4.32	5.50	6.12
	4-or-more-person HH	11.87	8.42	5.11	4.88	5.47
2	1-person HH	1.23	0.44	0.34	0.34	0.47
	2-person HH	1.12	0.49	0.32	0.33	0.36
	3-person HH		0.62	0.35	0.43	0.43
	4-or-more-person HH		0.79	0.62	0.51	0.57
3	1-person HH	0.83	0.32	0.23	0.26	0.35
	2-person HH	1.18	0.35	0.26	0.26	0.28
	3-person HH		0.76	0.56	0.45	0.53
	4-or-more-person HH	1.87	0.46	0.55	0.45	0.55
4	1-person HH	0.89	0.29	0.29	0.29	0.30
	2-person HH	1.61	0.38	0.37	0.24	0.35
	3-person HH		0.44	0.42	0.46	0.44
	4-or-more-person HH		0.42	0.49	0.52	0.50
5	1-person HH	0.27	0.25	0.18	0.12	0.25
	2-person HH	0.57	0.36	0.22	0.15	0.25
	3-person HH	0.15	0.41	0.42	0.30	0.38
	4-or-more-person HH	0.31	0.29	0.34	0.25	0.31
6	1-person HH	1.36	0.56	0.79	0.86	0.66
	2-person HH		0.58	0.58	0.48	0.54
	3-person HH		1.59	0.60	0.65	0.72
	4-or-more-person HH			1.03	0.72	0.84
Means		1.99	1.05	0.93	0.92	1.00

Table 3.7 Means of Household Weights by Household Size, Number of Workers, and District

District	Household Size	No workers	One worker	Two or more workers	Total
1	1-person HH	5.43	3.28		4.04
	2-person HH	3.47	4.36	3.81	3.89
	3-person HH	17.68	6.92	4.66	6.12
	4-or-more-person HH	13.26	5.83	4.80	5.47
2	1-person HH	0.45	0.50	.	0.47
	2-person HH	0.23	0.49	0.40	0.36
	3-person HH	1.20	0.47	0.36	0.43
	4-or-more-person HH	.	0.48	0.65	0.57
3	1-person HH	0.32	0.63	0.49	0.57
	2-person HH	0.23	0.33	0.29	0.28
	3-person HH		0.51	0.55	0.53
	4-or-more-person HH		0.63	0.49	0.55
4	1-person HH	0.28	0.31		0.30
	2-person HH	0.23	0.47	0.39	0.35
	3-person HH	0.84	0.50	0.35	0.44
	4-or-more-person HH	0.86	0.46	0.51	0.50
5	1-person HH	0.27	0.23	.	0.25
	2-person HH	0.24	0.19	0.32	0.25
	3-person HH	0.86	0.34	0.38	0.38
	4-or-more-person HH	0.31	0.27	0.33	0.31
6	1-person HH	0.71	0.62		0.66
	2-person HH	0.44	0.57	0.61	0.54
	3-person HH	3.88	0.65	0.61	0.72
	4-or-more-person HH		0.85	0.84	0.84
Total		0.93	1.04	1.02	1.00

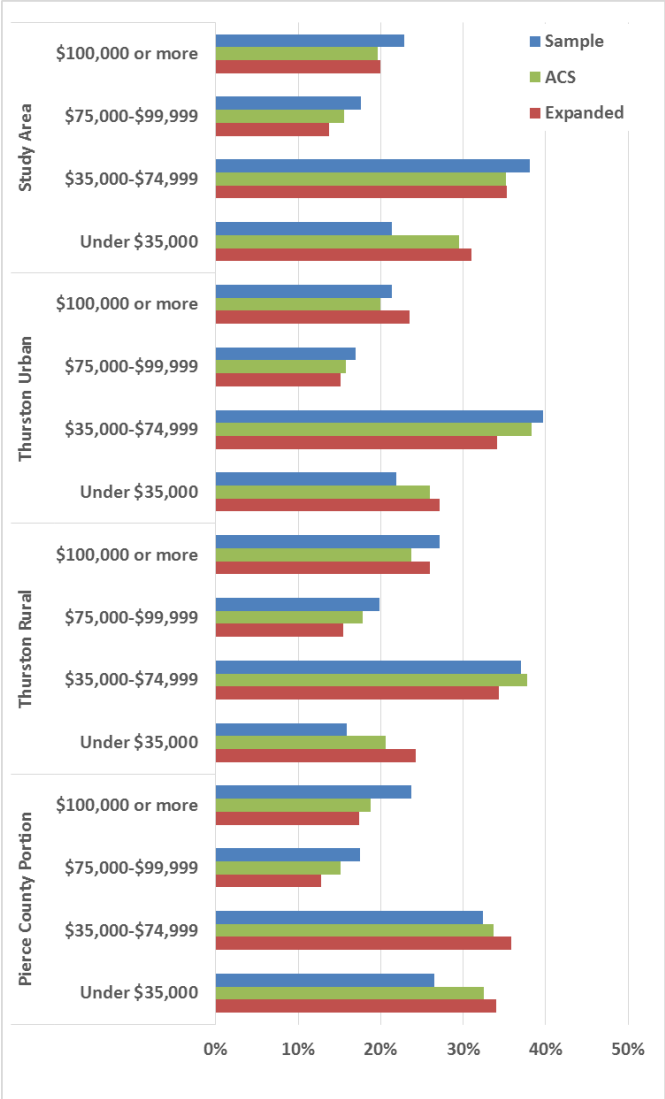
The expansion weights ranged between 9.31 and 9,079 for household level and between 9.9 and 9,704 for person level data. In general, person weights were 3.5 to 10 percent higher than the household indicating that the sample included households that are smaller in size than the average household size in the region.

To assess the performance of the expansion factors, the survey data were tabulated by select socioeconomic characteristics that were not included in the expansion factor computations such as household income, gender

and educational attainment. Figures 3.3 through 3.5 show frequency distributions observed before and after the expansion and the comparisons of these survey patterns to ACS distributions.

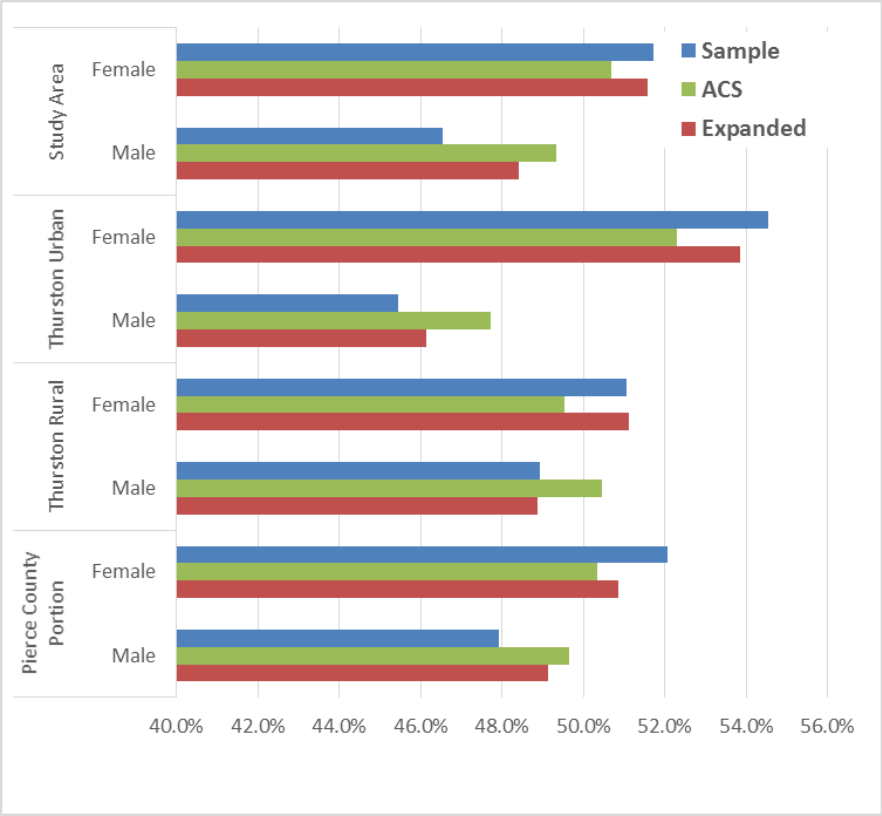
The expansion provided a close match for most of the income categories for the entire study area (**Figure 3.3**). When the study area is broken into subregions, the gaps between the expanded data and ACS slightly increased. In most categories, the expansion provided a correction in the right direction, reducing the gap between the unweighted sample and the ACS data. Close relationships between vehicle ownership and the number of workers with the household income levels can be attributed to this outcome. However, the income category $35,000 - $74,999 had larger discrepancies between the ACS and expanded data shares at the district level comparisons.

Figure 3.3 Income Distribution Comparison Before and After Expansion



Respondents' gender was another factor that was not controlled for by the expansion procedure. Typically, gender differences between sample data and ACS data are minor and fall within the 3 percent range. As shown in Figure 3.4, expansion had a modest impact in correcting the differences between the sample data and ACS data and the changes were in the expected direction for all segments.

Figure 3.4 Gender Distribution Comparison Before and After Expansion



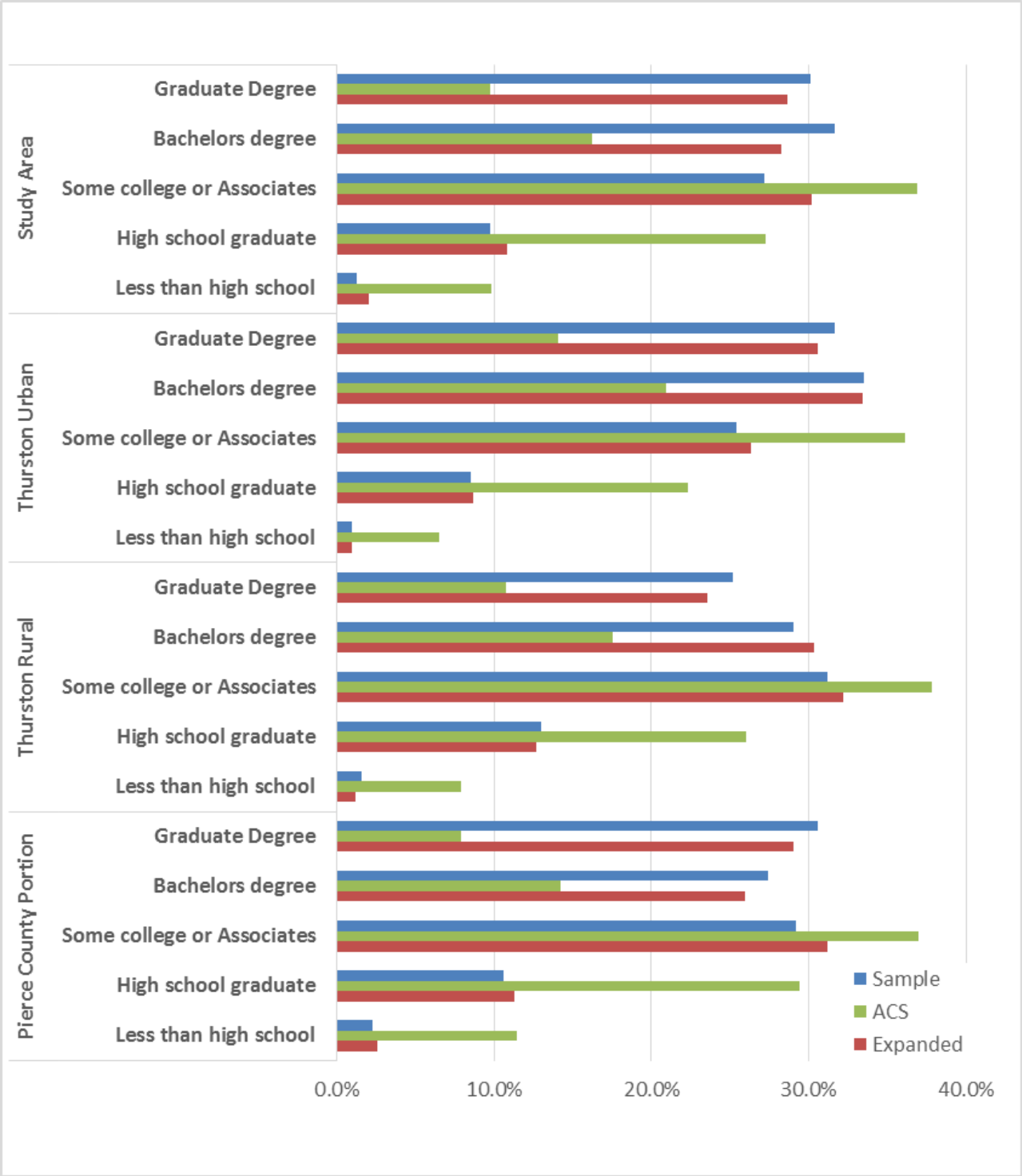
The survey sample drew households with respondents with higher levels of educational attainment (college or graduate degrees). Since educational attainment was not targeted or monitored during the survey, and the relationships between educational attainment, vehicle ownership and number of workers in the household are not very strong, the amount of correction introduced by the expansion was limited as shown in **Figure 3.5**. For the expanded data, shares of graduate and bachelor's degree holders were overrepresented in the expense of individuals with educational background of few years of college or less.

In general, the expansion procedure implemented corrections in the patterns of household and person level characteristics simultaneously. The expansion showed important improvements in matching marginal distributions in key variables that are closely related with characteristics chosen for expansion. <u>However, users need to use caution when inferring or reporting about items that are not related with targeted variables. The data may be needed to be reweighted for such purposes</u>.

3.2 Data Cleaning

This section outlines the steps undertaken to refine and recode the Household Travel Survey data. This was necessary since our preliminary analysis of the data showed that there were some inconsistencies, potentially due to respondent error. These errors led to illogical entries for some trips, excessive trip reporting (for example, the access or egress portions of a transit trip were recorded as separate trips), and in some cases underreporting of trips (for example, one "home to home" trip, instead of two home-based other trips). We conducted a set of detailed logical checks to search for such trips and created code to transform these records in a manner consistent with the rest of the data. The types of trips that are affected by these adjustments included:

Figure 3.5 Educational Attainment Comparison Before and After Expansion



- Home based school trips,
- Transit trips,
- Home based work trips,
- Home to home trips, and
- Trips from out of region households.

In the following sections, the logic used to identify and resolve similar issues is described in detail. These adjustments resulted in reduction of 377 trip records, and updates. The final trip file has 17,752 trips from 2,123 households reporting at least one trip.

Home-Based School Trips

We observed that some of the home based school trips were made by non-student adults. For some of these trips, the respondent was accompanying a school age student traveling to a school location, and for the rest, the respondent was alone. For the former condition, the travel purpose was changed to a drop-off and the generic purpose of "Home-based Other" (HBO) was assigned for a more aggregate level trip purpose definition. For the latter pattern, the trip purpose was replaced as "personal", since it is possible for non-student adults to travel to school for personal reasons, drop-off documents, participate in school meetings or social activities held during off-school hours. The generic label of HBO was also used for these trips. This step resulted in making corrections to 122 trip records.

The other home-based school correction was made to differentiate trips to universities or other adult learning centers. The original trip purpose categories did not distinguish these trips. All home-based school trips that are made alone by student adults, are relabeled as "Home-based College" trips. This resulted in 124 corrected trip records.

Transit Trips

For some of the trips where transit was used, access and/or egress portions of the transit trips were recorded as separate trips. For these trips, entries reporting just access or egress portions of a transit trip were removed from the trip file. The origin, destination, start and end times, trip purpose at the origin and the destination, and trip purpose fields were updated for the main transit trip, and the access and egress data were updated accordingly. This step resulted in the removal and adjustment of 112 trip records.

Home-Based Work Trips

Home-based work trips are an important part of the travel behavior since they are repetitive and happen during the peak periods. In addition, there are data sources available to validate models predicting HBW trip making. However, in some cases, trips to work include infrequent or non-systematic intermediate stops for short activities such as making an ATM transaction, getting a cup of coffee or making a stop at the post office.

These short activities result in one home-based non-work trip and a non-home based trip. In order to preserve the actual trip purpose structure, trips made to intermediate stops on the way to work from home and from work to home for an activity less than 10 minutes were merged into a single HBW trip. These records were updated to reflect home and workplace locations as origin or destination, trip start and end times, travel times, and travel mode. If the travel mode changed during the home based work trip chain, the following modal hierarchy was used to assign travel mode to the entire trip chain (**Table 3.8**).

This step resulted in the creation of 252 new home-based-work trip chains and the elimination of 252 trips made to an intermediate stop for a short activity.

Table 3.8 Modal Hierarchy Assumption

Mode Pairs Observed	Mode Assigned
Drive alone, drive with others	The mode used for the longer leg
Bus, walk	Bus
Drive with others, walk	Drive with others
Drive alone, bus	The mode used for the longer leg
Drive alone, vanpool	Vanpool
Drive alone, walk	Drive alone
Drive with others, vanpool	Vanpool
Drive alone, other	Drive alone
Drive with others, other	Drive with others
Train, walk	Train

Home-based Home Trips

Home based home trips were reported by some respondents typically for activities with no true destination. The real purpose of these trips was generally the trip itself such as walking the dog, or going out for a run. However, in some cases these trips appeared as a result of reporting errors. We have analyzed trips that were labeled as home-based-home (HBH) trips and introduced a few corrections.

There were 227 trip records with a HBH label, out of those 125 were mislabeled since at least one of the trip ends for these records was outside home. Six of these records indicated either a HBW or HBSch trip, the HBH label was corrected and reassigned depending on the address (home, workplace, or school). The remaining 119 trips were made to other destinations, since no other information was available for non-home trip ends in the trip record, these activities were labeled as “Other”, and these trips were labeled as HBO trips.

There were 240 trip records for which home location was reported for both trip ends. Out of those, 56 trip records were mislabeled either as a NHB or a home-based trip with a specific purpose (e.g., work, school, shopping). Trip purposes of these relabeled as a HBO trip.

Household Geocoding

For 13 trip records, the household location was not matched with an expansion weights. These trips were not included in the final dataset.

4.0 Population Synthesis

4.1 Overview

Socioeconomic and demographic variables are proven to have an impact on travel behavior. Therefore, it is desirable to segment the population by socioeconomic characteristics starting from the trip generation step. However, in most cases the desired level of detail exceeds the available detail in land use estimates and projections and the information provided by the Census products. Most ACS tabulations include two-dimensional tables at the tract or blockgroup level of detail. These limitations require more computationally elaborate land use models, or ways to estimate the joint distributions of socioeconomic variables. Applications of discrete choice models to segment the population in the desired number of categories are common. However, these applications rely on simplifying assumptions to generate the desired joint distributions and require additional effort if a different form of segmentation is desired.

The Population Synthesis step provides a flexible and a robust means to estimate joint distributions for a population based on a set of desired socioeconomic variables such as household size, number of vehicles, and income. The procedure uses Census based socioeconomic data to define the marginal distributions of the key demographic dimensions at the Census tract level of detail. Although smaller geography can be used, it is not recommended due to the relatively large margins of error (MOE) at the blockgroup and TAZ level of detail.

The 2007-2011 ACS 5-Year Public Use Micro Sample (PUMS) database provides the source to generate the seeds for these joint distributions. The PopGen tool, a publicly available population synthesizer developed by Arizona State University, generates a synthetic population by choosing subjects from the PUMS data multiple times to match the targeted joint distributions. The PopGen software is also capable of generating synthetic populations while controlling and matching the distributions both for household-level attributes (such as vehicle ownership) and person-level attributes (such as gender and age groups).

The software utilizes a standard iterative proportional fitting algorithm (IPF) to draw households from the sample data such that the marginal distributions from the selected households match the distribution of the control data for the variables under consideration. The tool runs iteratively to adjust for household level control variables and person level control variables to generate a population that matches targets on both dimensions.

An illustrative example that details the key steps in setting up a PopGen run is provided in Appendix B.1

4.2 Approach

The previous TRPC model included segmentation by the following variables:

- Household size;
- Number of vehicles in the household;
- Number of workers in the household; and
- School enrollment.

In order to maintain the segmentation patterns in the previous version of the model, the variables above were used as targets to create a synthetic population for the study area. The resultant synthetic population was used to generate a wide variety of joint distributions. This section summarizes the methodology and approaches

used to synthesize population in the South Sound Travel Study area including Thurston County, Grays Harbor County, Pierce County, Lewis County and Mason County.

The majority of the data sets used in the process are publicly available online and each data sources is described below.

- Marginal distributions of the whole region were derived from the 2008-2012[2] 5-year ACS data. Tables including variables of interest were extracted at block group level of detail.
- Disaggregate data for the seed matrix came from the 2007-2011 5-year PUMS dataset, which is a subset of ACS data that includes micro level records for individual households and persons. The 2008-2012 5-year PUMS data were not used, since the level of detail was aggregated to the county level due to changes in geographic boundaries in 2012 to abide by disclosure regulations. Data from 2011 or earlier years use 2000 Census boundaries; data starting in 2012 use 2010 Census boundaries.
- The control variables included household size, number of workers, number of vehicles, and school enrollment in the household.
- Public Use Microdata Areas (PUMA) are the most detailed geographic areas available in ACS PUMS data; blockgroup are the finest level of geographic detail in ACS data and only available in five-year data sets; and the TRPC model uses data at the TAZ level of detail. Therefore, geographic correspondence files are developed between these layers.
- The aggregate number of households at the TAZ level provided by TRPC staff is used as the control total in the post-hoc processing procedures.

The process of expanding the seed, PUMS dataset, to mirror known ACS aggregate distributions of controlled variables is conducted in PopGen. Households in the seed sample are drawn, based on selection probabilities, to match the marginal distributions. Then, the resulting synthesized population is checked for goodness-of-fit. The selection procedure is repeated until the best fit is achieved. The main steps involved are listed as following:

- Develop geographic correspondence files.
- Set household and person level marginal totals. Marginal distributions of the variables of interest at block group level were obtained by processing ACS 2008-2012 five-year data. Household control variables at block group level included: household size, number of workers, and number of vehicles. Person level control variable was number of student age children in the household.
- Set household and person level sample data. ACS PUMS 2007-2011 five-year data sets were used as seed matrix of household and person joint distribution.
- The resulting synthetic population is comprised of individual household and individual people in blockgroup level of detail. Based on the equivalences between ACS and TAZ geographies, the joint distribution characteristics of selected population are translated to the TAZ level.

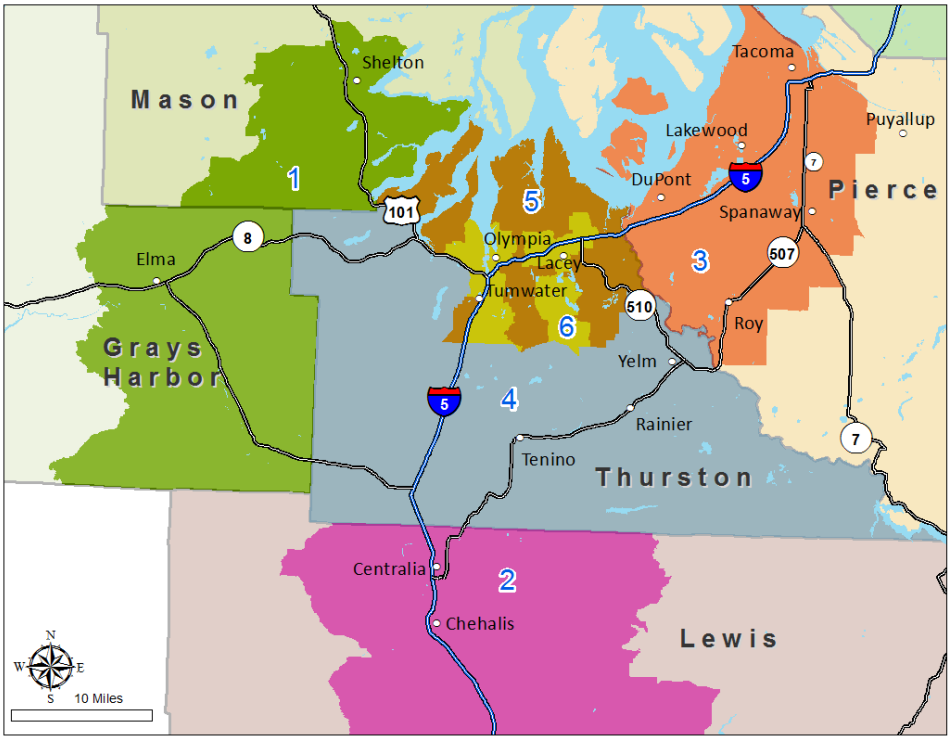
4.3 Results

In total, 450,132 households and 1,085,419 person observations were generated for the entire five county region. In the study area, there were 294,212 households and 709,905 person observations. In order to provide more detail in comparisons, the study area was divided into six districts that are nested in the 41-district model

[2] Most currently available data was sought after for generating targets for synthetic population estimation.

district structure and are shown in Figure 4.1. These districts delineate Thurston County's core urban area (Districts 5 and 6), rural Thurston County (District 4), portion of the Pierce County included in the model area (District 3), and portions of the study area on the west (District 1) and the south (District 2) of Thurston County.

Figure 4.1 District Structure for Population Synthesis Summaries



A set of comparisons between ACS patterns and TRPC's synthetic population is provided in Figures 4.2 through 4.9 which included marginal distributions of variables that are targeted by the population synthesis, a selection of two-dimensional joint distributions, and a selection of variables that were not targeted.

As shown Figures 4.2 through 4.5, the marginal distributions of targeted variables were matched almost perfectly.

Figures 4.6 and 4.7 feature comparison two-dimensional joint distribution of shares of households by size and vehicle ownership for urban areas in Thurston County (District 5 and 6). Since marginal distributions of both household size and vehicle ownership were controlled for, the joint distributions from the ACS and the synthesized population showed very similar patterns: the differences between observed vs. estimated shares ranged between -.5 and 1.3 percent for District 5, and -0.5 and 0.5 percent for District 6. The other districts and additional comparisons of distributions of households by size and number of workers, and households by number of vehicles and number of workers are provided in Appendix B.2. Those joint distributions from the synthesized population performed comparable to those detailed above.

Income distribution was not targeted by the population synthesizer. Figure 4.8 features comparisons of shares of households in each income level. In general, there is an internal agreement in the patterns of shares of households by income groups. Group differences ranged between -12 and 10 percent. Most of the variation was observed in the $55,000 - $100,000 income level and high income group shares. For urban areas in Thurston County lower income shares observed in the synthetic population were slightly higher than those in the ACS.

Figure 4.2 Comparisons of Shares of Households by Size

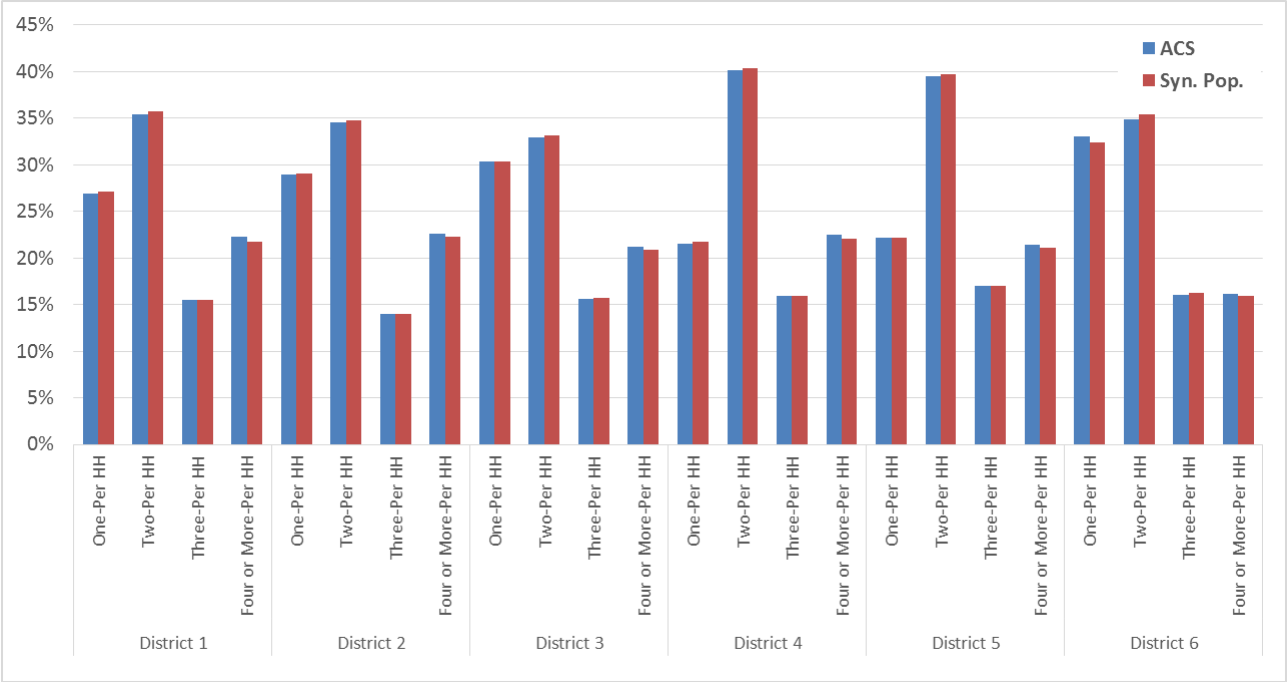


Figure 4.3 Comparisons of Shares of Households Number of Vehicles

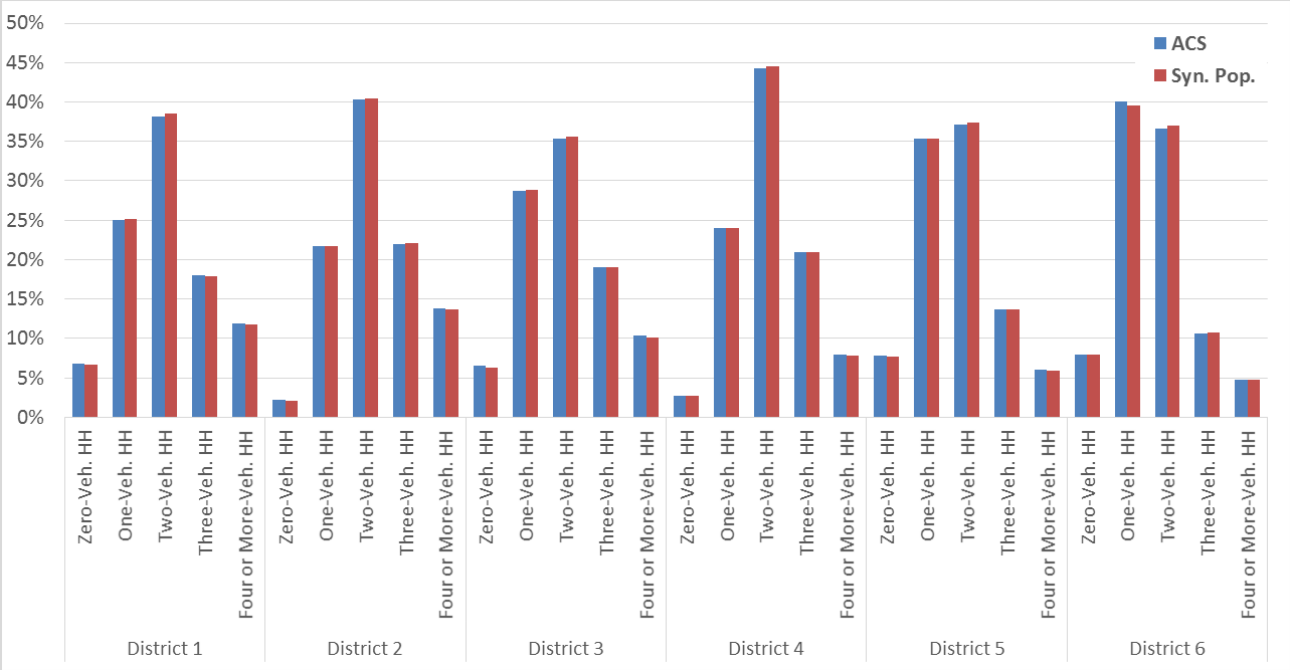


Figure 4.4 Comparisons of Shares of Households Number of Workers

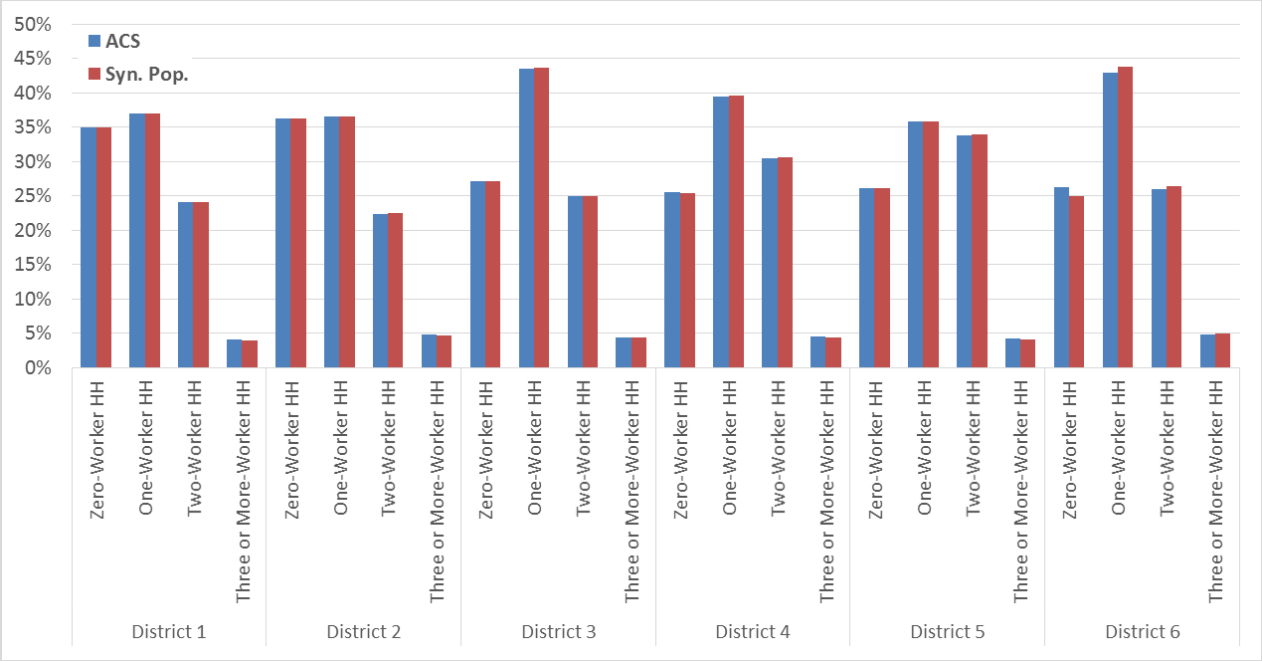


Figure 4.5 Comparisons of Shares of Persons by School Enrollment

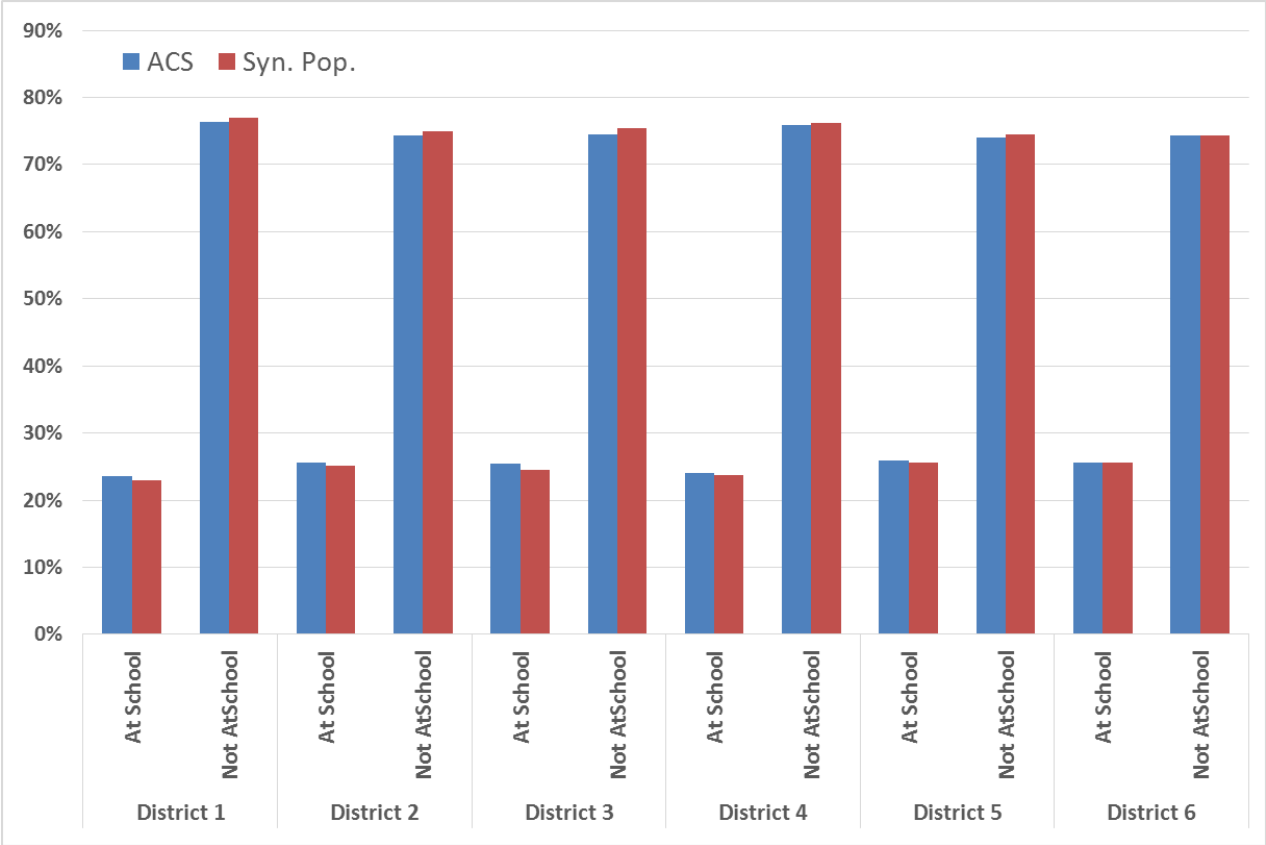


Figure 4.6 Comparisons of Shares of Households by Size and Vehicles – District 5

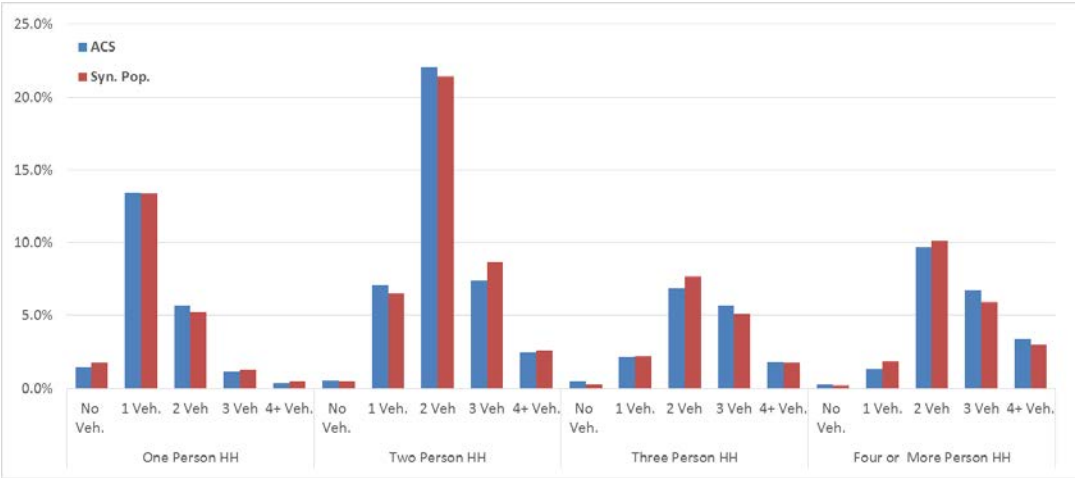


Figure 4.7 Comparisons of Shares of Households by Size and Vehicles – District 6

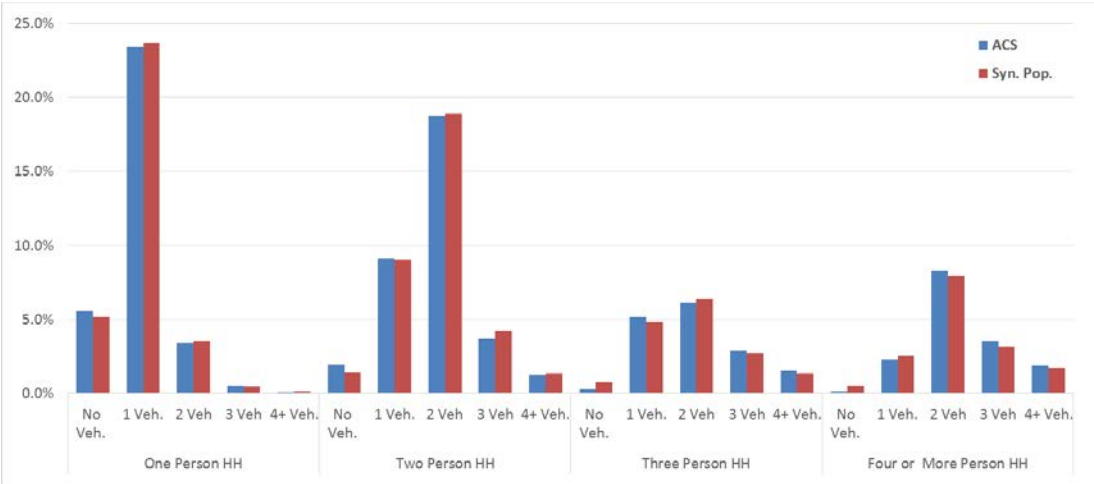
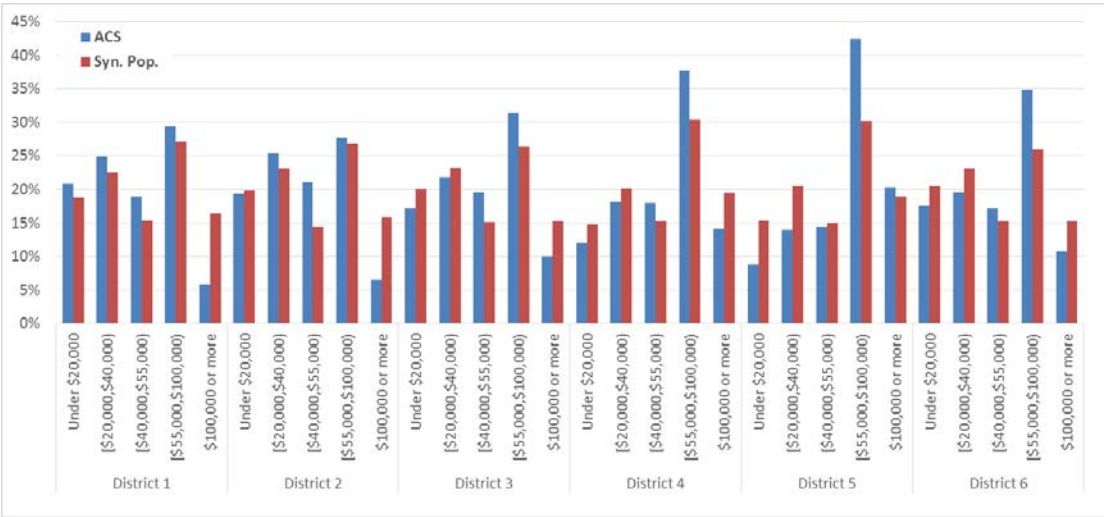
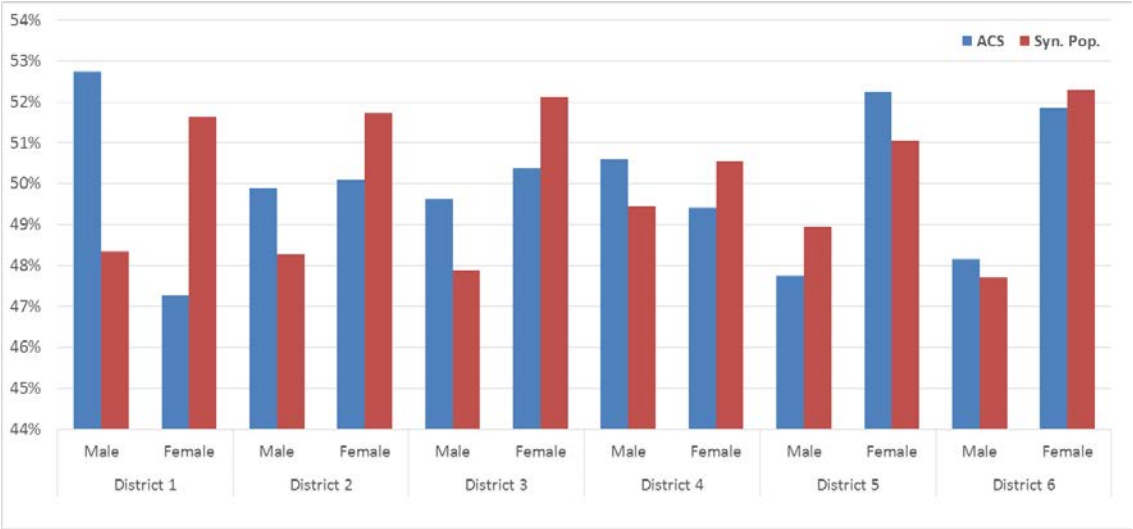


Figure 4.8 Comparisons of Shares of Households by Income Levels



Gender was another uncontrolled parameter in the population synthesis since the model was not sensitive to gender variations in travel behavior and in most applications, gender distributions generally match population distributions. Figure 4.9 shows that gender distribution was not matched well in District 1 (portions of Mason and Grays Harbor Counties), District 2 and 3 also had deviations exceeding one percent. For more advanced modeling approaches, population synthesis should be updated to include more detailed targets. However, the synthetic population developed for the study area is sufficient for the level of detail required for successful application of the TRPC model.

Figure 4.9 Comparisons of Shares of Population by Gender



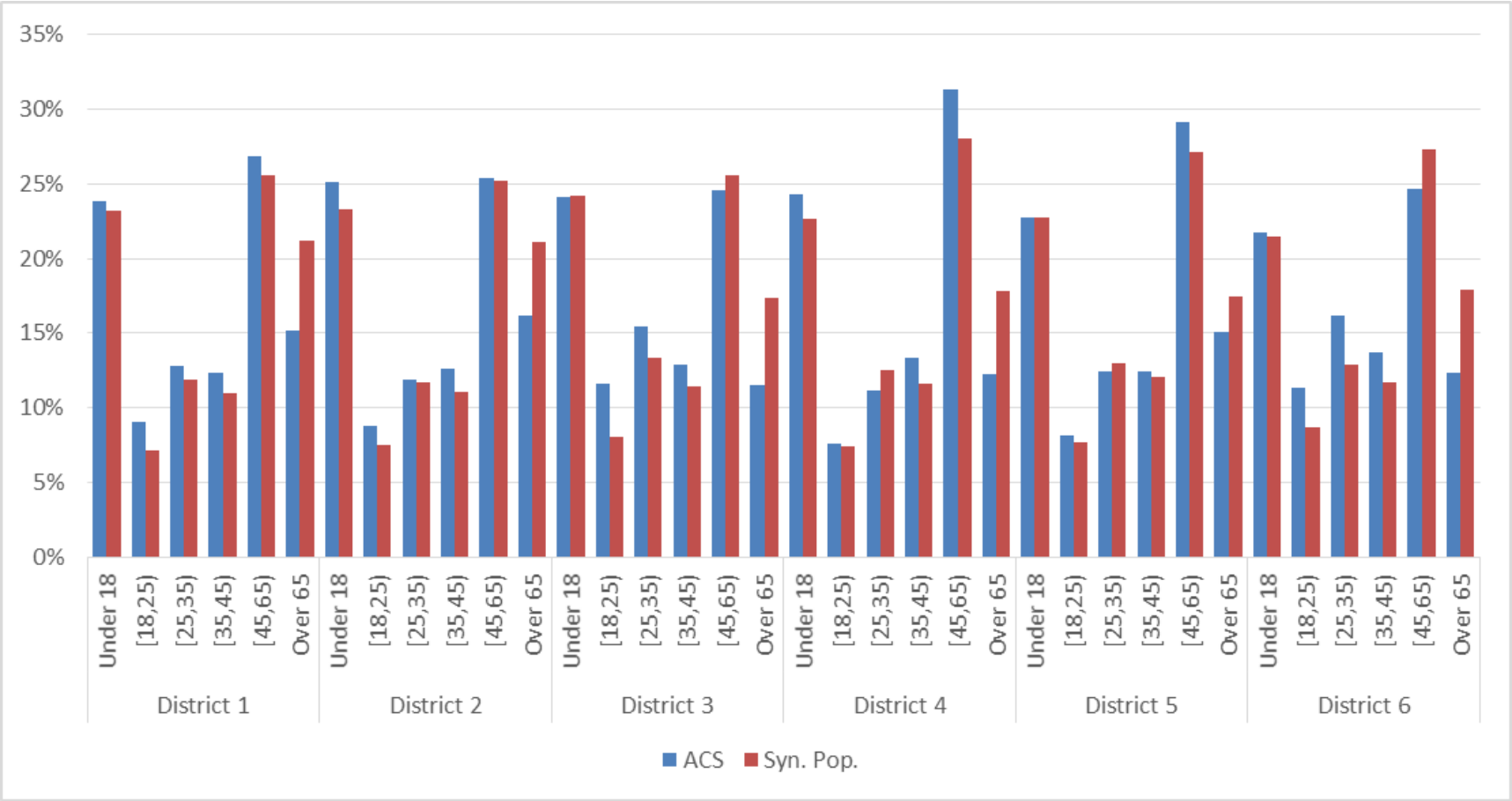
In order to provide necessary flexibility to modeling needs for the next steps, four sets of joint distributions were prepared. These distributions segmented the population by the following key variables at the TAZ level of detail.

- Household size (4) by number of vehicles (4) - 13 cells in total
- Household size (4) by number of workers (4) - 13 cells in total
- Household size (4) by household income (4) - 16 cells in total
- Household size (4) by number of school age kids (3) - 9 cells in total

We have also provided in **Appendix B.3** the detailed documentation provided by Arizona State University related to the Population Synthesizer PopGen. A total of nine sections are included detailing the following:

- Installation;
- Data Structure;
- Project Setup using Census or user provided data;
- Modifying data and setting up a PopGen run;
- Running PopGen to generate a synthetic population; and
- Exporting results and visualizing the final output.

Figure 4.10 Age Group Comparisons



4.4 Future Year Socioeconomic Projections

As described in sections 4.1 through 4.3 the synthetic population developed for the Thurston Region depended on blockgroup level patterns of key socioeconomic variables. The resultant population was then used to estimate joint distributions of socioeconomics to be used in the next set of models.

For developing future year projections, forecasts of number of households and population were provided by the TRPC staff. These estimates were developed independently from each other. Two different approaches were followed to generate future year joint distributions of socioeconomic variables by,

- Using base-year joint distributions, and
- Matching implied future-year average household sizes.

Future-year Distributions by Using Base-year Distributions

The estimation of future year socioeconomic distributions was based on the joint distributions obtained from synthesized population for the base year. The key assumption is that relative distributions in each of the four two-dimensional tables (HHSIZE x WORKERS, HHSIZE x VEHICLES, HHSIZE x INCOME, and HHSIZE x KIDS) will remain the same in 2040. This assumption is needed since PopGen cannot synthesize future year population without forecasted marginal targets for the variables above. The information for the future year included only number of households and population (household population only) in each TAZ.

Future-year Distributions by Matching Future-year TAZ Level Average Household Size

These distributions were derived by an analytical procedure that matched both number of households and population forecasts for 2040. The procedure used the MS Excel Add-In, "Solver" in which the distribution of household sizes was adjusted to match the population forecasts. A linear programming (LP) formulation is used to set the difference between the forecasted and implied population to zero by changing the household size distribution.

The formulation only used the total number of households in the TAZ as a constraint. The minimum number of households in each size category was set to at least 1.0 and the total number of households was constrained to the number of households forecasted for that TAZ. The results were reviewed and adjusted manually where the objective function (difference between calculated and forecasted population) was not met due to unity assumptions.

The two-dimensional joint distributions were recalculated to maintain relative distributions in each size category estimated for the base year.

The LP formulation resulted in an indeterminate system where multiple solutions are possible. Therefore, we **do not recommend** using the second set after a careful examination. If possible, additional constraints should be imposed to improve the stability of the solutions, however, these require more detailed information or new set of assumptions.

5.0 Trip Generation

The estimation of daily travel is referred to as trip generation where the amount of travel is calculated for each trip purpose. Home-based trips are forecast from the home locations to activities outside the home including work, school, shopping, and university. The home-based non-work related trips are often aggregated into a single home-based other (HBO) trip purpose.

Four-step models forecast trip productions and attractions, with each trip having one production end and one attraction end. Productions are related to the home end of the trip while attractions are related to the non-home end. For example, a single worker may generate two home-based work (HBW) trip productions at home – a trip from home to work and a trip from work to home. At the work location, the same worker would generate two attractions for the same two trips. Trip productions and attractions focus on the locations generating the travel, not the directionality of travel.

The TRPC model also accounts for non-home-based (NHB) trips which neither start nor end at home. Conventionally, the origin of a non-home based trip is designated as the production end. Since NHB trips are taken by persons living in a household, the TRPC model generated those trips at the household level and allocated these NHB trips to origins and destinations outside the home in the later stages.

- The trip generation methodology relied on classifying households into socioeconomic categories based on household size and household income for most trip purposes for the TRPC model. A special classification (household size and number of school age children) was used for home-based school trips. These classifications were used to generate trip production rates for each trip purpose.

- The trip generation methodology also incorporates a trip attraction framework. Trip attraction models are linear regression models with explanatory variables including employment, number of households, and population. Although the TRPC model design includes a destination choice model, the resulting linear regression model equations are used as a means of quality assurance for the destination choice model application.

The key data source for trip generation is the household travel survey and socioeconomic data for the region which are described briefly in the next section.

5.1 Socioeconomic Data

The preparation of socioeconomic data is one of the key steps in model development. Having a high quality socioeconomic dataset improves the accuracy of the model in representing regional travel behavior. Trip generation models consist of “production” and “attraction” components, where the estimation of trip productions relies on household characteristics and the attraction models use sociodemographic data and school enrollment.

The application of the trip production models also used regional socioeconomic data. The primary source of socioeconomic data was TRPC’s land use estimates about the number of households, student enrollment and employment by industry (in six broad categories) at the TAZ level of detail. In addition, InfoUSA data was acquired for the study area to provide more detailed industrial classification and geographical level of detail and to add another source for comparisons. InfoUSA data was also used in the truck model update particularly

for estimating and validating internal to external (I-E), external to internal (E-I) and external to external (E-E) movements.

5.1.1 TRPC Land Use Estimates to Support Trip Generation Model Estimation

TRPC land use data primarily relies on the 2010 Decennial Census, TRPC's and Puget Sound Regional Council's (PSRC) forecasts on housing growth and relocation projections, and employment estimates provided by TRPC, PSRC, the Employment Security Department (ESD) of State of Washington, and JBLM.

Since the TAZ level of detail and industry categories used in segmenting employment data raised concerns for violating the disclosure avoidance rules, the TAZ level data was suppressed. In order to still be able to use employment by industry classes, TRPC staff aggregated the employment data into a model district structure that is shown in **Figure 5.1**. A total of 41 districts was used to create enough data points to evaluate trip productions and to estimate attraction models.

Figure 5.1 Boundaries of the Modeling Districts

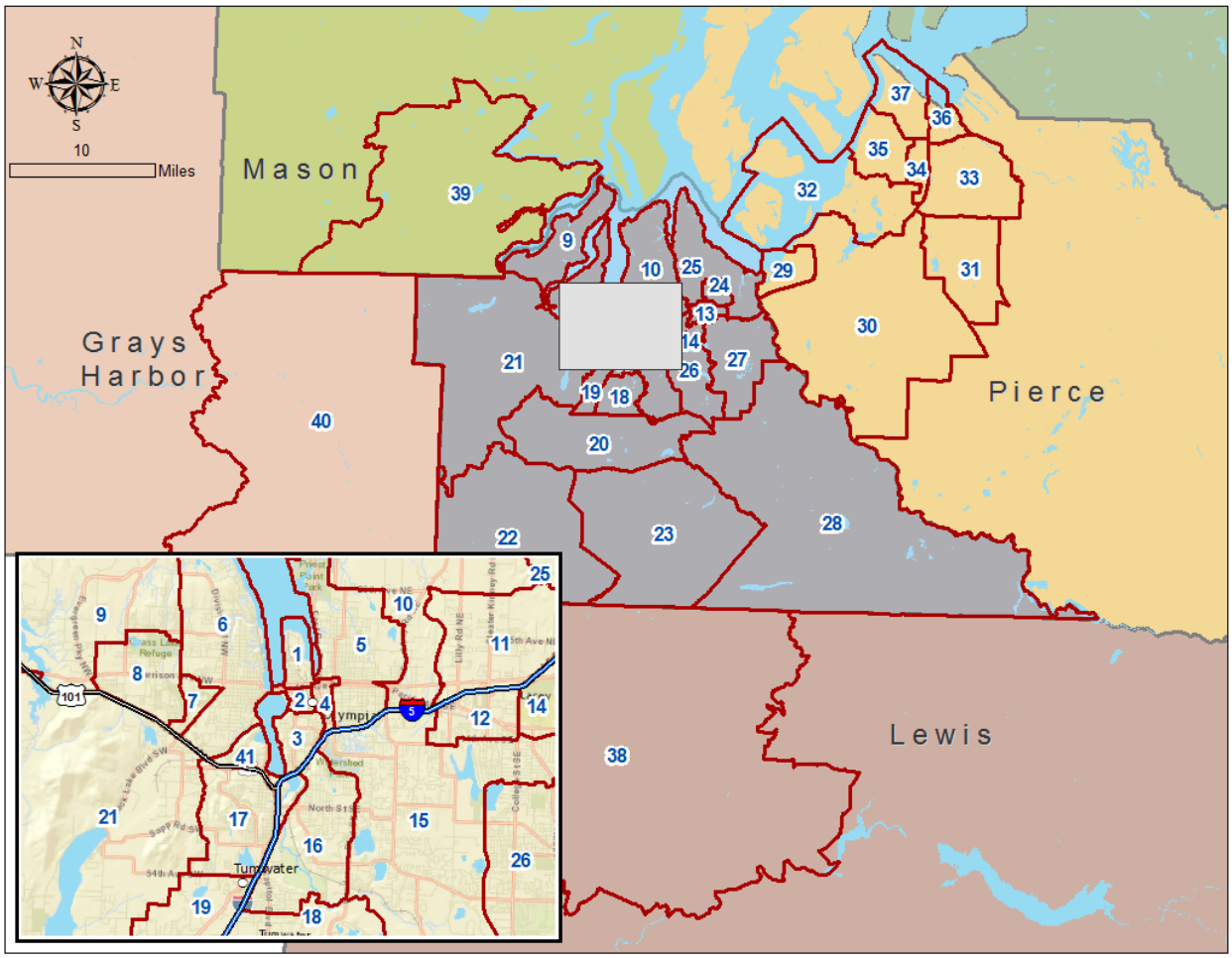


Table 5.1 shows a summary of the number of households and employment at the County level of detail based on the district level data. **Table 5.2** shows County level estimates provided by the TRPC staff which can be used for scaling estimates derived by using district level data.

The employment data was categorized using the groupings of two-digit North American Industry Classification Scheme (NAICS) or ESD ownership (for public sector employment) codes shown in **Table 5.3**.

Table 5.1 Year 2013 County Level Estimates of Employment by Industry - District Level Data

County*	Construction and Resources	FIRE and Services	Manufacturing Wholesale Trade and Utilities	Retail and Food	Public Sector / Government and Higher Education	Public Sector / K-12 Employment	Totals
Grays Harbor	361	454	699	398	672	341	**2,925**
Lewis	1,590	5,683	3,885	4,971	2,234	1,304	**19,666**
Mason	540	1,760	1,645	1,518	3,630	647	**9,740**
Pierce	7,953	72,696	15,975	30,066	71,995	11,034	**209,719**
Thurston	8,512	52,696	8,835	22,928	29,266	6,240	**128,477**
Totals	**18,956**	**133,289**	**31,039**	**59,881**	**107,797**	**19,565**	**370,528**

*: For all counties except Thurston, these figures are only for the portion of the county included in the model area

Source: TRPC

Table 5.2 County Level Estimates of Employment by Industry - County Level Data

County*	Construction and Resources	FIRE and Services	Manufacturing Wholesale Trade and Utilities	Retail and Food	Public Sector / Government and Higher Education	Public Sector / K-12 Employment	Totals
Grays Harbor	923	770	965	513	676	341	**4,187**
Lewis	3,486	9,467	4,452	5,930	2,334	1,304	**26,972**
Mason	1,283	4,461	2,126	1,939	2,670	647	**13,126**
Pierce	7,782	69,641	15,398	31,493	75,374	11,619	**211,307**
Thurston	8,512	52,696	8,835	22,928	29,266	6,240	**128,477**
Totals	**21,986**	**137,034**	**31,776**	**62,802**	**110,320**	**20,150**	**384,069**

*: For all counties except Thurston, these figures are only for the portion of the county included in the model area

Source: TRPC

Table 5.3 Aggregations of Industry Categories used in the Employment Data

Category Label	NAICS Codes	ESD Ownership Codes
Construction and Resources	11, 21, 23	
FIRE and Services	51, 52, 53, 54, 55, 56, 61, 62, 71, 81	
Manufacturing. Wholesale Trade and Utilities	22, 31, 32, 33, 42, 48, 49	
Retail and Food	44, 45, 72	
Public Sector / Government and Higher Education		1, 2, 3
Public Sector / K-12 Employment	611110	1, 2, 3

Source: TRPC

The number of households was available at the TAZ level of detail. Joint distributions of socioeconomic variables derived from the synthesized population were used to apportion the total number of households into the cross-classification categories. **Table 5.4** shows a summary of the number of households by household size and income, and the cross-classification of household size and number of school age children at the county level detail.

Table 5.4 County Level Cross-classifications Used in Trip Generation

Household Type	Income	Grays Harbor	Lewis	Mason	Pierce	Thurston	Grand Total
One-person	Under $35,000	891	4,426	1,820	29,463	14,021	**50,621**
	$35,000-$74,999	359	1,564	679	16,734	9,718	**29,055**
	$75,000-$99,999	31	94	49	2,339	1,863	**4,375**
	$100,000 or More	23	123	34	1,812	1,209	**3,200**
Two-person	Under $35,000	650	2,476	1,043	14,159	7,674	**26,003**
	$35,000-$74,999	808	2,941	1,311	21,231	13,696	**39,988**
	$75,000-$99,999	306	1,115	456	8,136	6,663	**16,676**
	$100,000 or More	224	946	347	11,039	9,928	**22,483**
Three-person	Under $35,000	289	739	342	6,428	3,414	**11,212**
	$35,000-$74,999	415	1,521	515	9,170	4,927	**16,549**
	$75,000-$99,999	142	407	188	4,396	3,093	**8,225**
	$100,000 or More	136	362	216	5,970	4,962	**11,646**
Four-or-More-Person	Under $35,000	345	1,032	566	7,816	2,538	**12,297**
	$35,000-$74,999	437	2,065	759	13,375	6,243	**22,880**
	$75,000-$99,999	245	883	381	5,852	3,613	**10,975**
	$100,000 or More	201	913	289	8,242	7,106	**16,751**

Household Type	Number of School Age Children	Grays Harbor	Lewis	Mason	Pierce	Thurston	Grand Total
One Person	None	1,312	6,216	2,581	50,280	26,676	**87,065**
Two Person	None	1,840	6,819	2,926	49,081	34,649	**95,316**
	One	140	655	234	5,540	3,343	**9,912**
Three Person	None	657	1,972	774	16,090	10,224	**29,716**
	One	168	585	314	5,483	3,665	**10,217**
	Two or More	145	469	183	4,413	2,546	**7,756**
Four-or-More-Person	None	488	1,793	662	12,833	6,906	**22,682**
	One	233	896	392	6,515	3,676	**11,712**
	Two or More	518	2,203	930	15,928	8,982	**28,561**

Source: Base Year (2014) Synthetic Population Estimates - Cambridge Systematics

The TRPC's land use data also included separate estimates of household population, population living in group quarters, and number of students enrolled in K-12 and higher education institutions. **Table 5.5** provides the county level summaries.

Table 5.5 Year 2013 Population Estimates by County

County*	Number of Households[1]	Total Population[2]	Population in Households[1]	Population in Group Quarters[2]	Enrollment (K-12)[2]	Enrollment (Higher Education)[2]
Grays Harbor	5,502	14,418	14,367	51	2,142	-
Lewis	21,608	55,808	54,945	863	9,285	2,289
Mason	8,997	25,316	23,202	2,114	4,269	300
Pierce	166,163	438,404	418,208	20,196	102,301	28,848
Thurston	100,667	252,261	248,039	4,222	39,557	9,798
Totals	**302,937**	**786,207**	**758,761**	**27,446**	**157,554**	**41,235**

*: For all counties except Thurston, these figures are only for the portion of the county included in the model area
1: Summarized data at the TAZ level of detail.
2: Summarized data at the County level of detail
Source: Washington State Office of Financial Management; TRPC

5.1.2 InfoUSA Data

While the TRPC data is an excellent resource for population and household information, the InfoUSA data provided additional detail about employment by industry that is required for both the passenger and the truck models particularly to estimate the I-E, E-I and E-E movements. In addition, the data provided another estimate of employment as a means of reasonableness of the existing TRPC data.

Infogroup provided employment by establishment for all the areas in Grays Harbor, Lewis, Mason, Thurston counties, and the portion of Pierce County covered by the model area as identified by a set of zip codes.

- Infogroup compiled data on all establishments within the study area as of September 2014.
- The purchased file included information about each establishment including:
  - 8-digit North American Industry Classification Scheme (NAICS) code;
  - Exact address as well as latitude and longitude of location;
  - Establishment Size; and
  - Estimated number of employees.

Cambridge Systematics staff compared the geocoded locations against the exact address information. Locations that appeared to be incorrectly geocoded were updated to improve the quality of the location of the data. Out of 40,648 establishments in the database, geocodes of 2,922 establishments were updated. Those records were originally coded to zip or zip+4 area centroids.

The eight digit NAICS codes were reduced to two-digits and the industry groupings shown in Table 5.3 were created to approximate the aggregation scheme used in TRPC data. Since NAICS codes corresponded to ESD ownership codes 1 thru 3, public sector employment was summarized in two categories (92: Public Administration and partially by 99: Unclassified). It should be noted that Unclassified employment may include

private entities. In addition, all the establishments were mapped and those that were within the study area boundaries were selected for the tabulation shown in **Table 5.6**.

Table 5.6 County Level Employment Estimates by Industry Using InfoUSA Data

County	Construction and Resources	FIRE and Services	Manufacturing Wholesale Trade and Utilities	Retail and Food	Public Administration	Unclassified	Totals
Grays Harbor	188	1,423	497	581	248	58	**2,995**
Lewis	1,585	10,579	7,218	6,331	2,039	192	**27,944**
Mason	733	6,328	1,354	2,279	1,603	43	**12,340**
Pierce	7,767	91,637	23,360	39,034	19,700	767	**182,265**
Thurston	6,009	46,329	8,758	25,030	33,011	658	**119,795**
Totals	**16,282**	**156,296**	**41,187**	**73,255**	**56,601**	**1,718**	**345,339**

Source: Infogroup and Cambridge Systematics.

When the employment summaries from Table 5.2 and 5.6 are compared the following observations were made:

- InfoUSA data underestimated total employment by 10 percent (about 38,700 fewer jobs) in the model area.
- While patterns of employment levels across counties are consistent, discrepancies at the county level was within the range of ±1,200 jobs for Grays Harbor, Lewis and Mason counties. The InfoUSA data underestimated employment in Thurston County by 8,700 jobs, and pointed to 29,000 fewer jobs in the Pierce County portion of the model area.
- The distribution of employment by industry also varied within the ± 30 percent range indicating a need for a closer review of NAICS code labels for both datasets.

The model application and development of I-E, E-I, and E-E trip productions and attraction was part of a separate effort.

5.1.3 Census Transportation Planning Package (CTPP) Worker Flows

The Census Transportation Planning Package (CTPP) journey to work data was used for gauging the reasonableness of the level of worker flows between the study area and surrounding communities. In addition, CTPP data was also used in the analysis of worker flows to and from JBLM as part of the analysis of travel in the JBLM area as discussed in section 5.4. The 2006-2010 5-Year CTPP data is the main source of data on worker flows. The CTPP data is developed by the Census Bureau as part of the special tabulations program managed by the FHWA and AASHTO[3]. The data includes worker flows observed in the ACS samples collected during 2006-2010. **Tables 5.7** through **5.10** show county level summaries characterizing the level of worker flows observed within the 5-County region and within the model area.

[3] http://ctpp.transportation.org/Pages/default.aspx

Table 5.7 County to County Total Worker Flows

	Grays Harbor	Lewis	Mason	Pierce	Thurston	Totals
Grays Harbor	12,673	101	282	508	2,334	**15,898**
Lewis	23	11,773	19	994	3,485	**16,294**
Mason	186	10	7,051	888	3,557	**11,692**
Pierce	80	110	119	260,142	6,755	**267,206**
Thurston	404	1,411	753	20,019	82,413	**105,000**
Totals	**13,366**	**13,405**	**8,224**	**282,551**	**98,544**	**416,090**

Table 5.8 County to County Worker Flows within the TRPC Model Area

	Grays Harbor	Lewis	Mason	Pierce	Thurston	Totals
Grays Harbor	765		164	163	860	**1,952**
Lewis		7,161		442	2,717	**10,320**
Mason	35	10	2,584	105	2,120	**4,854**
Pierce		60	39	122,866	4,229	**127,194**
Thurston	145	1,391	623	16,446	82,413	**101,018**
Totals	**945**	**8,622**	**3,410**	**140,022**	**92,339**	**245,338**

Table 5.9 County to County Worker Flows outside the TRPC Model Area

	Grays Harbor	Lewis	Mason	Pierce	Thurston	Totals
Grays Harbor	11,908	101	118	345	1,474	**13,946**
Lewis	23	4,612	19	552	768	**5,974**
Mason	151	-	4,467	783	1,437	**6,838**
Pierce	80	50	80	137,276	2,526	**140,012**
Thurston	259	20	130	3,573	-	**3,982**
Totals	**12,421**	**4,783**	**4,814**	**142,529**	**6,205**	**170,752**

Table 5.10 Percent of County to County Worker Flows within the TRPC Model Area

	Grays Harbor	Lewis	Mason	Pierce	Thurston	Totals
Grays Harbor	6.0%	0.0%	58.2%	32.1%	36.8%	**12.3%**
Lewis	0.0%	60.8%	0.0%	44.5%	78.0%	**63.3%**
Mason	18.8%	100.0%	36.6%	11.8%	59.6%	**41.5%**
Pierce	0.0%	54.5%	32.8%	47.2%	62.6%	**47.6%**
Thurston	35.9%	98.6%	82.7%	82.2%	100.0%	**96.2%**
Totals	**7.1%**	**64.3%**	**41.5%**	**49.6%**	**93.7%**	**59.0%**

Source: 2006-2010 CTPP, "A302100 - Total Workers (1) (Workers 16 years and over)" table at the Census Tracts Level of Detail and Cambridge Systematics.

The tabulations above reveal the following patterns:

- Nearly 60 percent of all worker flows that occur within the 5-county region are within the boundaries of the model area.
- The majority of all worker flows produced in Thurston County was attracted to destinations in the model area (92 percent of total). Nearly 94 percent of all worker flows attracted to Thurston County were produced in the model area.
- Thurston County exported over 22,500 workers to other counties, with 18,600 of those remaining within the model area. The great majority (90 percent) of workers commuting outside the model area traveled to further away destinations in Pierce County.
- Thurston County imported more than 16,000 workers from other counties and 9,900 of those traveled from residential locations within the model area. Thurston County attracted 2,500 workers from Pierce County and about 1,450 workers from Grays Harbor and Mason Counties who lived outside the model area.
- The portion of Pierce County which was included within the model area accounted for nearly 48 percent of all worker flow productions and nearly half of the attractions of the entire Pierce County.
- In the model area, the total size of the commute market between Thurston and Pierce counties is about 226,000 workers (92 percent). Most Pierce County residents also worked within the portion of Pierce County in the model area (123,000) and the same was true for Thurston County workers (84,000).
- However, more than 4,200 workers traveled from Pierce to Thurston for work and there were almost 16,500 Thurston County residents who worked in the portions of Pierce County within the model area.

Besides the patterns of worker flows, CTPP data provides number of workers at the residence and workplace as a means of reasonableness measures for checking work trip productions and attractions.

In addition, worker flows by industry (B302102) at the tract level of detail were extracted and provided to MPO staff. It should be noted that “B” series summary tables are perturbed to avoid privacy disclosure. More information can be found in the E-Learning Modules provided by the AASHTO[4]. The CTPP data included the following aggregate industrial categorization:

- Agriculture, forestry, fishing and hunting, and mining; Construction; Armed Forces
- Manufacturing;
- Wholesale trade; Retail Trade; Transportation and warehousing, and utilities
- Information; Finance, insurance, real estate and rental and leasing; Professional, scientific, management, administrative, and waste management services
- Educational, health and social services
- Arts, entertainment, recreation, accommodation and food services
- Other services (except public administration); Public Administration

Table 5.11 tabulates the worker flows between Thurston County and the portion of Pierce County which is located within the model area.

[4] http://ctpp.transportation.org/Pages/elearningmodules.aspx

Table 5.11 Worker Flows by Industry between Thurston County and Pierce County within the Model Area

		Pierce County	Thurston County	ALL
Pierce County	Agricultural/Construction/Armed Forces	24,010	514	24,524
	Arts, Recreation, Accommodation, Food	11,419	252	11,671
	Education, Health and Social	30,149	639	30,788
	Inf./FIRES/Prof. Admin. Services, Waste	17,701	599	18,300
	Manufacturing	4,904	143	5,047
	Other Services	15,127	1,428	16,555
	Wholesale/Retail/TWU	19,437	631	20,068
	ALL	**122,747**	**4,206**	**126,953**
Thurston County	Agricultural/Construction/Armed Forces	4,620	6,807	11,427
	Arts, Recreation, Accommodation, Food	518	7,843	8,361
	Education, Health and Social	2,921	17,232	20,153
	Inf./FIRES/Prof. Admin. Services, Waste	2,794	12,738	15,532
	Manufacturing	748	3,235	3,983
	Other Services	3,035	20,860	23,895
	Wholesale/Retail/TWU	1,800	13,592	15,392
	ALL	**16,436**	**82,307**	**98,743**
ALL	Agricultural/Construction/Armed Forces	28,630	7,321	35,951
	Arts, Recreation, Accommodation, Food	11,937	8,095	20,032
	Education, Health and Social	33,070	17,871	50,941
	Inf./FIRES/Prof. Admin. Services, Waste	20,495	13,337	33,832
	Manufacturing	5,652	3,378	9,030
	Other Services	18,162	22,288	40,450
	Wholesale/Retail/TWU	21,237	14,223	35,460
	ALL	**139,183**	**86,513**	**225,696**

Source: 2006-2010 5-Year CTPP, B302102 - Industry (8) (Workers 16 years and over)

These patterns suggest that Thurston attracted higher shares of workers in the public sector and educational, health and social services. Pierce County attractions were concentrated in agricultural, construction, and military. Both private and public services had a considerable number of workers traveling from Thurston County to Pierce County within the model area.

5.2 Trip Productions

The TRPC model included six distinct trip purposes in this step:

- Home Based Work (HBW)
- Home Based Shopping (HBShp)
- Home Based School (HBSch)
- Home Based University (HBU)
- Home Based Other (HBO)
- Non-Home Based (NHB)

The trip production models are two dimensional cross-classification models based on various demographic variables. Households for each zone are cross-classified by household size, income level, and the number of children in school age (5-18). Necessary joint distributions of households by these variables were drawn from the synthetic population developed for the TRPC model.

Household size and income classification was used for all purposes other than the HBSch purpose which was segmented by household size and number of school age kids in the household. Income segmentation was preferred, since it provided more distinct differences in trip rates across the groups. More importantly, segmentation by income allows modeling the behavior of these groups separately. This is important since we expect different responses across income groups to changes in cost of travel which can be affected by policies such as transit fares, tolling or congestion pricing.

The following categories are used in segmenting the households:

- *Household size:* one-person, two-person, three-person households, and households with four-or-more-persons.
- *Household Income*: under $35,000, between $35,000 and $74,999, between $75,000 and $99,999, and $100,000 or higher.
- *Number of children in the household:* no children, one child, and two or more children.

The cross-classification trip production models were estimated primarily using the 2013 Household Travel Survey data. Trip rates for each trip purpose were obtained by tabulations of trip rates and the progression of trip rates across size and income dimensions was reviewed. It is expected that as household size and income levels increase; the trip rates also increase. It is possible to observe some anomalies due to uneven sampling rates and biases in the surveys. Cells displaying unexpected rates are combined with neighboring cells to smoothen these trip rates.

When trips from the Household Travel Survey were segmented by household size and income, the progression of trip rates showed a great degree of variation in size and gradation across the segments. In order to smoothen the observed trip rates, rates published in NCHRP 716[5] were used in an iterative proportional fitting procedure that was applied to match the trip totals inferred by the survey. Since HBShp and HBU trip rates were not detailed in NCHRP 716, rates from the Capital Area Metropolitan Planning Organization (CAMPO) model were used for these purposes.

The adjusted trip rates are listed in **Tables 5.12** through **5.17.** These rates were then applied to the TAZ level socioeconomic distributions to estimate trip productions. The review of HBU trips using enrollment data showed that university trips were underestimated by about 17 percent requiring a scaling adjustment of a similar

[5] National Cooperative Highway Research Program (NCHRP) Report 716: Travel Demand Forecasting: Parameters and Techniques, 2012.

magnitude. The rates presented in **Table 5.14** reflect this adjustment. In addition, each college student living in group quarters is assumed to produce 1.2 HBU trips which were later incorporated in the destination choice modeling step.

Table 5.12 Rates for Households by Size and Income Levels for Home-Based Work Trip Purpose (trips/hh)

Household Type	Less than $35,000	Between $35,000 and $74,999	Between $75,000 and $99,999	$ 100,000 or Higher
One-Person HH	0.397	0.529	1.113	1.508
Two-Person HH	0.963	1.139	1.284	2.206
Three Person HH	1.166	1.940	2.100	3.033
Four-or-More Person HH	1.949	2.029	2.583	3.033

Table 5.13 Rates for Households by Size and Income Levels for Home-Based Shopping Trip Purpose (trips/hh)

Household Type	Less than $35,000	Between $35,000 and $74,999	Between $75,000 and $99,999	$ 100,000 or Higher
One-Person HH	0.553	0.627	0.658	0.683
Two-Person HH	0.769	0.870	0.870	0.939
Three Person HH	0.949	1.073	1.153	1.226
Four-or-More Person HH	1.112	1.254	1.362	1.466

Table 5.14 Rates for Households by Size and Income Levels for Home-Based University Trip Purpose (trips/hh)

Household Type	Less than $35,000	Between $35,000 and $74,999	Between $75,000 and $99,999	$ 100,000 or Higher
One-Person HH	0.091	0.061	0.030	0.005
Two-Person HH	0.188	0.116	0.062	0.036
Three Person HH	0.300	0.226	0.121	0.071
Four-or-More Person HH	0.373	0.302	0.183	0.130

Table 5.15 Rates for Households by Size and Income Levels for Home-Based Other Trip Purpose (trips/hh)

Household Type	Less than $35,000	Between $35,000 and $74,999	Between $75,000 and $99,999	$ 100,000 or Higher
One-Person HH	0.885	1.136	1.136	1.230
Two-Person HH	2.129	2.234	2.234	2.273

Three Person HH	3.757	3.853	3.853	4.278
Four-or-More Person HH	5.788	6.287	6.287	6.906

Table 5.16 Rates for Households by Size and Income Levels for Non-Home-Based Trip Purpose (trips/hh)

Household Type	Less than $35,000	Between $35,000 and $74,999	Between $75,000 and $99,999	$ 100,000 or Higher
One-Person HH	0.971	2.168	2.567	3.129
Two-Person HH	1.446	2.542	3.345	4.440
Three Person HH	2.099	3.401	4.195	5.571
Four-or-More Person HH	2.746	4.922	5.976	7.804

Table 5.17 Rates for Households by Size and Income Levels for Home-Based School Trip Purpose (trips/hh)

Household Type	No School-Age Children in the HH	One School-Age Child in the HH	Two or More School Age Children in the HH
One-Person HH	0.000	0.000	0.000
Two-Person HH	0.000	1.000	0.000
Three Person HH	0.000	1.000	1.210
Four-or-More Person HH	0.000	1.465	2.123

The total number of trips produced for each income group by trip purpose is tabulated in **Table 5.18.** Home based school trips were aggregated into a single category after the trip production step.

The distribution of trips by purpose is consistent with similar distributions reported in the literature[6]. **Table 5.19** shows a comparison between the Greater Thurston Region data and the 2001 National Household Travel Survey (NHTS) results for urban areas with a population of 500,000 or less as reported in NCHRP 716.

In addition, HBW productions were contrasted with the number of workers at the residential end as reflected in the 2006-2010 CTPP data. **Table 5.20** provides a comparison of HBW productions by the model and the number of workers at the county level of detail. Workers living in counties other than Thurston County and outside the model boundaries were excluded.

The total HBW productions in the GTC area was over 445,000 trips and the 2006-2010 CTPP data showed more than 322,500 resident workers in the model area. This corresponds to a ratio of 1.38 HBW trips per worker. This is within the expected range[7] of 1.20 to 1.55 HBW trips per worker. When this ratio is broken down at the county level, Thurston and Pierce County ratios were found to be within the expected range. In the case of Grays Harbor, Lewis, and Mason counties the ratios were higher than 2.0 trips per worker. This seems to be due to differences in the estimates of the number of households and the number of workers

[6] NCHRP Report 716 - Travel Demand Forecasting: Parameters and Techniques, 2012

[7] TMIP Travel Model Validation and Reasonability Checking Manual 2nd Ed., Cambridge Systematics, 2010.

provided by CTPP and TRPC. **Table 5.20** also shows a ratio of the CTPP-based number of workers and the number of households estimated by the TRPC land use data. This discrepancy (0.50 – 0.66 vs. 11.1 – 1.14) can be explained by the temporal differences, and sampling errors that are known to impact the precision of ACS-based indictors of socioeconomics in low-density or small geography areas.

Table 5.18 Number of Trips Produced by Purpose and Income Groups

	Income Group	Grays Harbor	Lewis	Mason	Pierce	Thurston	Greater Thurston Region
HBW	Less than $35,000	2,007	7,086	3,244	48,851	23,150	**84,338**
	Between $35,000 and $74,999	2,828	11,448	4,408	78,980	45,279	**142,944**
	Between $75,000 and $99,999	1,370	4,731	2,021	37,790	27,833	**73,745**
	$ 100,000 or Higher	1,563	6,216	2,353	71,074	63,301	**144,506**
	HBW Total	**7,767**	**29,481**	**12,026**	**236,696**	**159,562**	**445,532**
HBU	Less than $35,000	422	1,489	679	10,353	4,959	**17,902**
	Between $35,000 and $74,999	344	1,418	540	9,703	5,452	**17,458**
	Between $75,000 and $99,999	82	286	122	2,192	1,579	**4,261**
	$ 100,000 or Higher	45	182	66	1,933	1,729	**3,954**
	HBU Total	**893**	**3,375**	**1,407**	**24,181**	**13,719**	**43,575**
HBShp	Less than $35,000	1,665	6,258	2,779	42,670	20,850	**74,222**
	Between $35,000 and $74,999	1,939	7,849	3,083	56,327	32,798	**101,995**
	Between $75,000 and $99,999	790	2,738	1,167	21,892	16,315	**42,902**
	$ 100,000 or Higher	693	2,789	1,039	31,395	27,964	**63,880**
	HBShp Total	5,088	19,633	8,068	152,285	97,926	**283,000**
HBSch		**1,942**	**7,887**	**3,319**	**60,414**	**36,480**	**110,042**
HBO	Less than $35,000	5,303	18,119	8,424	127,654	59,509	**219,008**
	Between $35,000 and $74,999	6,621	27,506	10,489	188,193	105,241	**338,050**
	Between $75,000 and $99,999	2,830	9,841	4,198	75,286	54,321	**146,475**
	$ 100,000 or Higher	2,528	10,282	3,754	111,071	99,008	**226,643**
	HBO Total	**17,280**	**65,749**	**26,865**	**502,204**	**318,079**	**930,177**
NHB	Less than $35,000	3,390	12,381	5,578	85,445	41,089	**147,882**
	Between $35,000 and $74,999	6,455	26,502	10,333	189,790	108,950	**342,031**
	Between $75,000 and $99,999	3,189	11,093	4,724	87,550	64,824	**171,381**
	$ 100,000 or Higher	3,419	13,899	5,115	154,170	137,429	**314,031**
	NHB Total	16,453	63,875	25,749	516,955	352,293	**975,325**
TOTAL		**49,424**	**189,999**	**77,433**	**1,492,734**	**978,059**	**2,787,650**

Table 5.19 Comparison of Shares of Trips Produced by Purpose

	HBW	HBSch	HBO	NHB
Greater Thurston Region	16.0 %	5.5 %	43.5 %	35.0 %
NCHRP 716	**14.6%**	**6.3 %**	**47.9 %**	**31.3 %**

Notes: Home-based School includes both K-12 and University trips. HBO includes trips for shopping.

Table 5.20 Comparison of Shares of Trips Produced by Purpose

	Workers at their Residence[1]	Number of Households[2]	HBW Trip Productions[3]	HBW Trips per Worker	Workers per Household
Grays Harbor	2,733	5,502	7,767	2.84	0.50
Lewis	11,872	21,608	29,481	2.48	0.55
Mason	5,791	8,997	12,026	2.08	0.64
Pierce	190,026	166,163	236,696	1.25	1.14
Thurston	112,111	100,667	159,562	1.42	1.11
Totals	**322,533**	**302,937**	**445,532**	**1.38**	**1.07**

Sources: 1: 2006 – 2010 CTPP Tract Level data. 2: TRPC Land Use Estimates 3: TRPC Travel Demand Model

5.3 Trip Attractions

This section summarizes the development of trip attraction models. Although we developed destination choice models for TRPC to distribute trips, the attraction models were used as a quality control measure and to provide an easier control of trip productions and attractions for external-to-internal and internal-to-external flows.

Attraction models are generally estimated as linear regression models using as explanatory variables employment by industry, student enrollment, number of households, and population living in group quarters. The household travel survey data provides the dependent variable expressed as the number of trips attracted to each district. Some level of aggregation is necessary since household survey data does not provide a sufficient spatial representation of trip origins and destinations. The district structure shown in **Figure 5.1** can be used in developing these attraction models.

The general structure of attraction models was consistent with the PSRC model. **Table 5.21** shows the relationships that were postulated between the magnitude of trips by purpose and key land use variables.

Table 5.21 Structural Relationships between Trip Attractions and Land Use

Trip Purpose	Construction Resources	Retail	FIRES	Government	Educational	Mfg. & WTCU	FTE College Enrollment	K-12 Students	Households
HBW	X	X	X	X	X	X			X
HBU							X		
HBSch								X	
HBShp		X							
HBO			X	X	X	X			X
NHB		X	X	X	X	X			X

The attraction rates were calibrated by TRPC by adjusting attraction rates to approximate trip productions after accounting for internal-to-external (IE) and external-to-internal (EI) flows as reflected in Pierce, Mason, and Lewis County Models. These trips are featured in **Table 5.22.**

Table 5.22 External Trip Productions and Attractions

		External Trip Ends														
		Productions						Attractions						Truck Trips		
County	TAZ	HBW	HBU	HBShp	HBO	NHB	HBSch	HBW	HBU	HBShp	HBO	NHB	HBSch	Light	Med	Heavy
Pierce	1061	539	-	498	1,667	1,214	64	3,280	0	676	2,263	1,292	353	10	1	0
Pierce	1062	2,078	206	1,095	3,667	1,998	1,714	444	2	702	2,349	1,917	523	47	11	3
Pierce	1063	16	-	96	322	240	27	124	-	144	481	272	57	3	0	0
Pierce	1064	1,146	99	190	637	154	296	22	-	29	98	211	1	16	6	2
Pierce	1065	6,394	648	2,012	6,737	2,482	1,260	271	0	469	1,571	2,043	104	114	40	11
Pierce	1066	2,172	171	925	3,097	1,627	1,331	241	-	571	1,912	1,359	439	146	34	10
Pierce	1067	7,421	766	2,654	8,885	6,160	1,678	2,741	-	2,358	7,895	6,525	992	443	113	44
Pierce	1069	491	20	346	1,160	998	219	465	-	560	1,876	990	171	46	10	4
Pierce	1070	2,702	274	1,578	5,281	3,048	1,252	752	-	883	2,955	2,817	168	79	22	9
Pierce	1072	15,521	1,608	2,509	8,400	14,119	662	17,601	121	4,776	15,990	14,422	1,587	2,066	2,271	2,277
Pierce	1073	89	2	300	1,006	906	93	506	17	516	1,727	896	637	9	2	0
Pierce	1074	624	10	622	2,083	1,939	170	997	15	1,029	3,444	1,845	1,691	60	28	17
Pierce	1076	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pierce	1077	111	1	146	487	528	25	1,269	46	523	1,750	745	122	27	12	10
Pierce	1078	7,926	1,137	1,292	4,324	6,114	1,465	2,460	7	1,025	3,431	5,346	213	329	142	83
Pierce	1079	25,288	1,799	1,860	6,227	21,814	1,062	44,240	46	6,333	21,202	17,574	768	3,515	4,804	4,143
Pierce	1080	403	-	11	38	205	2	304	-	110	369	228	0	65	53	69
Pierce	1081	7,915	1,784	1,321	4,421	7,214	593	11,317	1	3,105	10,393	10,607	281	354	109	70
Pierce	1082	0	-	2	7	226	0	616	-	35	117	77	1	79	15	39
Pierce	1083	550	161	38	128	59	5	37	-	0	0	1	-	13	23	12
Pierce	1084	23,755	2,280	2,674	8,951	7,799	1,011	5,429	0	1,330	4,452	9,628	117	1,216	929	400
Mason	1115	1,558	-	458	1,532	53	-	847	-	13	45	53	-	11	17	15
Mason	1116	6,079	-	2,061	6,901	215	-	1,964	-	32	107	215	-	28	43	38
Mason	1117	1,196	-	822	2,750	71	-	126	-	16	53	71	-	7	11	10
Mason	1118	106	-	62	207	-	-	-	-	-	-	-	-	-	-	-
Mason	1119	695	-	176	590	107	-	753	-	25	84	107	-	15	22	20
Mason	1120	635	-	277	928	4	-	324	-	1	3	4	-	2	3	3
Mason	1121	124	-	54	182	5	-	74	-	1	4	5	-	1	2	1
Lewis	1233	6,156	-	1,153	3,860	5,111	-	2,369	-	678	2,268	5,111	-	983	1,628	2,034
Lewis	1234	1,624	-	192	644	1,289	-	830	-	352	1,180	1,289	-	76	118	105
Lewis	1235	2,443	-	191	638	1,313	-	1,160	-	261	873	1,313	-	103	159	142
Lewis	1236	117	-	22	72	57	-	23	-	5	16	57	-	4	6	5
Lewis	1237	996	-	58	193	737	-	60	-	3	10	737	-	26	40	36
Lewis	1238	504	-	1	2	115	-	1	-	0	0	115	-	8	12	11
Lewis	1239	1,965	-	64	215	512	-	35	-	2	6	512	-	24	37	33
Lewis	1240	50	-	27	90	83	-	44	-	5	17	83	-	-	-	-
Lewis	1241	426	-	131	440	160	-	57	-	29	97	160	-	-	-	-
Lewis	1242	810	-	112	375	247	-	79	-	30	100	247	-	-	-	-
Greys Harbor	1305	2,052	-	384	1,287	1,704	-	790	-	226	756	1,704	-	-	-	1,549
TOTAL		**132,676**	**10,966**	**26,415**	**88,433**	**90,627**	**12,929**	**102,654**	**255**	**26,851**	**89,892**	**90,577**	**8,225**	**9,925**	**10,726**	**11,208**
Pierce		105,140	10,966	20,170	67,526	78,844	12,929	93,117	255	25,172	84,273	78,794	8,225	8,637	8,627	7,204
Mason		10,394	-	3,910	13,091	454	-	4,089	-	88	296	454	-	63	98	88
Lewis		15,091	-	1,950	6,529	9,625	-	4,658	-	1,364	4,568	9,625	-	1,225	2,001	2,368
Greys Harbor		2,052	-	384	1,287	1,704	-	790	-	226	756	1,704	-	-	-	1,549

Trip productions and attractions were balanced later by the model. **Table 5.23** summarizes the trip productions and attractions by purpose and county as they appear in the model input. For all trip purposes other than home based school, total productions and attractions were comparable.

For county level comparisons, Pierce County showed some variation, since the model area partially covers the county. A higher degree of discrepancies was observed in the home based university and home based school purposes.

For Thurston County, there were about 20,000 trips imported from outside the county for shopping and home based other purposes.

Table 5.23 Comparison of Trip Productions and Attractions by County and Trip Purpose

	HBW		HBU		HBSch		HBShp		HBO		NHB		ALL Trips	
	Prod	Attr	Prod	Attr	Prod	Attr	Prod	Attr	Prod	Attr	Prod	Attr	Prod	Attr
Grays Harbor	7,767	4,195	893	-	1,942	3,434	5,088	1,658	17,280	10,058	16,453	8,846	49,424	28,191
Lewis	29,481	29,477	3,375	3,159	7,887	14,960	19,633	21,658	65,749	56,421	63,875	65,008	189,999	190,683
Mason	12,026	14,882	1,407	414	3,319	6,933	8,068	7,851	26,865	28,982	25,749	28,869	77,433	87,931
Pierce	236,696	272,661	24,181	40,805	60,414	104,747	152,285	133,974	502,204	494,365	516,955	502,323	1,492,734	1,548,875
Thurston	159,562	166,562	13,719	13,570	36,480	64,402	97,926	117,189	318,079	337,689	352,293	374,781	978,059	1,074,193
GTC Totals	445,532	487,777	43,575	57,948	110,042	194,476	283,000	282,330	930,177	927,515	975,325	979,827	2,787,650	2,929,873

6.0 Mode Choice Model Development and Validation

6.1 Overview

Mode choice models were developed for the following six trip purposes:

- Home based work (HBW),
- Home based university (HBU),
- Home based school (HBSch),
- Home based shopping (HBShp),
- Home based other (HBO), and
- Non-home based work (NHB).

These are the same trip purposes used in the trip generation and destination choice model components. Because of limited data availability, the home based university trip purpose was combined with the home based work trip purpose for the mode choice model estimation though some of the estimated coefficients were allowed to have different values for work and university travel. The mode choice models were estimated using a combined data set from the main Household Travel Survey and the special targeted samples for Vanpool program participants and Park and Ride users.

The resultant dataset can be viewed as a stratified sample. Stratified sampling strategies for data collection are often employed to achieve savings in data collection costs, and to enhance the information available about travelers who make relatively unique travel mode choices.

Model Framework

The mode choice models are estimated using a nested logit framework. Nested logit models are discrete choice models, which attempt to explain the behavior of individuals making a choice between a finite number of separate alternatives, in this case travel modes. In a nested logit model, the probability of choosing a particular alternative *i* is given by the following formula:

$$P\ (i \mid m) = \frac{\exp\left(\frac{U_i}{\mu_m}\right)}{\exp\left(\frac{\Gamma_m}{\mu_m}\right)} \frac{\exp(\Gamma_m)}{\sum_k(\exp(\Gamma_k))}$$

where:

P (*i* | *m*) = probability of choosing alternative *i,* which is a member of nest *m*

U_i = utility of alternative *i*

exp = exponential function

μ_m = a logsum parameter associated with nest *m*

$\Gamma_m = \mu_m \log(\sum_{k \in m} \exp(U_k/\mu_m))$, which represents a logsum associated with nest *m*

The utility function U_i represents the worth of alternative *i* compared to other alternatives and is expressed as a linear function:

$$U_i = B_{0i} + B_{1i}X_{1i} + B_{2i}X_{2i} + \ldots + B_{ni}X_{ni}$$

where the X_{ki} variables represent attributes of alternative *i*, the decision maker, or the environment in which the choice is made and B_{ki} represents the coefficient reflecting the effect of variable X_{ki} on the utility of alternative *i*. The "logsum" values Γ_m represent the combined worth of the alternatives in nest *m*. The parameter μ_m in the logsum controls for the similarity of the alternatives grouped in the nest. As the value of μ_m moves from 1 to 0 the modeled similarity of the alternatives increases.

The coefficients were estimated using statistical "maximum likelihood" methods using specialized logit model estimation software, in this case Larch[8]. In the case of logit mode choice models, the alternatives are the travel modes while the attributes may include attributes of the modes (e.g., travel time from the origin to destination by the particular mode), the decision maker or his or her household (e.g., income level), and the environment (e.g., population density).

6.2 Model Estimation and Testing Procedure

The mode choice models were specified to represent the choice among ten possible modes:

- Drive alone (DA),
- Shared ride with two people (SR2),
- Shared ride with three or more people (SR3),
- Vanpool directly from home or nearby, (VANW),
- Vanpool from another location, typically with auto access to a park-and-ride lot (VAND),
- Bus with walk access (BUSW),
- Bus with drive access (BUSD),
- School Bus (SBUS), for home based school and non-home based trips only,
- Walk, and
- Bike.

Vanpools differ from other shared ride alternatives in that the initial coordination among users is done with the assistance of the local transit agency, and the average occupancy on the "line haul" portion of the trip is much greater, averaging about five people, as opposed to two or three riders in more traditional carpools. Vanpool costs are not generally subsidized, although dividing vehicle operating costs over a large number of users does reduce the cost somewhat compared to smaller carpools.

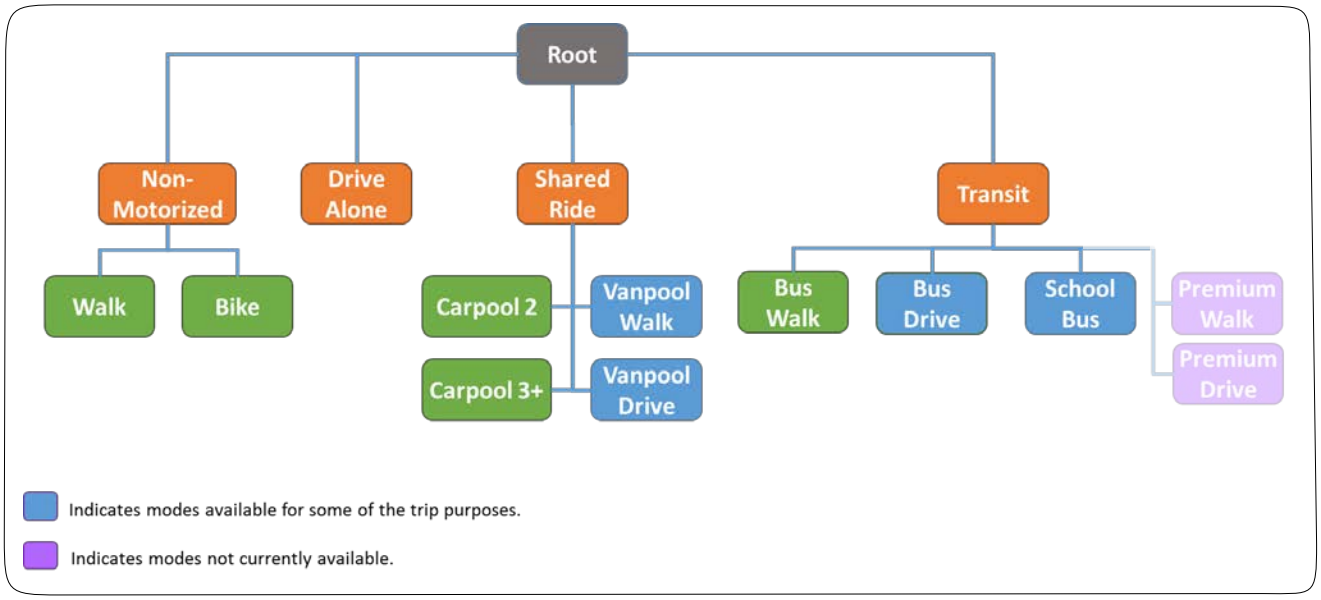
The mode choice was modeled with a utility maximizing nested logit structure. A generalized structure is shown in **Figure 6.1**. The base structure comprises of drive alone which appears as a separate choice and other modes which are grouped into three nests:

- Bike and walk were grouped together in a non-motorized nest,
- Carpool and two vanpool modes were all grouped together in a shared ride nest, and

[8] "Larch" the logit architect is a open-source software tool for the estimation and application of logit-based discrete choice models. (https://github.com/jpn--/larch)

- Bus modes were grouped together in a transit nest.

Figure 6.1 Mode Choice Model Structure



Vanpool modes are available for HBW, HBU, and HBO purposes, and School Bus mode is available for HBSch and NHB purposes. The premium transit modes can be added in a future application of the model as shown in **Figure 6.1**.

Table 6.1 shows the number of trips by mode and trip purpose from the combined survey data set that includes the main household and special target samples.

Table 6.1 Distribution by Chosen Mode and Purpose in Estimation Data Set

Mode	HBW/HBU	HBShop	HBSchool	HBO	NHB	All
Drive Alone	2,287	1,031	41	2,593	3,398	9,350
Bike	80	20	30	91	59	280
Walk	79	79	90	527	477	1,252
Carpool with two persons	242	401	206	1,394	1,497	3,740
Carpool with three or more persons	58	148	251	758	636	1,851
Bus Transit Walk Access	79	26	20	85	96	306
Bus Transit Drive Access	8	0	0	2	3	13
Vanpool Walk Access	79	0	0	10	71	160
Vanpool Drive Access	18	0	0	6	16	40
School Bus	0	0	279	0	87	366
Total	**2,930**	**1,705**	**917**	**5,466**	**6,340**	**17,358**

Based on the data availability, the final set of modes for each trip purpose was determined as follows:

- **HBW/HBU, HBO**: Drive Alone, Bicycle, Walk, Carpool 2, Carpool 3+, Vanpool Walk Access, Vanpool Drive Access, Transit Walk Access, Transit Drive Access
- **HBSchool**: Drive Alone, Bicycle, Walk, Carpool 2, Carpool 3+, Transit Walk Access, School Bus

- **HBShop**: Drive Alone, Bicycle, Walk, Shared Ride 2, Shared Ride 3+, Transit Walk Access
- **NHB**: All modes

Observation Exclusions

In addition to the trips included in **Table 6.1,** there were just over 2,300 trip observations in the original combined data set that were not used for model estimation. The following criteria were used to exclude observations that could not be used for estimation:

- Origin or destination zone was missing or was outside of the study region;
- Invalid chosen mode for the specific model (mode was not included in the model);
- Chosen mode was not available – especially relevant for trips where respondents reported biking or walking, but the distance from origin to destination implied that trip would take in excess of one hour (walking) or 90 minutes (biking).

Unavailability of Modes

A series of criteria was established for modal availability prior to model estimation:

- It was assumed that the private vehicle modes were available to all travelers since respondents that do not own automobiles may use either shared car services or use rental cars to drive alone.
- Transit modes (walk or auto access) were available only where the transit level of service variables for the origin-destination pair were defined in the transit network skims.
- It was also assumed that the walk mode was not available if the walking travel time was greater than one hour, and the bike mode was not available if the bike travel time was greater than 90 minutes.
- School bus was available only for the home based school and non-home based trip purposes.

Model Variables

The following variables were considered for the mode choice utilities:

Level of service variables[9]

- In-vehicle time (including drive access and wait time for drive access to vanpool)
- Out-of-vehicle time including the following:
  - Transit out-of-vehicle times that include:
    - Walk access time for the walk access mode,
    - Drive access time for the drive access mode,
    - Walk egress times,
    - Initial and transfer wait times, and
    - Transit vehicle boarding time.
  - Vanpool out-of-vehicle times that include:

[9] All time variables are in minutes, all cost variables in dollars, and all distance variables in miles.

    - » Transfer wait time for drive access to vanpool and
    - » Terminal times.
  - Walk time for the walk mode,
  - Bicycle time for the bicycle mode, and
  - Drive alone and shared ride modes out-of-vehicle travel times include terminal times.
- Costs including transit fare, auto parking cost, and auto operating cost
  - Daily parking costs were used for the HBW, HBU, and NHB trip purposes, while hourly costs were used for HBShp (estimated based on observations at 1.25 hours) and HBO (estimated at 2 hours) trip purposes. Parking costs were not included in the HBSch model.
  - Auto operating costs were estimated at 25 cents per mile.
  - Auto operating costs for shared ride modes were divided by the expected average number of persons in the vehicle (for shared ride with 3 or more people this was 3.5, and the value was 5 for the vanpool mode).
- All other level of service variables was obtained directly from the provided network skims.

Other variables

- Variables indicating rates of auto ownership in the production (home) TAZ were used for some home-based trip purposes.
- Indicator variables representing income levels were used in the utility functions for some trip purposes.
- For home based school trip purposes, variables representing the density of population at the production (home) zone were used.
- An attraction accessibility measure expressed as “the number of other attractions that can be reached in 20 minutes via transit from the attraction TAZ” was used for some trip purposes.

Model Estimation Results

Table 6.2 through **Table 6.6** show the estimated mode choice model parameters for the five trip purposes. For many of the trip purposes, the travel time coefficients were constrained to levels that are deemed acceptable by the Federal Transit Administration. Those parameters were labeled as “fixed value” in the t-Stat column of the tables below.

For some parameters, estimates were constrained relative to another parameter’s estimates. Those parameters are denoted in t-Stat columns with the constrained parameter written out (e.g., the out-of-vehicle travel times in **Table 6.4**).

A nesting structure that resulted in reasonable models to explain regional travel behavior was selected. The same nesting structure was posited for all trip purposes as shown in **Figure 6.1.**

The values of time were measured for different purposes and modes (non-motorized vs. motorized) for reasonableness. Values of time were highest for home-based work trips, as expected.

Table 6.2 Home Based Work and Home Based University Trips

Parameter	Estimate	t-Stat
Travel Time		
In Vehicle Travel Time	-0.02	*fixed value*
Out of Vehicle Terminal Time	-0.04	*fixed value*
Out of Vehicle Wait Time	-0.04	*fixed value*
Out of Vehicle Walk Time	-0.04	*fixed value*
Out of Vehicle Drive Access Time	-0.06	*fixed value*
Non-motorized Time	-0.08179	-12.29
Travel Cost		
Cost	-0.169	-5.08
Cost (High Income)	-0.1237	-3.45
Cost (Missing Income)	-0.1409	-2.07
Alternative Specific Constants		
Transit - Walk Access	-3.56	-8.89
Transit - Drive Access	-5.038	-10.45
Carpool with three or more people	-3.216	-12.19
Carpool with two people	-2.704	-15.19
Vanpool Walk Access	-3.751	-8.52
Vanpool Drive Access	-4.004	-6.3
Bicycle	-2.229	-12.36
Walk	-0.2626	-1.13
University Trip Constants		
HBU Trips with Non-Private Vehicle Modes	1.251	4.55
Low Income Household (less than $35k)		
Transit Modes	0.8358	3.29
Shared Ride Modes	0.5773	3.58
Production TAZ Percentage (0-100) of Zero-Vehicle Households		
Transit Modes	0.02448	2.27
Non-motorized Modes	0.02748	3.08
Production TAZ Percentage (0-100) of One-Vehicle Households		
Transit Modes	0.02579	3.74
Shared Ride Modes	0.007878	2.04
Total Attractions (1,000's,) in TAZ's where Transit Travel Time is <20 minutes from Attraction TAZ		
Transit Modes	0.005206	2.1
Shared Ride Modes	0.001672	1.16
Non-motorized Modes	0.003434	1.65
Nesting Coefficients		
Shared Ride	0.2894	-7.66
Transit	0.7	*fixed value*
Non-motorized	0.5359	-5.25
Sampling Bias Coefficients		
Bicycle	0.8658	2.07
Walk	-0.5241	-0.49
Carpool with two people	-0.1985	-0.66
Carpool with three or more people	-0.101	-0.19
Transit with Walk Access	-1.031	-1.01
Transit with Drive Access	1.949	2.36
Vanpool Walk	4.762	11.63
Vanpool Drive	5.3	5.12
Log Likelihood at Convergence	-2,177	
Log Likelihood at Constants	-2,552	
Log Likelihood at Null Parameters	-5,988	
Rho Squared w.r.t. Constants	0.148	
Rho Squared w.r.t. Null Parameters	0.637	

Table 6.3 Home Based School Trips

Parameter	Estimate	t-Stat
Travel Time		
In Vehicle Travel Time	-0.01	fixed value
Out of Vehicle Terminal Time	-0.02	fixed value
Out of Vehicle Wait Time	-0.02	fixed value
Out of Vehicle Walk Time	-0.02	fixed value
Out of Vehicle Drive Access Time	-0.02	fixed value
Non-motorized Time	-0.1251	-10.05
School Bus Time	-0.03831	-3.04
Alternative Specific Constants		
Transit - Walk Access	0.3756	0.84
School Bus	3.543	7.26
Carpool with three or more people	2.067	8.79
Carpool with two people	1.899	8.03
Bicycle	1.433	4.08
Walk	4.243	10.19
Total Population (1000's) Per Square Mile in Production TAZ		
Transit	0.2711	3.84
Shared Ride	0.1396	4.12
Non-motorized	0.1212	2.06
Nesting Coefficients		
Shared Ride	0.7	fixed value
Transit	0.7	fixed value
Non-motorized	0.7	fixed value
Sampling Bias Coefficients		
Bicycle	-1.253	-1.99
Walk	-1.125	-1.99
Carpool with two people	-1.522	-4.07
Carpool with three or more people	-1.871	-4.95
Transit - Walk Access	-2.479	-2.29
School Bus	-1.387	-3.88
Log Likelihood at Convergence	-1,326	
Log Likelihood at Constants	-1,430	
Log Likelihood at Null Parameters	-1,737	
Rho Squared w.r.t. Constants	0.073	
Rho Squared w.r.t. Null Parameters	0.237	

Table 6.4 Home Based Shopping Trips

Parameters	Estimate	t-Stat
Travel Time		
In Vehicle Travel Time	-0.01932	-2.99
Out of Vehicle Terminal Time	-0.05796	= InVehTime * 3
Out of Vehicle Wait Time	-0.03864	= InVehTime * 2
Out of Vehicle Walk Time	-0.05796	= InVehTime * 3
Out of Vehicle Drive Access Time	-0.03864	= InVehTime * 2
Non-motorized Time	-0.1051	-9.27
Travel Cost		
Cost	-0.2014	-2.67
Alternative Specific Constants		
Transit - Walk Access	-4.01	-6.33
Carpool with three or more people	-1.736	-17.74
Carpool with two people	-0.991	-13.84
Bicycle	-2.887	-11.31
Walk	0.002051	0.01
Low Income Household (less than $35k)		
Transit	2.731	4.92
Non-motorized	0.4322	1.74
Production TAZ Percentage (0-100) of Zero-Vehicle Households		
Transit	0.03206	2.07
Non-motorized	0.0172	1.68
Nesting Coefficients		
Shared Ride	0.7	fixed value
Transit	0.7	fixed value
Non-motorized	0.7	fixed value
Sampling Bias Coefficients		
Bicycle	0.4757	0.46
Walk	-0.1827	-0.23
Carpool with two people	0.5622	2.19
Carpool with three or more people	0.4315	1.13
Transit - Walk Access	-100	fixed value
Log Likelihood at Convergence	-1,743	
Log Likelihood at Constants	-1,851	
Log Likelihood at Null Parameters	-3,056	
Rho Squared w.r.t. Constants	0.058	
Rho Squared w.r.t. Null Parameters	0.430	

Table 6.5 Home-Based Other Trips

Parameter	Estimate	t-Stat
Travel Time		
In Vehicle Travel Time	-0.01	fixed value
Out of Vehicle Terminal Time	-0.02	= InVehTime * 2
Out of Vehicle Wait Time	-0.02	= InVehTime * 2
Out of Vehicle Walk Time	-0.02	= InVehTime * 2
Out of Vehicle Drive Access Time	-0.02	= InVehTime * 2
Non-motorized Time	-0.08851	-21.51
Travel Cost		
Cost	-0.1234	-4.06
Cost (High Income)	-0.09679	-2.1
Cost (Missing Income)	-0.1061	-1.08
Alternative Specific Constants		
Transit - Walk Access	-4.046	-17.16
Transit - Drive Access	-10	fixed value
Carpool with three or more people	-1.083	-22.74
Carpool with two people	-0.5876	-15.5
Vanpool Walk Access	-5.226	-12.88
Vanpool Drive Access	-5.226	= ASC_VanW
Bicycle	-1.852	-18.27
Walk	1.12	11.09
Low Income Household (less than $35k)		
Transit Modes	1.967	8.25
Non-motorized Modes	0.2959	2.34
Production TAZ Percentage (0-100) of Zero-Vehicle Households		
Transit Modes	0.02541	2.83
Total Attractions (1,000's, all purposes) in TAZ's where Transit Travel Time is <20 minutes from Attraction TAZ		
Transit Modes	0.01373	6.21
Nesting Coefficients		
Shared Ride	0.7	fixed value
Transit	0.7	fixed value
Non-motorized	0.7	fixed value
Sampling Bias Coefficients		
Bicycle	-0.04706	-0.09
Walk	0.1054	0.36
Carpool with two people	0.1244	0.88
Carpool with three or more people	0.639	4.27
Transit - Walk Access	-100	fixed value
Transit - Drive Access	-100	fixed value
Vanpool Walk Access	4.216	6.06
Vanpool Drive Access	4.471	6.27
Log Likelihood at Convergence	-6,580	
Log Likelihood at Constants	-6,994	
Log Likelihood at Null Parameters	-11,220	
Rho Squared w.r.t. Constants	0.059	
Rho Squared w.r.t. Null Parameters	0.414	

Table 6.6 Non-Home Based Trips

Parameter	Estimate	t-Stat
Travel Time		
In Vehicle Travel Time	-0.01	fixed value
Out of Vehicle Terminal Time	-0.02	= InVehTime * 2
Out of Vehicle Wait Time	-0.02	= InVehTime * 2
Out of Vehicle Walk Time	-0.02	= InVehTime * 2
Out of Vehicle Drive Access Time	-0.02	= InVehTime * 2
Non-motorized Time	-0.06276	-16.44
School Bus Time	-0.04	= InVehTime * 4
Travel Cost		
Cost (High Income)	-0.07292	-1.91
Cost (Middle Income)	-0.1212	-3.72
Cost (Low Income)	-0.2191	-4.11
Cost (Missing Income)	-0.1663	-2.05
Alternative Specific Constants		
Transit - Walk Access	-4.173	-17.18
Transit - Drive Access	-6.433	-13.15
School Bus	-1.298	-7.83
Carpool with three or more people	-1.132	-20.23
Carpool with two people	-0.4555	-9.43
Vanpool Walk Access	-4.003	-16.79
Vanpool Drive Access	-10	fixed value
Bicycle	-2.824	-18.17
Walk	-0.3152	-3.81
Low Income Household (less than $35k)		
Transit Modes	1.927	8.5
High Income Household (more than $100k)		
Transit Modes	-1.251	-2.59
Shared Ride	-0.199	-2.81
Total Attractions (1,000's, all trip purposes) in TAZ's where Transit Travel Time is <20 mins from Attraction TAZ		
Transit Modes	0.005067	2.12
School Bus	-0.02796	-3.94
Shared Ride	-0.0044	-5.26
Total Attractions (1,000's, all trip purposes) in TAZ's where Transit Travel Time is <20 mins from Production TAZ		
Transit Modes	0.009817	4.19
School Bus	-0.04157	-4.62
Shared Ride	-0.004845	-5.75
Nesting Coefficients		
Shared Ride	0.7	fixed value
Transit	0.7	fixed value
Non-motorized	0.5842	-6.31
Sampling Bias Coefficients		
Bicycle	0.6748	1.42
Walk	0.9842	4.51
Carpool with two people	-0.2027	-1.39
Carpool with three or more people	0.5824	3.75
Transit - Walk Access	0.4987	0.94
Transit - Drive Access	0.4987	= SampleBiasBusW
Vanpool Walk Access	4.685	12.78
Vanpool Drive Access	12.23	45.57
School Bus	0.6222	1.63
Log Likelihood at Convergence	-7,635	
Log Likelihood at Constants	-8,173	
Log Likelihood at Null Parameters	-13,890	
Rho Squared w.r.t. Constants	0.066	
Rho Squared w.r.t. Null Parameters	0.450	

6.3 Validation

The calibration of the mode choice model is important for several reasons:

- First, it is critical to accurately capture mode splits in the model so the resulting model may be used for transit, bike-pedestrian, and highway corridor analysis studies.
- Second, the mode-specific person trips generated after the mode choice model are assigned to the model networks and are used to assess the regional level of congestion.
- Third, the calibrated mode choice models can be used to forecast adoption of modes under several operating scenarios that may be considered for the future year.

Therefore, the study team implemented a detailed mode choice calibration approach to ensure that the models better represent observed travel patterns. The mode choice calibration first focused on comparisons of modal shares at an aggregate level and was designed to test the performance of the model across several different income dimensions by trip purpose.

Model Framework

Key aspects of the mode choice model included the following:

- Mode choice models were formulated using a nested logit model structure. The model coefficients were coded to ensure that the nested structure was properly represented.
- The mode choice models used level of service variables as key explanatory variables. Type of variables included in-vehicle and out-of-vehicle travel times, travel distance, parking cost, and auto operating costs.
- The mode choice models were partially segmented by household income categories. Therefore, the models have the ability to capture differences in travel patterns of segments with different household incomes.
- The mode choice included a unique approach for modeling shared rides. For all purposes other than school and shopping, shared ride options included an explicit representation of vanpools. The model evaluated two distinct options for vanpool formation that differentiated between joining a vanpool at home or at the origin or joining a vanpool in a parking lot.
- The non-motorized component of the model included a distinction between walk and bike.
- All variables in the model were readily calculated from the TAZ file and level of service matrices (skims).

Calibration Process

The model results were compared against household survey data across trip purpose and income segments. Alternative specific constants that capture modal preference by income segment were adjusted. All other coefficients were left unchanged from the modeling process.

The models were calibrated in an iterative fashion. Changes were made only to the alternative specific constants in a controlled fashion and the model was re-run to produce output summaries that were compared with the household travel survey data.

Since there was no transit onboard survey data available, transit targets were approximated by purpose and income segments based on professional judgement and local experience. Vanpool program registration and total number of reported trips were used to establish targets for the vanpool mode. **Table 6.7** shows the targets used for transit and vanpool modes. Additional surveys of transit riders and vanpool users in the future can be used to establish more reliable data driven targets.

Table 6.7 Targets for Trips Made by Transit and Vanpool Modes

TRANSIT TRIPS									
	Less than $35,000		$35,000 - $99,999		$100,000 or Above		ALL		
Trip Purposes	Walk	Drive	Walk	Drive	Walk	Drive	Walk	Drive	ALL
HBW	7,400	680	3,380	300	1,780	140	12,560	1,120	**13,680**
HBU	1,280	80	565	50	300	20	2,150	150	**2,300**
HBSch	660	0	300	0	150	0	1,120	0	**1,120**
HBShp	1,080	0	490	0	250	0	1,820	0	**1,820**
HBO	3,420	180	1,480	160	780	80	5,680	420	**6,100**
NHB	7,060	580	3,200	280	1,675	140	11,950	1,000	**12,950**
Totals	**20,900**	**1,520**	**9,415**	**790**	**4,935**	**380**	**35,280**	**2,690**	**37,970**
VANPOOL TRIPS									
	Less than $35,000		$35,000 - $99,999		$100,000 or Above		ALL		
Trip Purpose	Walk	Drive	Walk	Drive	Walk	Drive	Walk	Drive	ALL
HBW	25	10	850	50	575	25	1,450	85	**1,535**
HBO	25	10	65	20	110	10	200	40	**240**
NHB	70	10	950	60	265	50	1,285	120	**1,405**
Totals	**120**	**30**	**1,865**	**130**	**950**	**85**	**2,935**	**245**	**3,180**

Calibration Results

Tables 6.8 through **6.13** present the original estimated constants as well as the calibrated constants to show the net impacts of model calibration. Calibration generally targeted the walk mode for HBW, HBShp, and HBO purposes, and the vanpool mode for HBU and NHB purposes.

Figures 6.2 through **6.7** feature comparisons of observed versus predicted modal shares across income groups for each of the six purposes modeled. The observed trips and shares were derived from the Household Travel Survey database and asserted targets for transit and vanpool trips.

- Estimated trips were compiled by summarizing the trip tables after the mode choice step from the TRPC model for the flows within Thurston County and the portion of Pierce County within the model area.
- Home-based school purpose was estimated and validated without income segmentation.
- HBU targets were scaled up based on trip productions presented in **Table 5.23**. Vanpool modes were removed from the HBU purpose, due to lack of target data for this segment. School bus option was also dropped in NHB mode choice models.
- The comparisons of modal shares between the survey and the model data reveal that validation targets were matched reasonably well at the marginal totals.
- For HBW and HBO model shares by income segments were also close, within ± two percent and ± four percent, respectively although the low income segment did not match that well for home based work travel.
- Modal shares across income categories for HBShp and HBU trips in the survey data had some unexpected patterns. In the cases of these segments, the validation approach reflected local knowledge and professional judgment.
- NHB purpose low income modal share also showed a rather large difference for the drive alone mode.

Table 6.8 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Home Based Work Purpose

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	-2.127	-1.900	-2.704	-2.880	-2.704	-2.930
Carpool 3+	-2.639	-2.100	-3.216	-5.488	-3.216	-3.455
Vanpool Walk	-3.174	-2.740	-3.751	-3.880	-3.751	-3.880
Vanpool Drive	-3.427	-2.750	-4.004	-3.580	-4.004	-3.580
Walk to Transit	-2.724	-1.290	-3.560	-3.230	-3.560	-3.530
Drive to Transit	-4.202	-5.208	-5.038	-4.736	-5.038	-5.375
Walk	-0.263	1.980	-0.263	1.430	-0.263	-0.268
Bike	-2.229	-1.670	-2.229	-1.390	-2.229	-1.855

Table 6.9 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Home Based University Purpose

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	-2.127	-3.580	-2.704	-3.530	-2.704	-4.230
Carpool 3+	-2.639	-3.830	-3.216	-3.430	-3.216	-5.230
Vanpool Walk	-3.174	-11.965	-3.751	-12.072	-3.751	-11.899
Vanpool Drive	-3.427	-13.613	-4.004	-14.057	-4.004	-13.334
Walk to Transit	-2.724	-4.230	-3.560	-4.280	-3.560	-3.480
Drive to Transit	-4.202	-7.230	-5.038	-6.180	-5.038	-6.225
Walk	-0.263	0.410	-0.263	0.320	-0.263	0.380
Bike	-2.229	-2.730	-2.229	-3.230	-2.229	-2.985

Table 6.10 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Home Based School Purpose

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	1.899	2.075	1.899	2.075	1.899	2.075
Carpool 3+	2.067	2.317	2.067	2.317	2.067	2.317
Walk to Transit	0.376	0.082	0.376	0.082	0.376	0.082
School Bus	3.543	3.350	3.543	3.350	3.543	3.350
Walk	4.243	5.250	4.243	5.250	4.243	5.250
Bike	1.433	1.625	1.433	1.625	1.433	1.625

Table 6.11 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Home Based Shopping Purposes

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	-0.991	-0.333	-0.991	-0.971	-0.991	-1.281
Carpool 3+	-1.736	-1.307	-1.736	-1.356	-1.736	-1.431
Walk to Transit	-1.279	-3.781	-4.010	-3.781	-4.010	-4.231
Walk	0.434	2.019	0.002	1.519	0.002	0.619
Bike	-2.455	-2.781	-2.887	-3.336	-2.887	-3.681

Table 6.12 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Home Based Other Purpose

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	-0.588	-0.740	-0.588	-0.440	-0.588	-0.490
Carpool 3+	-1.083	-0.815	-1.083	-0.740	-1.083	-0.885
Vanpool Walk	-5.226	-5.607	-5.226	-4.865	-5.226	-4.690
Vanpool Drive	-5.226	-6.685	-5.226	-5.265	-5.226	-5.790
Walk to Transit	-2.079	-4.590	-4.046	-6.990	-4.046	-8.040
Drive to Transit	-8.033	-6.540	-10.000	-6.440	-10.000	-9.990
Walk	1.416	3.260	1.120	3.110	1.120	2.310
Bike	-1.556	-1.090	-1.852	-1.490	-1.852	-1.583

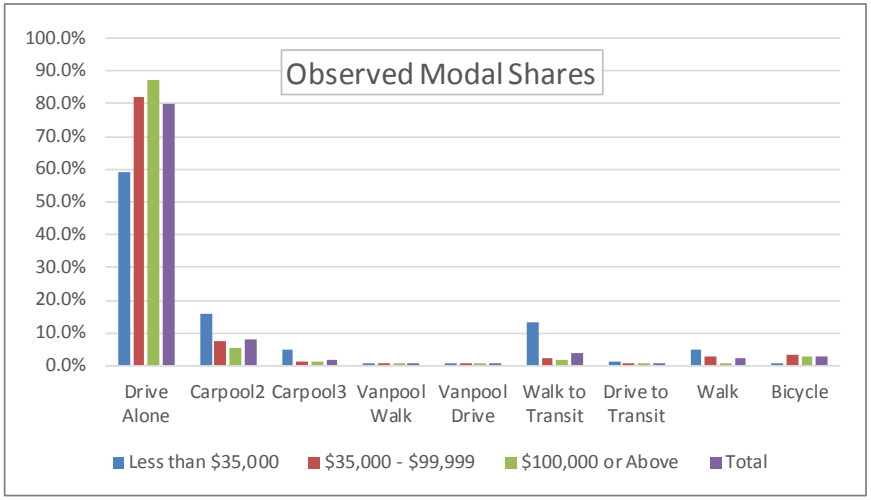
Table 6.13 Estimated vs. Calibrated Alternative Specific Mode Choice Constants – Non-Home Based Purpose

Modes	Less than $35,000		$35,000 - $99,999		$100,000 or Above	
	Estimated	Calibrated	Estimated	Calibrated	Estimated	Calibrated
Drive Alone	0.000	0.000	0.000	0.000	0.000	0.000
Carpool 2	-0.456	0.335	-0.456	-0.315	-0.655	-0.090
Carpool 3+	-1.132	-0.190	-1.132	-1.065	-1.331	-3.190
Vanpool Walk	-4.003	-4.490	-4.003	-3.790	-4.202	-4.490
Vanpool Drive	-10.000	-4.490	-10.000	-3.790	-10.199	-4.490
Walk to Transit	-2.246	-3.440	-4.173	-4.890	-5.424	-5.785
Drive to Transit	-4.506	-6.065	-6.433	-6.015	-7.684	-6.340
School Bus	-1.298	-1.288	-1.298	-1.288	-1.298	-1.288
Walk	-0.315	0.860	-0.315	0.710	-0.315	0.610
Bike	-2.824	-1.740	-2.824	-2.775	-2.824	-2.740

Figure 6.2 Comparison of Observed and Predicted Modal Shares for HBW Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	32,602	120,514	95,393	**248,508**
Carpool2	8,689	10,900	6,086	**25,675**
Carpool3	2,743	1,883	1,267	**5,893**
Vanpool Walk	25	850	575	**1,450**
Vanpool Drive	10	50	25	**85**
Walk to Transit	7,400	3,380	1,780	**12,560**
Drive to Transit	680	300	140	**1,120**
Walk	2,721	3,963	1,074	**7,758**
Bicycle	366	4,903	2,887	**8,157**
Total	**55,236**	**146,742**	**109,227**	**311,205**

Model Estimates	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	28,452	121,468	92,444	**242,364**
Carpool2	8,418	11,017	6,124	**25,559**
Carpool3	5,893	2	1,253	**7,147**
Vanpool Walk	248	411	248	**907**
Vanpool Drive	532	410	225	**1,167**
Walk to Transit	11,838	3,772	1,579	**17,189**
Drive to Transit	127	997	336	**1,460**
Walk	2,837	7,155	961	**10,953**
Bicycle	975	6,903	3,085	**10,963**
Total	**59,320**	**152,135**	**106,255**	**317,710**



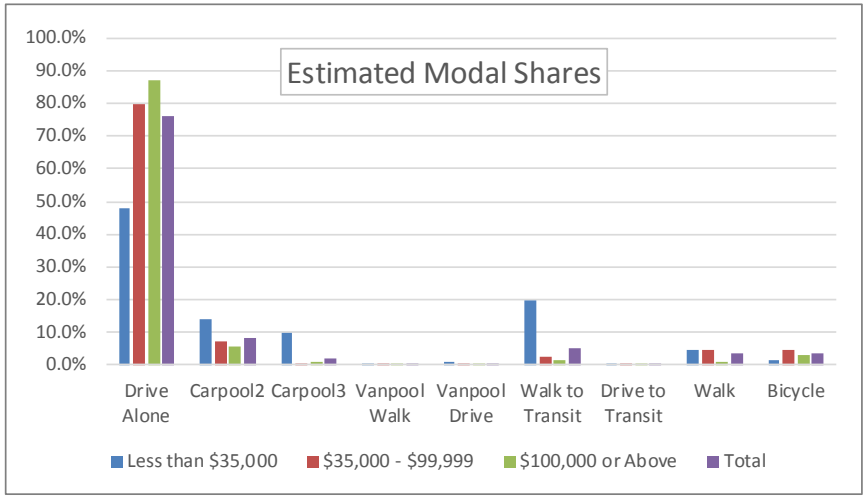
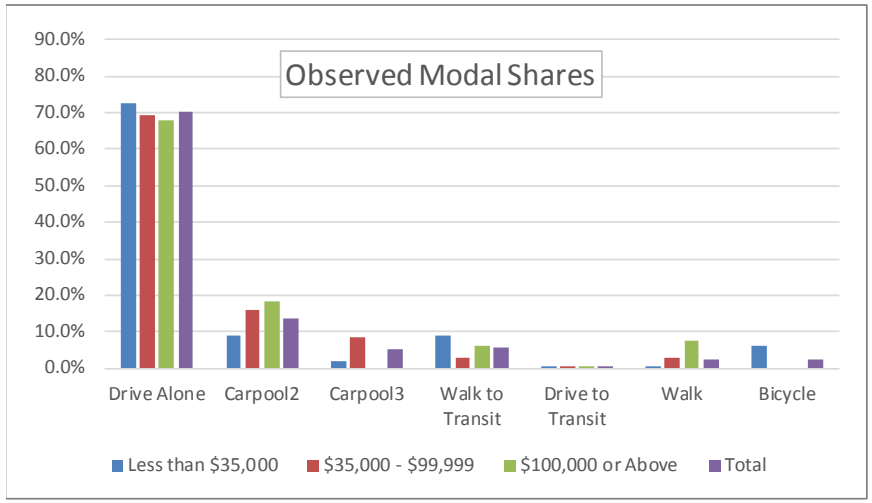


Figure 6.3 Comparison of Observed and Predicted Modal Shares for HBU Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	10,309	13,107	3,242	**26,658**
Carpool2	1,282	3,014	871	**5,167**
Carpool3	264	1,645	0	**1,909**
Walk to Transit	1,280	565	300	**2,145**
Drive to Transit	80	50	20	**150**
Walk	81	564	354	**999**
Bicycle	871	0	0	**871**
Total	**14,167**	**18,945**	**4,787**	**37,899**

Model Estimates	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	11,045	15,811	3,230	**30,087**
Carpool2	686	390	71	**1,146**
Carpool3	399	719	3	**1,122**
Walk to Transit	1,618	856	221	**2,694**
Drive to Transit	50	125	53	**228**
Walk	1,481	1,228	126	**2,835**
Bicycle	665	502	76	**1,243**
Total	**15,944**	**19,631**	**3,780**	**39,355**



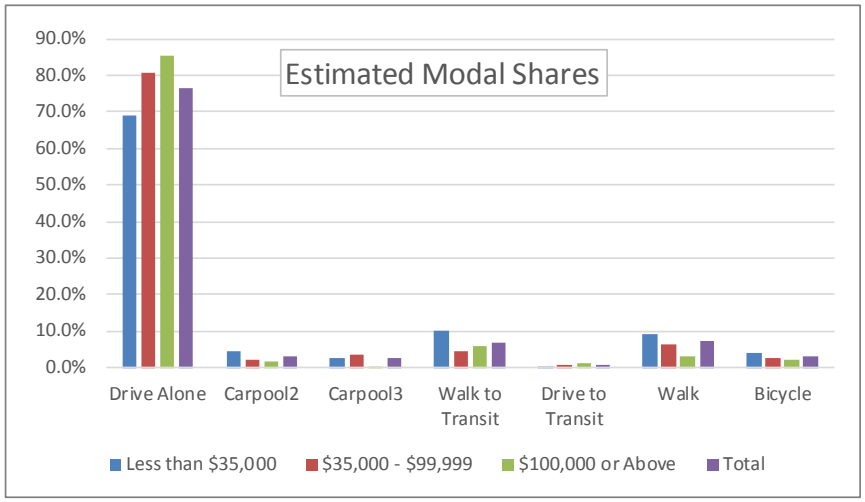


Figure 6.4 Comparison of Observed and Predicted Modal Shares for HBSch Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Observed All Income Groups	Estimated All Income Groups
Drive Alone	0	1,271	1,768	**3,039**	**2,514**
Carpool2	1,695	13,182	11,602	**26,478**	**21,604**
Carpool3	10,309	20,951	11,841	**43,101**	**41,581**
Walk to Transit	660	300	150	**1,110**	**2,098**
School Bus	650	5,500	2,500	**8,650**	**8,548**
Walk	3,710	5,221	4,683	**13,613**	**13,305**
Bicycle	0	1,707	1,553	**3,260**	**2,668**
Total	**17,023**	**48,132**	**34,097**	**99,251**	**92,318**

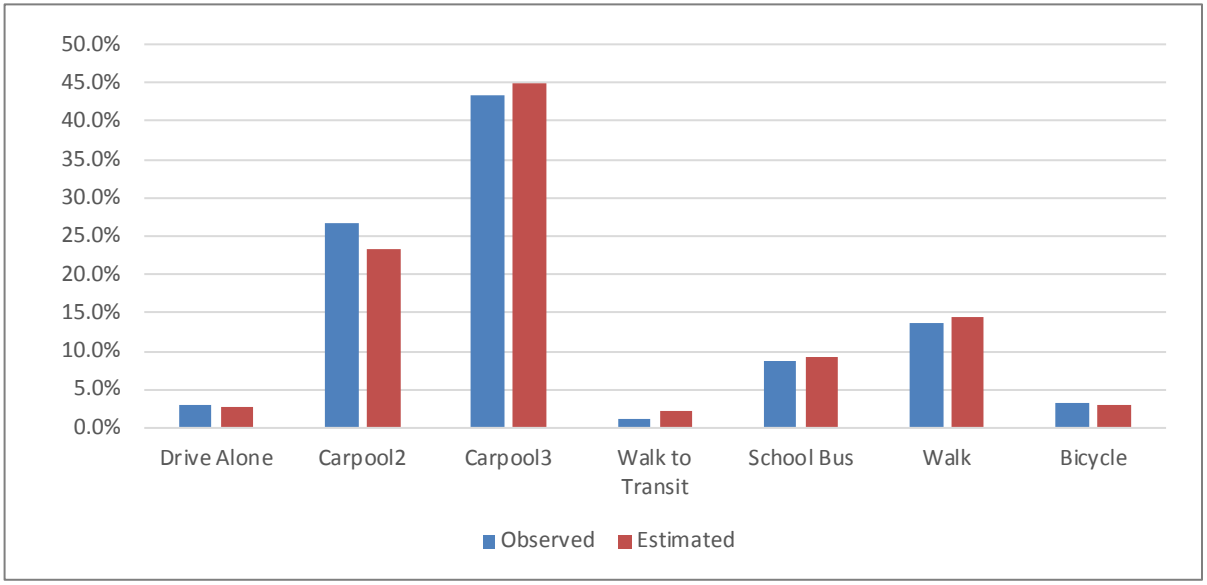
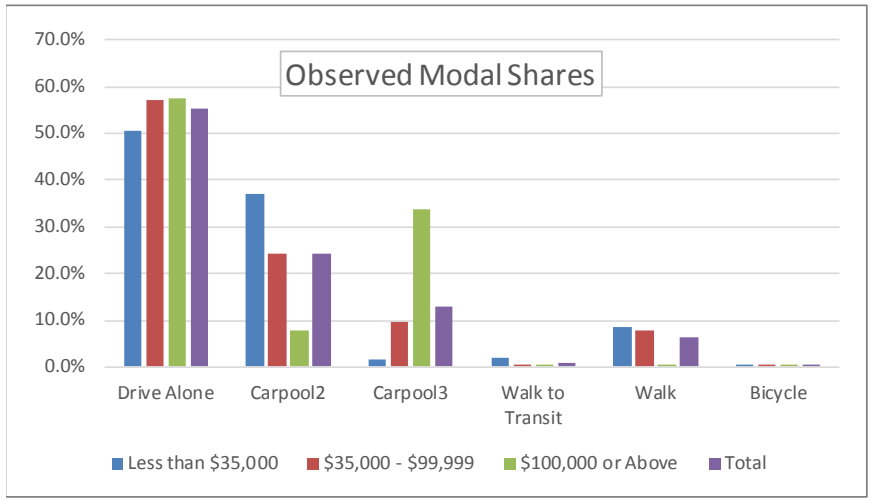


Figure 6.5 Comparison of Observed and Predicted Modal Shares for HBShp Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	27,436	54,756	25,758	**107,950**
Carpool2	20,039	23,403	3,484	**46,926**
Carpool3	867	9,313	15,101	**25,280**
Walk to Transit	1,080	490	250	**1,820**
Walk	4,710	7,658	75	**12,443**
Bicycle	127	301	184	**612**
Total	**54,259**	**95,922**	**44,851**	**195,032**

Model Estimates	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	25,083	68,724	36,329	**130,137**
Carpool2	19,156	25,937	9,633	**54,726**
Carpool3	5,298	16,745	8,687	**30,730**
Walk to Transit	2,256	371	118	**2,745**
Walk	7,091	8,260	1,806	**17,156**
Bicycle	450	423	155	**1,028**
Total	**59,334**	**120,458**	**56,729**	**236,521**



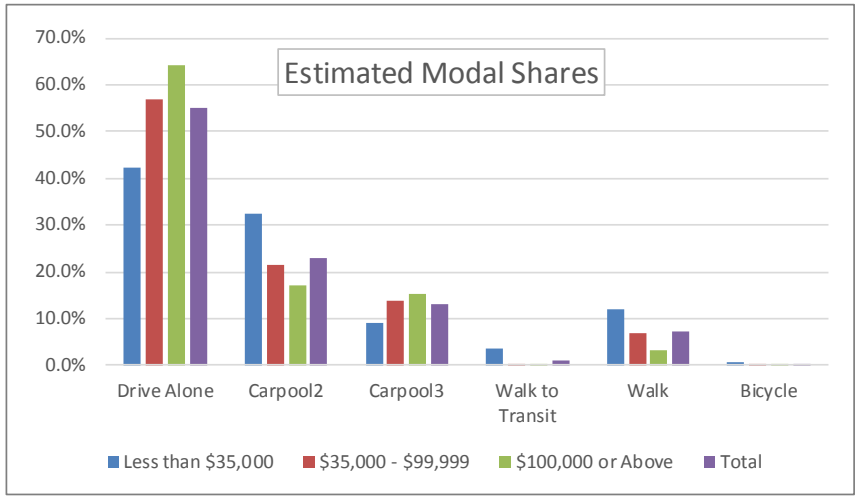
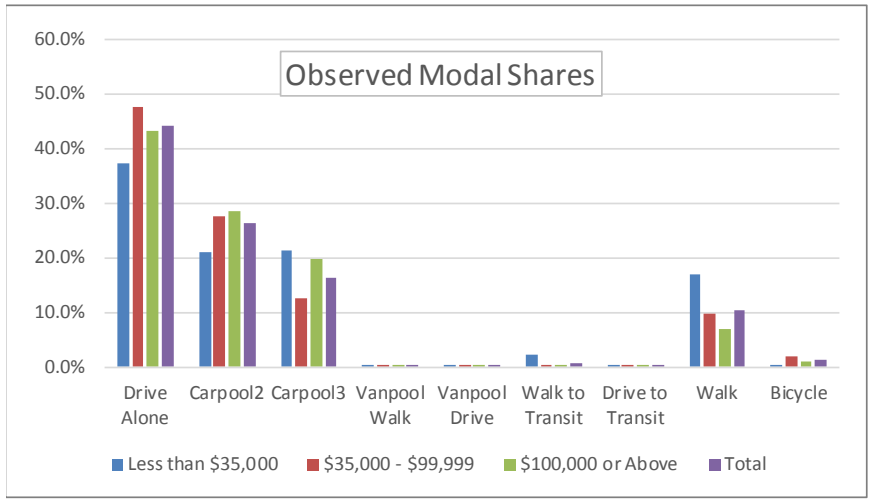


Figure 6.6 Comparison of Observed and Predicted Modal Shares for HBO Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	57,093	180,368	74,415	**311,876**
Carpool2	32,479	104,176	49,016	**185,671**
Carpool3	32,963	47,228	34,211	**114,402**
Vanpool Walk	25	65	110	**200**
Vanpool Drive	10	20	10	**40**
Walk to Transit	3,420	1,480	780	**5,680**
Drive to Transit	180	160	80	**420**
Walk	25,958	36,560	11,910	**74,429**
Bicycle	915	7,359	1,660	**9,934**
Total	**153,043**	**377,415**	**172,193**	**702,651**

Model Estimates	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	74,760	170,578	95,295	**340,632**
Carpool2	32,903	104,896	55,187	**192,985**
Carpool3	32,537	75,920	33,890	**142,347**
Vanpool Walk	7	116	29	**152**
Vanpool Drive	39	238	162	**439**
Walk to Transit	8,786	2,109	310	**11,204**
Drive to Transit	1,032	518	264	**1,814**
Walk	22,817	38,958	14,989	**76,763**
Bicycle	4,085	4,536	2,667	**11,287**
Total	**176,965**	**397,867**	**202,793**	**777,625**



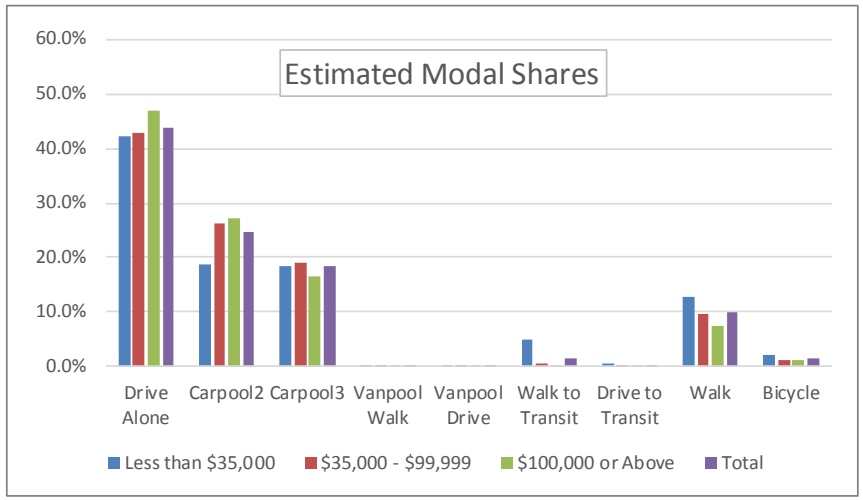
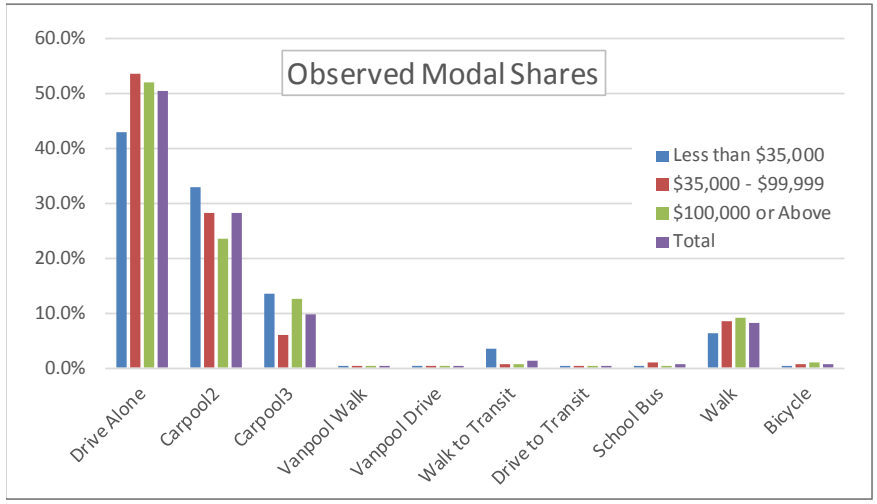
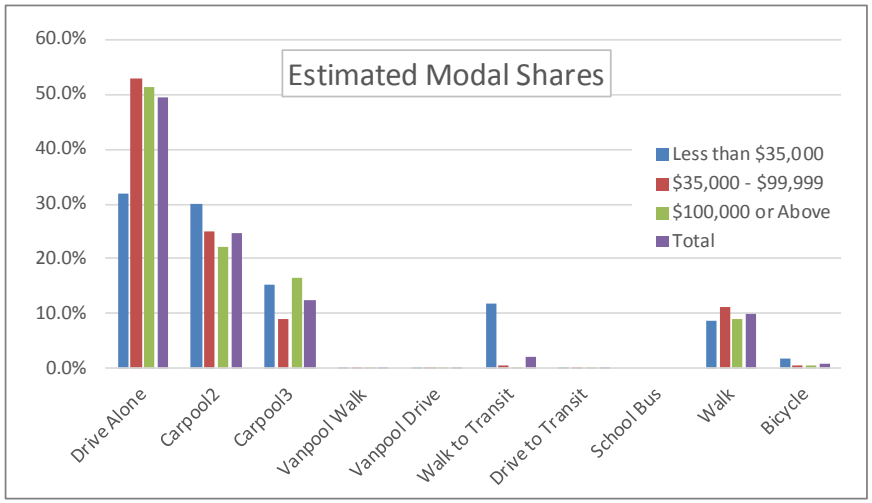


Figure 6.7 Comparison of Observed and Predicted Modal Shares for NHB Trips

Target Market Sizes	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	87,921	191,752	112,587	**392,260**
Carpool2	67,925	101,281	50,926	**220,133**
Carpool3	27,674	21,872	27,305	**76,851**
Vanpool Walk	70	950	265	**1,285**
Vanpool Drive	10	60	50	**120**
Walk to Transit	7,060	3,200	1,675	**11,935**
Drive to Transit	580	280	140	**1,000**
School Bus	700	4,200	950	**5,850**
Walk	12,836	30,366	19,868	**63,070**
Bicycle	384	2,745	2,079	**5,208**
Total	**205,159**	**356,707**	**215,845**	**777,711**

Model Estimates	Less than $35,000	$35,000 - $99,999	$100,000 or Above	Total
Drive Alone	38,217	222,555	141,111	**401,882**
Carpool2	35,754	104,939	61,153	**201,847**
Carpool3	18,462	37,931	45,987	**102,380**
Vanpool Walk	26	558	89	**673**
Vanpool Drive	38	735	111	**885**
Walk to Transit	14,212	3,072	202	**17,486**
Drive to Transit	405	782	118	**1,306**
School Bus	0	0	0	**0**
Walk	10,407	46,924	25,391	**82,722**
Bicycle	2,091	2,890	1,812	**6,793**
Total	**119,612**	**420,387**	**275,974**	**815,974**





7.0 Destination Choice Model Development and Validation

7.1 Overview

The second step in 4-step travel demand modeling is the trip distribution which determines how many of the trips produced in trip generation step will travel to which particular zone. Trip distribution uses three basic explanatory variables; trips produced in the origin, trip attracted to the destination or a size variable, and impedance as a function of travel time and/or cost.

The most commonly used trip distribution model is a gravity model. However, destination choice models provide a better behavioral basis for trip distribution by allowing for a wider range of explanatory variables than gravity models. For example, use of logsum parameters from mode choice models provides a more comprehensive measure of accessibility. Destination choice models also allow using the same market segmentation, adopted in trip generation and model choice models, based on relevant household characteristics (such as income levels, vehicle ownership) to incorporate differences in sensitivities to changes in level of service across those segments.

The destination choice models are developed in a multinomial logit framework where the alternatives are the attraction zones, and the choice probabilities are applied to the trip productions in each zone. The utility functions include variables related to travel impedance and the size variable, additional variables about demographics or area-type characteristics can be introduced.

The logit destination choice model is singly constrained since the number of attractions is only an input variable, not a constraint or target. Sometimes such a model is artificially constrained at the attraction end using zone-specific constants or post processing of model results.

This chapter covers the development of the destination choice models for all person trip purposes. Destination choice models were developed for the following six trip purposes:

- Home based work (HBW)
- Home based university (HBU)
- Home based school (HBSch)
- Home based shopping (HBShp)
- Home based other (HBO)
- Non-home based (NHB)

These are the same trip purposes used in trip generation step as detailed in Section 5.2. Due to the small size of the sample of home-based university trips, this segment was merged with home-based work, although several parameters were segmented on trip purpose. The destination choice models were estimated using data from the Household Travel Survey.

Model Framework

The destination choice models are multinomial logit models, which attempt to explain the behavior of individuals making a choice between a finite number of separate alternatives, in this case destination zones.

In the logit model, the probability of choosing a particular alternative *i* is given by the following formula:

$$P(i) = \exp(U_i) / \sum_j \exp(U_j)$$

where:

P(i) = probability of choosing alternative i

Ui = utility of alternative i

exp = exponential function

The utility function Ui represents the worth of alternative i compared to other alternatives and is expressed as a linear function:

$$U_i = B_{0i} + B_{1i}X_{1i} + B_{2i}X_{2i} + \ldots + B_{ni}X_{ni}$$

where the X_{ki} variables represent attributes of alternative i, the decision maker, or the environment in which the choice is made and B_{ki} represents the coefficient reflecting the effect of variable X_{ki} on the utility of alternative *i*.

7.2 Model Estimation

The coefficients were estimated using statistical "maximum likelihood" methods using specialized logit model estimation software. Larch, an open source model estimation software, was used for estimating destination choice model for the TRPC model.

Model Variables

As mentioned above, in logit destination choice models, the alternatives were the destination zones while the attributes included measures of impedance, zonal features such as trip productions, socioeconomics, and the environmental variables such as attraction zone area type.

- The mode choice logsum is a measure of the impedance, or cost, of traveling from one zone to another. It is a combined measure of the impedance using the various available modes (highway, transit, and non-motorized) and is computed from the logit mode choice model utilities. The logsum was computed for each trip purpose as follows:

  $\text{Logsum}_{ij} = \ln \Sigma_k \exp(\Gamma_{ijk})$

  where Γ_{ijk} = logsum of nest *k* from zone *i* to zone *j* (from the mode choice model), and the summation is over all nests (drive alone, pooled ride, transit, and nonmotorized).
- In addition to the mode choice logsum, polynomial functions of the highway distance were used as an additional impedance measure for each trip purpose. Highway distance was used rather than travel time because it is mode-neutral. Thus, if a trip by auto becomes longer in duration (e.g. due to an increase in congestion), trip destinations will shift differently depending on whether the destination is well served or poorly served by other modes.
- Intrazonal impendences are not generally computed by models. Therefore, intrazonal times were added to skim matrices separately. The half of the average travel distance between each zone and three of the nearest neighboring zones was assigned as the magnitude of the intrazonal travel distance. The outlying distances were capped at 85th percentile of the original intrazonal distance distribution. The intrazonal travel times were calculated by applying average speed.
- Size variables are used to measure the attractiveness of particular zones. For most trip purposes the size variable was the number of modeled attractions for the trip purpose.
- Size variables were entered into the utilities as the natural logarithms of the particular variables (for example, ℓn(attractions)).
- Variables representing the density of population or attractions at the attraction zone were used (in some cases, density of attractions by certain purposes was also used). These were entered as polynomial functions to allow for non-linear effects.

- Special use indicator variables were also used to identify special attractors, including JBLM, the state capitol, and major medical facilities.
- Intrazonal indicators that capture the effect of mixed land use on short travel were also included.
- For home-based school purpose, the difference between the distance to the destination zone and the distance to closest zone with a school was included in the model. This variable entered the utility function only when the value was between 0 and 2 miles, and allowed for a non-linear effect that varied depending on the distance to the closest school facility.
- The models were partially segmented by income category to quantify the impact of household income on travel parameters such as travel distance.

Tables 7.1 through 7.5 show the final destination choice model specifications for the six trip purposes. For many of the trip purposes, the size variable coefficients were constrained to unity. Those parameters were labeled as "fixed value" in the t-Stat column of the tables below.

Table 7.1 Home-Based Work and Home-Based University Destination Choice Model Parameter Estimates

Parameter	Estimate	t-Stat
Mode Choice Logsum		
Mode Choice Logsum Value	0.7	fixed value
TAZ Attraction Size		
log (Number of HBW Attractions)	1.0	fixed value
log (Number of HBU Attractions)	1.0	fixed value
O-D Distance (SOV AM Skim)		
Linear	-0.2203	-11.24
Squared	0.0036	2.97
Cubed	-3.10E-05	-1.51
O-D Distance (SOV AM Skim), for High Income		
Linear	-0.0840	-1.98
Squared	0.00826	2.89
Cubed	-0.000167	-3.06
Work Attractions (in 1,000's) Per Square Mile		
Linear	-0.02809	-3.21
Square Root	1.113	4.1
Cube Root	-2.043	-4.48
Total Number of Attractions (in 1,000's) within 20 minutes by Transit		
Linear	0.03276	4.47
Square Root	-1.484	-4.74
Cube Root	2.909	4.87
Production and Attraction in Same TAZ		
Same TAZ (HBW Only)	1.145	6.55
High Income and Same TAZ (HBW Only)	-1.385	-2.78
Same TAZ (HBU Only)	10.0	fixed value
Special Attractors		
High Income and Capitol (HBW Only)	0.9483	6.98
Model Estimation Statistics		
Log Likelihood at Convergence	-14,243	
Log Likelihood at Null Parameters	-15,828	
Rho Squared w.r.t. Null Parameters	0.100	

Table 7.2 Home-Based School Destination Choice Model Parameter Estimates

Parameter	Estimate	t-Stat
Mode Choice Logsum		
Mode Choice Logsum Value	0.7	fixed value
TAZ Attraction Size		
log (Number of HBSchool Attractions)	1.0	fixed value
O-D Distance (SOV AM Skim)		
Linear	-0.8179	-8.98
Squared	0.02964	4.26
Cubed	-0.000422	-2.76
Production and Attraction in Same TAZ		
Same TAZ	-0.5585	-2.75
Other Parameters		
Distance to Closest School - Distance to Destination (capped at -2 miles)	0.3713	3.38
Model Estimation Statistics		
Log Likelihood at Convergence	-1,765	
Log Likelihood at Null Parameters	-3,097	
Rho Squared w.r.t. Null Parameters	0.430	

Table 7.3 Home-Based Shopping Destination Choice Model Parameter Estimates

Parameter	Estimate	t-Stat
Mode Choice Logsum		
Mode Choice Logsum Value	0.7	fixed value
TAZ Attraction Size		
log (Number of HBW Attractions)	1.0	fixed value
O-D Distance (SOV AM Skim)		
Linear	-0.8748	-23.53
Squared	0.04394	11.39
Cubed	-0.000839	-7.97
Total Population (in 1,000's) Per Square Mile		
Linear	-0.3019	-3.16
Square Root	2.332	3.68
Cube Root	-1.898	-3.36
Number of Shopping Attractions (in 1,000's)		
Linear	-0.08806	-8.63
Square Root	2.608	8.04
Cube Root	-3.606	-6.66
Number of Non-Shopping Attractions (in 1,000's)		
Linear	-0.01255	-9.96
Production and Attraction in Same TAZ		
Same TAZ	0.717	4.48
Model Estimation Statistics		
Log Likelihood at Convergence	-6,277	
Log Likelihood at Null Parameters	-8,960	
Rho Squared w.r.t. Null Parameters	0.299	

Table 7.4 Home-Based Other Destination Choice Model Parameter Estimates

Parameter	Estimate	t-Stat
Mode Choice Logsum		
Mode Choice Logsum Value	0.7	fixed value
TAZ Attraction Size		
log (Number of HBO Attractions)	1.0	fixed value
O-D Distance (SOV AM Skim)		
Linear	-0.5369	-33.84
Squared	0.01879	14.94
Cubed	-0.000259	-9.68
O-D Distance (SOV AM Skim), for High Income		
Linear	-0.1993	-5.99
Squared	0.01547	5.00
Cubed	-0.000324	-4.3
Total Population (in 1,000's) Per Square Mile		
Linear	0.1272	6.39
Square Root	-0.4645	-8.11
Number of Shopping Attractions (in 1,000's)		
Linear	-0.02648	-8.82
Square Root	0.635	22.9
Number of School Attractions (in 1,000's)		
Linear	0.007832	1.03
Square Root	0.2561	6.74
All Other Attractions (in 1,000's) Per Square Mile		
Linear	0.007455	6.00
Square Root	-0.3593	-16.3
Total Number of Attractions (in 1,000's) within 20 minutes by Transit		
Linear	0.03017	5.97
Square Root	-0.9403	-4.93
Cube Root	1.595	4.61
Production and Attraction in Same TAZ		
Same TAZ	1.172	19.9
Special Attractors		
Medical	0.8988	8.27
Capitol	-0.7495	-3.56
Model Estimation Statistics		
Log Likelihood at Convergence	-27,248	
Log Likelihood at Null Parameters	-35,345	
Rho Squared w.r.t. Null Parameters	0.229	

Table 7.5 Non-Home-Based Destination Choice Model Parameter Estimates

Parameter	Estimate	t-Stat
Mode Choice Logsum		
Mode Choice Logsum Value	0.7	fixed value
TAZ Attraction Size		
log (Number of NHB Attractions)	1.0	fixed value
O-D Distance (SOV AM Skim)		
Linear	-0.5948	-36.64
Squared	0.02588	16.99
Cubed	-0.00042	-11.28
O-D Distance (SOV AM Skim), for High Income		
Linear	0.04352	1.66
Squared	-0.00634	-2.88
Cubed	0.000186	3.77
Total Population (in 1000's) Per Square Mile		
Linear	0.1217	3.05
Square Root	-0.7608	-2.62
Cube Root	0.5852	2.15
Number of Shopping Attractions (in 1,000's)		
Linear	-0.02563	-11.76
Square Root	0.3472	15.86
Number of School Attractions (in 1,000's)		
Linear	0.01094	1.32
Square Root	0.2133	5.29
All Other Attractions (in 1,000's) Per Square Mile		
Linear	0.005255	5.15
Square Root	-0.2038	-10.62
Total Number of Attractions (in 1,000's) within 20 minutes by Transit		
Linear	0.03313	7.28
Square Root	-0.6675	-3.81
Cube Root	0.8121	2.53
Production and Attraction in Same TAZ		
Same TAZ	0.6062	11.18
Special Attractors		
Destination is JBLM	-0.7187	-4.13
Both Origin and Destination is JBLM	0.68	2.56
Model Estimation Statistics		
Log Likelihood at Convergence	-30,271	
Log Likelihood at Null Parameters	-36,724	
Rho Squared w.r.t. Null Parameters	0.176	

7.3 Validation

The destination choice model is a key component of the travel demand model. Therefore, a series of checks was conducted on this model to ensure that the model produces results consistent with travel behavior reflected in the household travel survey.

Key aspects of the destination choice model included:

- The destination choice model was partially segmented by household income categories for HBW, HBU, HBO, and NHB trip purposes. Therefore, the model has the ability to capture differences in travel patterns of different household income segments.
- The destination choice models included distance variables as a means to capture the effects of levels of service on destination choice. The distance coefficients were adjusted during calibration to match household travel survey patterns.
- In addition, the coefficients for intrazonal dummy variables that capture the effect of traveling within a TAZ were also adjusted to match overall travel distribution patterns.

Calibration Process

The model results were compared against household survey data across several dimensions including:

- Shares of intrazonal trips by trip purpose and income segment;
- Average travel time by trip purpose and income segment;
- Travel time histograms by trip purpose; and
- District-level travel patterns within Thurston and Pierce Counties by trip purpose.

The models were calibrated in an iterative fashion. Changes were made to the distance and intrazonal model coefficients, and the subsequent model data was processed to produce output summaries. Those were later compared to the household travel survey data. **Table 7.6** outlines the changes in the distance and intrazonal coefficients between the estimated models and the final set of suggested coefficients.

Table 7.6 Comparisons of Estimated and Calibrated Coefficients for Trip Distances and Intrazonal Trips

		Distance Coefficient		Intrazonal Coefficient	
Trip Purpose	Income Categories	Estimated	Calibrated	Estimated	Calibrated
Home Based Work	Less than $35,000	-0.2203	-0.3074	1.1450	1.2370
	$35,000 - $99,999	-0.2203	-0.2931	1.1450	1.0178
	$100,000 or Above	-0.0840	-0.1618	-1.3850	-1.2356
Home Based University	Less than $35,000	-0.2203	-0.1612	10.0000	10.2176
	$35,000 - $99,999	-0.2203	-0.2616	10.0000	9.8316
	$100,000 or Above	-0.0840	-0.3083	10.0000	9.9260
Home Based School	Less than $35,000	-0.8179	-0.7549	-0.5585	-0.7036
	$35,000 - $99,999	-0.8179	-0.7805	-0.5585	-0.5401
	$100,000 or Above	-0.8179	-0.8038	-0.5585	-0.5351
Home Based Shopping	Less than $35,000	-0.8748	-0.8866	0.7171	0.8087
	$35,000 - $99,999	-0.8748	-0.8636	0.7171	0.7270
	$100,000 or Above	-0.8748	-0.9669	0.7171	0.6330
Home Based Other	Less than $35,000	-0.5369	-0.5506	1.1720	1.2882
	$35,000 - $99,999	-0.5369	-0.5898	1.1720	1.2853
	$100,000 or Above	-0.1993	-0.2948	1.1720	1.2176
Non-Home Based	Less than $35,000	-0.5948	-0.6085	0.6062	0.6555
	$35,000 - $99,999	-0.5948	-0.6477	0.6062	0.7114
	$100,000 or Above	0.0435	-0.0519	0.6062	0.9000

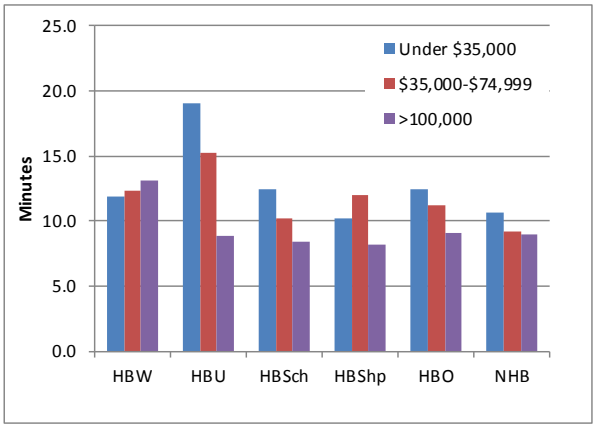
Calibration Results

Results from the calibrated models are presented in this section. **Figures 7.1 and 7.2** show comparisons of average impedance and percentage intrazonal by trip purpose and household income.

Figure 7.1 Comparisons of Average Travel Times by Purpose and Income

SURVEY	Under $35,000	$35,000-$74,999	>100,000
HBW	11.9	12.4	13.1
HBU	19.0	15.2	8.9
HBSch	12.5	10.2	8.4
HBShp	10.2	12.0	8.2
HBO	12.4	11.2	9.1
NHB	10.6	9.2	9.0

MODEL	Under $35,000	$35,000-$74,999	>100,000
HBW	16.0	15.7	16.2
HBU	14.7	16.8	20.8
HBSch	7.5	7.5	7.5
HBShp	9.8	10.8	11.1
HBO	13.5	14.5	14.2
NHB	8.4	8.9	9.1



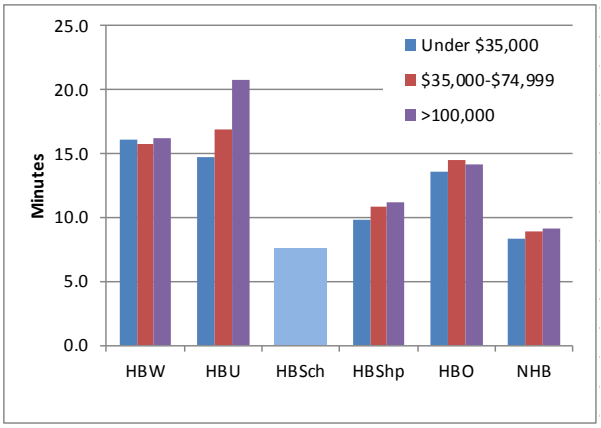
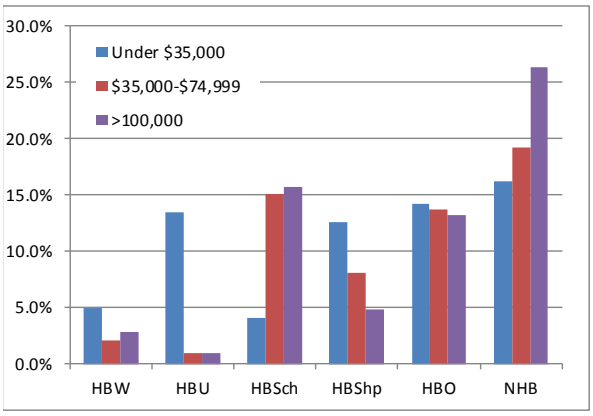
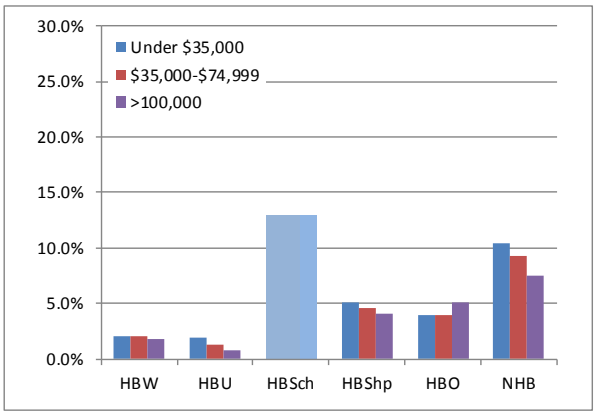


Figure 7.2 Comparisons of Shares of Intrazonal Trips by Purpose and Income

Purpose	Under $35,000	$35,000-$74,999	>100,000
HBW	5.0%	2.1%	2.9%
HBU	13.5%	1.0%	1.0%
HBSch	4.1%	15.1%	15.7%
HBShp	12.6%	8.0%	4.9%
HBO	14.3%	13.7%	13.2%
NHB	16.2%	19.2%	26.3%

Purpose	Under $35,000	$35,000-$74,999	>100,000
HBW	2.1%	2.1%	1.8%
HBU	1.9%	1.3%	0.7%
HBSch	13.0%	13.0%	13.0%
HBShp	5.0%	4.6%	4.1%
HBO	4.0%	3.9%	5.1%
NHB	10.4%	9.3%	7.6%





The model showed minor deviations in average travel times in HBShp and NHB purpose trips. While, average times for HBW and HBO purposes in the model were higher than the survey.

For HBSch, the model indicated shorter trips than the survey. Since the school trip productions were adjusted by attractions incorporating school district geography, the patterns observed from the survey were not targeted. HBSch trips were not segmented in the model, therefore, statistics for this purpose are presented as a uniform distribution across the income groups.

The HBU patterns showed large variations due to sampling biases in this category, since this market segment was not targeted in the household travel survey. The model indicated longer trip distances for HBU trips from households in the high income group, potentially pointing to the commuting students living with their parents, or can afford live off-campus.

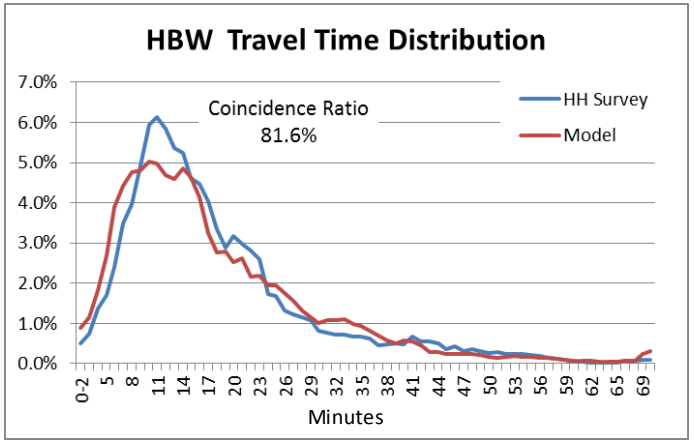
In addition, the survey results showed higher frequencies of short-distance HBW trips. A share of 20 percent was observed for HBW trips two miles or less in distance. For HBO trips, more than 43 percent of the trips were within two miles from the home location. Therefore, trip distance frequencies were monitored, but were not targeted closely. Instead, travel times were used.

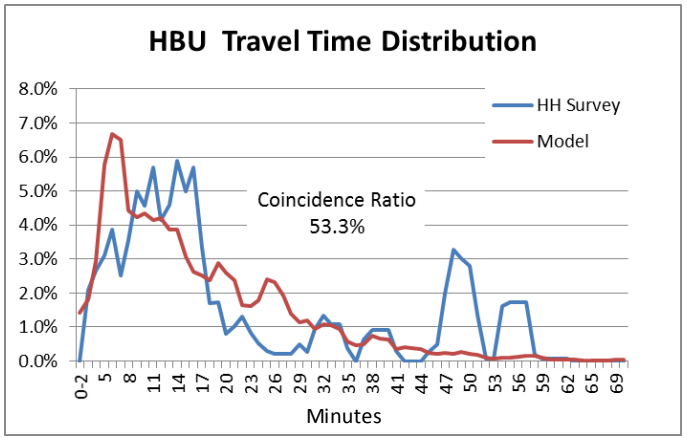
The model intrazonals were lower than the survey intrazonals for every purpose. Differences in HBO and NHB were more noticeable. In addition, survey showed a greater variation across the income groups when compared to the patterns obtained from the model.

Figures 7.3 through 7.5 outline the summary of all the remaining comparisons made during destination choice calibration.

- Overall, the model represented observed travel time frequencies from the household survey reasonably well. Coincidence ratios ranging between 76.3 percent to 81.6 percent, except for the HBU purpose. Since the household travel survey sample was not a representative sample of university students, comparisons based on university registration records may provide a better basis and may already point to a better match by the model.
- Home based trip purposes produced high frequencies of short distance trips when compared against model results. However, the trip tables in the model, when assigned to highway network, yielded reasonable levels of matches against traffic counts. This points a need to review and revise household survey data and to explore alternative ways of data acceptances and expansion.
- Comparisons of district level flows are constrained to areas with the areas sampled by the household travel survey. A district structure was devised for summarizing travel flows as shown in **Figure 7.6**
    - Since the model area included a portion of the Pierce County and the survey sampling rate was lower for Pierce County portion of the study area, Pierce County district trip productions and attraction were not represented well enough by the survey. Therefore, relatively large differences were observed for flows either produced or attracted in/to Pierce County district.
    - The district level flows reflected in the model, were able to capture the general patterns indicated by the household travel survey, for HBW, HBShp, HBO, and NHB trip purposes.
    - Notable differences in travel patterns were detected in patterns associated with
        - Tumwater area for HBW, HBShp HBO and NHB trips, and
        - Intra Olympia district flows for HBW, and NHB purposes.

Figure 7.3 Comparisons of Travel Distance Frequency Distributions for HBW and HBU Trip Purposes





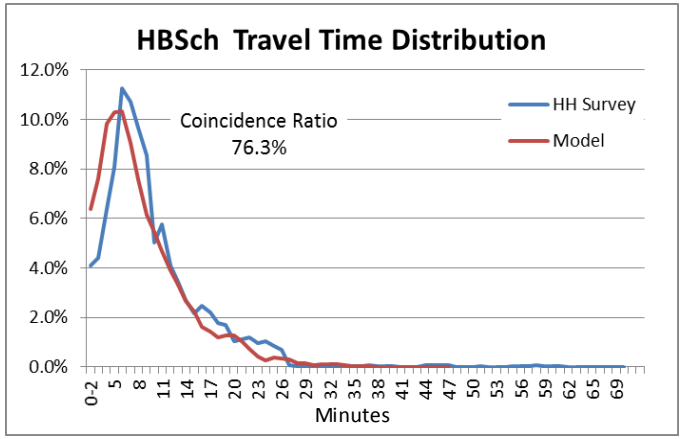
SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	7,969	830	5,301	0	88	935		18,178
Lacey Area	5,154	5,262	11,611	608	7,938	3,799		39,742
Tumwater Area	12,452	3,386	24,647	347	2,615	1,623		54,814
Yelm/ SE Thurston	828	0	1,939	4,651	2,044	923		10,901
JBLM	0	0	755	0	8,213	0		8,967
Pierce Co.	1,147	0	2,218	0	15,076	80,546		100,809
Rural & Ext								
Total	36,031	11,817	56,812	5,765	40,861	89,558		275,994

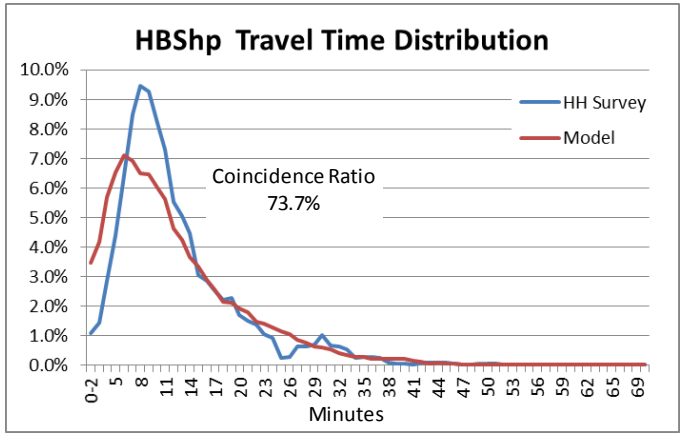
MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	3,007	1,397	4,207	116	605	200		11,414
Lacey Area	5,929	10,052	14,558	1,304	5,646	1,863		44,995
Tumwater Area	8,491	5,916	20,283	859	2,518	834		50,558
Yelm/ SE Thurston	775	1,249	2,771	8,162	2,226	1,470		19,674
JBLM	89	304	198	250	7,805	3,901		15,522
Pierce Co.	265	887	586	1,671	35,118	109,904		238,289
Rural & Ext								
Total	30,546	25,189	66,981	14,455	76,041	203,580		640,660

SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	29	0	153	0	0	40		611
Lacey Area	0	442	1,175	0	0	418		2,585
Tumwater Area	65	144	668	0	0	45		2,992
Yelm/ SE Thurston	0	0	338	410	0	105		853
JBLM	0	0	0	0	0	0		0
Pierce Co.	0	0	701	0	0	1,415		2,924
Rural & Ext								
Total	94	586	3,571	410	0	2,856		13,978

MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	0	9	449	0	0	80		973
Lacey Area	0	124	1,331	0	0	1,408		3,602
Tumwater Area	0	46	2,358	0	0	381		4,421
Yelm/ SE Thurston	0	47	605	0	0	686		1,714
JBLM	0	3	24	0	0	1,606		1,656
Pierce Co.	0	2	25	0	0	23,815		24,049
Rural & Ext								
Total	0	244	6,719	0	0	40,917		58,289

Figure 7.4 Comparisons of Travel Distance Frequency Distributions for HBSch and HBShp Trip Purposes





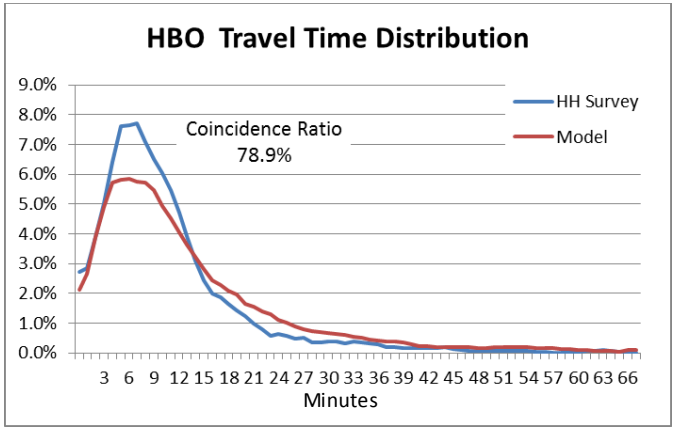
SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	2,653	0	1,139	0	0	400		4,192
Lacey Area	725	8,591	3,342	816	0	490		14,808
Tumwater Area	86	2,051	14,789	0	0	0		17,699
Yelm/ SE Thurston	0	0	0	5,038	0	0		5,038
JBLM	0	0	0	0	0	0		0
Pierce Co.	0	129	0	0	0	41,503		41,632
Rural & Ext								
Total	3,941	10,846	24,452	5,854	2,488	42,392		101,517

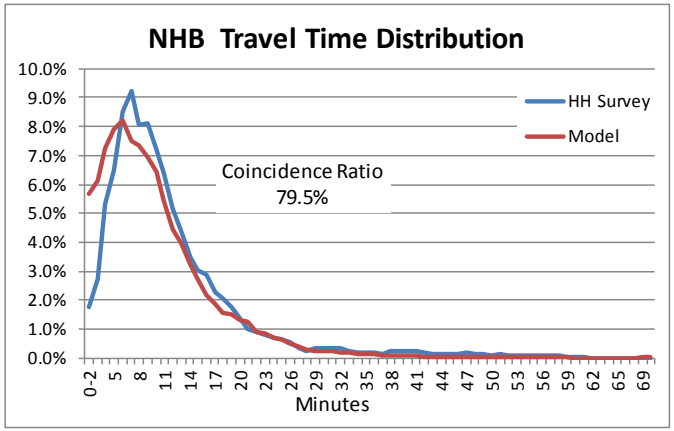
MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	1,160	0	625	0	0	0		1,816
Lacey Area	384	7,266	1,871	361	366	638		10,886
Tumwater Area	249	1,628	9,784	0	0	0		11,671
Yelm/ SE Thurston	0	27	0	4,941	5	5		5,008
JBLM	0	352	0	111	1,859	3,641		5,966
Pierce Co.	0	76	0	298	306	47,101		49,178
Rural & Ext								
Total	1,793	9,349	13,137	5,821	2,543	57,973		114,816

SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	3,073	1,501	4,686	46	0	0		11,026
Lacey Area	842	11,214	5,346	0	2,104	252		20,597
Tumwater Area	1,407	1,415	25,908	79	55	232		34,521
Yelm/ SE Thurston	163	508	578	1,689	76	147		3,161
JBLM	0	0	0	0	0	841		841
Pierce Co.	0	0	0	0	2,305	82,613		84,918
Rural & Ext								
Total	7,125	17,789	47,469	1,813	6,199	84,844		186,418

MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	3,516	625	3,225	0	0	0		7,756
Lacey Area	302	12,441	6,054	2	20	3		27,148
Tumwater Area	2,406	2,110	22,692	1	0	0		32,575
Yelm/ SE Thurston	36	713	1,422	8,984	247	644		12,201
JBLM	56	2,429	584	15	2,372	2,741		8,602
Pierce Co.	38	1,665	401	4	5,369	115,849		146,146
Rural & Ext								
Total	9,877	20,503	46,022	9,044	8,420	133,509		319,464

Figure 7.5 Comparisons of Travel Distance Frequency Distributions for HBO and NHB Trip Purposes





SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	17,026	1,822	10,371	61	135	1,086		**36,173**
Lacey Area	4,557	35,114	21,141	1,352	2,700	2,473		**73,683**
Tumwater Area	11,956	7,750	79,391	606	1,443	1,360		**117,682**
Yelm/ SE Thurston	67	269	3,080	12,636	960	313		**17,564**
JBLM	0	0	0	0	2,226	3,942		**9,158**
Pierce Co.	1,623	1,067	2,118	1,504	9,625	272,645		**291,858**
Rural & Ext								
Total	**42,283**	**49,237**	**132,175**	**16,216**	**22,304**	**285,258**		**650,735**

MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	9,013	1,619	7,453	52	612	694		**21,816**
Lacey Area	8,603	33,116	26,624	2,303	7,394	7,599		**90,143**
Tumwater Area	17,964	9,887	52,841	935	2,741	3,097		**101,632**
Yelm/ SE Thurston	184	590	876	17,571	5,631	13,264		**41,385**
JBLM	802	1,925	1,622	681	11,942	13,811		**33,722**
Pierce Co.	3,328	7,176	6,668	3,452	37,038	358,256		**487,147**
Rural & Ext								
Total	**58,742**	**58,400**	**131,039**	**27,684**	**71,628**	**444,885**		**1,052,193**

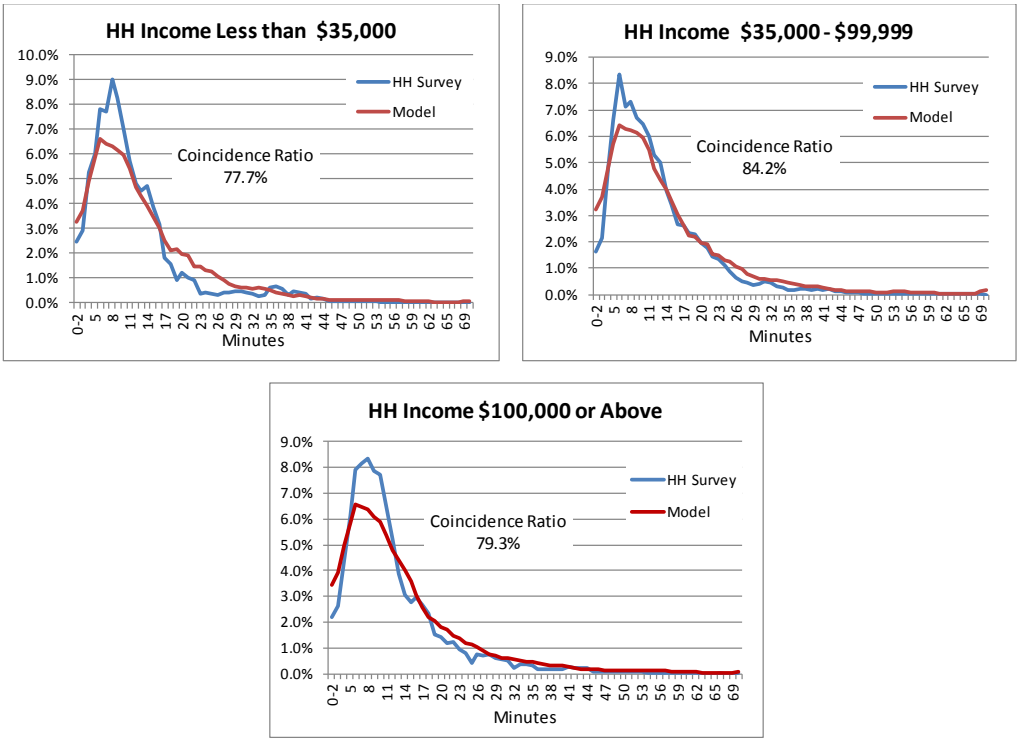
SURVEY	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	27,957	2,917	16,502	135	659	1,564		**57,564**
Lacey Area	2,256	28,480	15,568	525	1,956	943		**54,337**
Tumwater Area	14,523	14,802	94,829	602	1,153	4,684		**149,939**
Yelm/ SE Thurston	81	484	1,721	9,713	294	1,165		**13,702**
JBLM	41	2,677	1,347	417	15,430	7,056		**28,166**
Pierce Co.	973	1,269	4,046	823	3,209	274,530		**285,283**
Rural & Ext								
Total	**52,641**	**56,791**	**154,286**	**12,318**	**24,180**	**294,903**		**702,306**

MODEL	Olympia	Lacey Area	Tumwater Area	Yelm/ SE Thurston	JBLM	Pierce Co.	Rural & Externals	Total
Olympia	17,338	4,849	17,962	64	96	19		**51,638**
Lacey Area	4,618	35,576	19,475	658	3,962	734		**69,184**
Tumwater Area	18,067	20,335	83,780	574	453	88		**147,175**
Yelm/ SE Thurston	181	1,860	1,695	21,797	654	667		**28,514**
JBLM	85	1,578	315	1,360	24,463	20,275		**52,691**
Pierce Co.	37	669	137	3,051	18,778	366,694		**460,311**
Rural & Ext								
Total	**51,723**	**69,274**	**147,416**	**28,519**	**52,628**	**459,612**		**1,107,609**

Figure 7.6 District Structure Developed for Travel Pattern Analysis

Figure 7.7 provides a set of comparisons of travel time frequency distributions for all trips across income groups. The distributions from the survey and model matched fairly well with coincidence ratios ranging between 77.7 and 84.2 percent. However, the distributions from the model did not show noticeable variance across the income groups. This could be partly due to aggregation over the trip purposes and might be further examined in future efforts.

Figure 7.7 Travel Time Frequency Distributions by Income Groups – All Trips



8.0 Time of Day Modeling

8.1 Overview

The time-of-day choice models are calculated using the Household Travel Survey. These models are aimed to address three questions:

- What are the peak periods of travel?
- What is the share of travel by purpose during individual time periods?
- What is the directionality of travel by purpose and time period?

This section outlines the findings from the analysis of the Household Travel Survey data to address the three questions listed above.

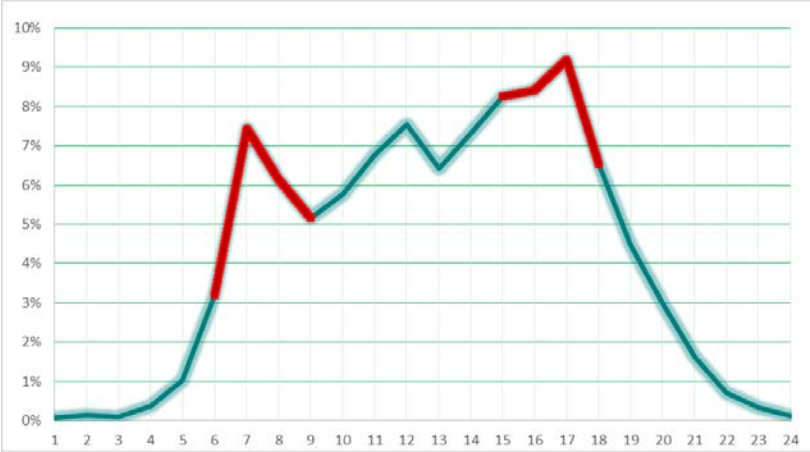
Definition of Peak Periods

Most travel demand models developed for small to medium sized urban areas has four time periods:

- AM Peak: 6 AM – 9 AM
- Mid-Day: 9 AM - 3 PM
- PM Peak: 3 PM – 6 PM
- Overnight: 7 PM – 6 AM

The Household Travel Survey data was analyzed to characterize the demand during the peak and off-peak time periods as shown in **Figure 3.1**.

Figure 8-1 Temporal Distribution of Trips in the Household Travel Survey



- **AM Peak.** The 6:00 AM – 9:00 AM travel window accounts for nearly 22 percent of all travel in the region.
  - Furthermore, this travel window accounts for 37 percent of all home based work travel.
  - The first hour of the AM Peak shows a rapid growth in volume reaching a peak at 7:00 AM. During the next two hours, there was a decline about two-percent. This indicates a rapid peaking of traffic volume and a dissipating pattern in the next two hours indicating that there is some capacity in the later portions of the AM Peak.

- **Off-Peak Period**. The time window in the middle of the day that is between the two peak periods is considered the mid-day period and the time window after the PM peak leading to the next AM peak is considered the overnight period.
  - The mid-day period showed a growth trend between 9:00 AM and 3:00 PM, while peaking at noon time.
  - The traffic volume reaches AM Peak level before 3:00 PM.
  - Nearly 34% of the region's trips occurs during this period.
- **PM Peak**. The 3:00 PM – 6:00 PM travel window carries over 32 percent of all travel in the region.
  - The peak is reached at 5:00 PM and it reduces to mid-day levels by 6:00 PM.

The analysis of overall variation of travel demand during the day indicated that peaking is more prevalent to PM Peak period where recovery occurs sometime within the 5:00 PM – 6:00 PM period. It was decided that PM Peak behavior will be analyzed in greater detail with behavioral models as descried in subsections 8.2 through 8.4

Travel Share by Time Period

The survey data were analyzed to developed time-of-day factors for each time period (**Table 8.1**).

- A majority of home-based work trips occur during the two peak periods (60 percent).
- Home-based school trips (77 percent) also occur predominantly during the peak periods.
- Home-based non-mandatory travel is limited during the AM peak period, but is reasonably well-distributed across the rest of the day.
- Nearly 50 percent of all non-home based trips happens during the mid-day period which is also consistent with lunch patterns typically observed for workers. Another 35 percent occurs during the PM peak and early evening hours that are likely to be associated with pick-ups and daily errands.
- Each of the percentages shown in **Table 8.1** was used to split the trip tables into four separate time periods.

Table 8-1 Time-of-Day Person Trip Factors for Internal Trips

Time of Day Periods	HBW	HBU	HBSch	HBShp	HBO	NHB
Early AM (3:00 - 5:59 AM)	0.075	0.000	0.000	0.000	0.010	0.005
AM PEAK (6:00 - 8:59 AM)	0.370	0.365	0.520	0.035	0.125	0.090
Midday (9:00 AM - 2:59 PM)	0.180	0.390	0.220	0.450	0.325	0.490
PM PEAK (3:00 - 5:59 PM)	0.235	0.170	0.250	0.305	0.250	0.290
Night (6:00 - 9:59 PM)	0.090	0.020	0.010	0.205	0.270	0.120
Late Night (10:00 PM - 2:59 AM)	0.050	0.055	0.000	0.005	0.020	0.005
Total	1.000	1.000	1.000	1.000	1.000	1.000

Convert P-A Trips to O-D Trips

The trip tables generated in the model are in a production-attraction (P-A) format. Prior to assignment, it is necessary to convert this P-A format to an origin-destination (O-D) format to ensure that the networks are loaded the right way (for e.g. inbound segments headed to downtown must be congested in the AM while outbound segments must be congested in the PM peak).

Table 8.2 outlines the directionality factors that must be applied to the P-A tables to convert those into the O-D format. Separate factors were generated for each time period and purpose. **Table 8.3** features the factors for the joint distribution of time of day and directionality. These factors are applied after the application of the mode choice model.

- A majority of travel in the AM peak period has an origin at home (production = origin). Home-based shopping and home-based other purposes have the largest shares of return-to-home trips in the AM peak (20 - 29 percent).
- In the PM peak, the exact opposite happens with a majority of trips traveling from a non-home location to home – especially for the home-based work purpose.
- For the non-home based trip purposes, it is assumed that the trip produced at the origin, therefore, no directionality adjustments were made.

Table 8.2 Directionality Factors by Time of Day Periods and Trip Purpose

Time of Day Periods	Direction	HBW	HBU	HBSch	HBShp	HBO
Early AM	P to A	0.933				1.000
(3:00 - 5:59 AM)	A to P	0.067				0.000
AM PEAK	P to A	0.932	0.973	1.000	0.708	0.800
(6:00 - 8:59 AM)	A to P	0.068	0.027	0.000	0.292	0.200
Midday	P to A	0.501	0.410	0.205	0.533	0.600
(9:00 AM - 2:59 PM)	A to P	0.499	0.590	0.795	0.467	0.400
PM PEAK	P to A	0.043	0.059	0.060	0.328	0.580
(3:00 - 5:59 PM)	A to P	0.957	0.941	0.940	0.672	0.420
Night	P to A	0.056	0.000	0.000	0.293	0.370
(6:00 - 9:59 PM)	A to P	0.944	1.000	1.000	0.707	0.630
Late Night	P to A	0.200	0.000		0.000	0.250
(10:00 PM - 2:59 AM)	A to P	0.800	1.000		1.000	0.750

Table 8.3 Joint Time of Day and Directionality Factors by Trip Purpose

Time of Day Periods	Direction	HBW	HBU	HBSch	HBShp	HBO	NHB
Early AM	P to A	0.070	0.000	0.000	0.000	0.010	0.005
(3:00 - 5:59 AM)	A to P	0.005	0.000	0.000	0.000	0.000	
AM PEAK	P to A	0.345	0.355	0.520	0.025	0.100	0.090
(6:00 - 8:59 AM)	A to P	0.025	0.010	0.000	0.010	0.025	
Midday	P to A	0.090	0.160	0.045	0.240	0.195	0.490
(9:00 AM - 2:59 PM)	A to P	0.090	0.230	0.175	0.210	0.130	
PM PEAK	P to A	0.010	0.010	0.015	0.100	0.145	0.290
(3:00 - 5:59 PM)	A to P	0.225	0.160	0.235	0.205	0.105	
Night	P to A	0.005	0.000	0.000	0.060	0.100	0.120
(6:00 - 9:59 PM)	A to P	0.085	0.020	0.010	0.145	0.170	
Late Night	P to A	0.010	0.000	0.000	0.000	0.005	0.005
(10:00 PM - 2:59 AM)	A to P	0.040	0.055	0.000	0.005	0.015	

8.2 Time of Day Choice Model for the PM Peak Period

This section details the development of a time-of-day model as a separate component of the TRPC travel demand model. As shown in **Figure 8.1**, peaking behavior is more prevalent in the PM Peak. Therefore, the model development effort was focused on the impact of congestion on the choice of departure time within and near the PM peak period. The PM peak period is defined as the time period between 4:00 PM and 6:00. A 30-minute shoulder both before and after the peak was also included.

Table 8.4 shows the distribution of trip frequency by 30-minute time period that was selected from the Household Travel Survey dataset. It was assumed that time of day shifts would occur during the PM peak period for intra-district trips within the model area. There were 2,490 trip records that satisfied these conditions.

Table 8.4 Trip Frequency by Time of Day Slices and Trip Purpose

Time of Day Periods within the PM Peak	HBW	Other Purposes	ALL
15:30-16:00	63	295	358
16:00-16:30	85	301	386
16:30-17:00	102	323	425
17:00-17:30	162	381	543
17:30-18:00	69	301	370
18:00-18:30	68	340	408
Total	549	1,941	2,490

The overall share of HBW trips was 14.6 percent, the share of HBW trips during the PM Peak was 22 percent, more than 50 percent of the overall share. In addition, the choice of time of day periods for HBW trips are more restricted by schedule flexibility. Therefore, the trips were segmented into HBW and non-HBW markets for developing time of day choice models.

8.3 Data Collection

The main data item needed for estimating time of day choice models is In-Vehicle Travel Times (IVTT) for each time period considered. Typically, IVTT data are produced by models or by post-processing of highway skims. This approach sometimes fails to portray actual behavior. In order to capture a better representation of travel time variations in the region, an Application Program Interface (API) was developed to query Google Maps road network to capture the shortest travel time between a given Origin-Destination (O-D) pair. The tool was designed to store a list of O-D pairs as inputs, and it allows users to automatically search for the shortest travel time for any future date at a desired rate for a given time period. The shortest travel time for each of the O-D pair is reported in a text file in 'csv' (comma-delimited) format.

The Household Travel Survey trips that were made during the PM Peak and the shoulder periods yielded a set of 2,399 unique O-D pairs. Centroid coordinates (in decimal degrees) for each pair were inputted to the tool, and IVTTs for the fastest paths were recorded at a rate of 15 minutes starting from 3:00 PM to 7:45 PM Pacific time between the dates of January 11th, 2016, Monday and January 15th, 2016, Friday.

To capture the variation in travel time on a typical work day, data on Friday were excluded. This resulted a total of 48 observations for each OD pair for the period between 3:30 PM and 6:30 PM. (two 15-minute observations for each of the six time periods during four workdays).

Congestion in the PM peak period is considered to be one of the main factors that contribute to people's decision on departure time. To factor in congestion in the model, a measure of congestion based on the variation in travel time across different time periods was created. Specifically, a travel time range for the 48 travel time observations for each pair of zones was calculated, and then divided by the average of those observations. Higher values in this ratio pointed to a higher degree of congestion.

Schedule flexibility is another factor that influences people's choice of departure time aside from congestion. People with a fixed schedule are less likely to switch their departure time due to congestion. Since it's not possible to explicitly capture each person's schedule flexibility with the current dataset, we used a set of criteria to filter out people who have a relatively flexible schedule. Specifically, we selected non-military respondents who used flexible work time benefits and whose primary commute mode was automobile or taxi. **Table 8.5** shows the distribution of trip frequency for this subsample from the Household Travel Survey dataset.

Table 8.5 Trip Frequency by Time of Day for the Sample with Flexible Schedules

Time of Day Periods within the PM Peak	HBW	Other Purposes	ALL
15:30-16:00	31	20	51
16:00-16:30	49	34	83
16:30-17:00	53	33	86
17:00-17:30	66	37	103
17:30-18:00	53	40	93
18:00-18:30	51	39	90
Total	303	203	506

8.4 Model Development

Multinomial discrete choice models were estimated for time of day choice for the PM peak period for both work and non-work purposes. The six time periods listed in **Table 8.4** were the available choices where the time period from 5:00 PM to 5:30 PM was selected as the base alternative. The model includes a constant term and two explanatory variables. The utility function of individual i choosing departure time period j is expressed as:

$$U_{ij} = Constant_i + \beta_1 \times Travel\ Time_j + \beta_2 \times TT_VARIANCE_i.$$

Table 8.6 shows the time-of-day model estimated for the subsample discussed in Section 8.2. Model estimation results indicated that long travel times had a negative impact on travel, and people tend to leave early to avoid excessively prolonged travel resulting from congestion. More detailed observations based on the review of the parameter estimates are as follows:

- *Constants for each alternative.* Controlling for other variables, negative constants indicate a lower possibility of choosing alternative time periods than the base period 5:00 PM - 5:30 PM. This preference of travelling during the base period is stronger for HBW trips. Moreover, all other factors being equal, the time period following the base period have the highest possibility to be selected compared to others for work purpose. The increase in disutility for traveling after 6:00 PM indicated a potential limitation on schedule flexibility. For other trip purposes, later periods seemed more favorable.

Table 8.6 Parameter Estimates for the PM Peak Time of Day Choice Model

Parameters	Time Periods	HBW			NON-HBW		
		Estimate	Std. Error	t-value	Estimate	Std. Error	t-value
Constant	15:30-16:00	-0.944	0.687	-1.374	-0.899	0.53	-1.696
	16:00-16:30	-1.242	0.614	-2.022	-0.196	0.445	-0.441
	16:30-17:00	-0.930	0.559	-1.664	-0.081	0.447	-0.181
	17:30-18:00	-0.331	0.657	-0.504	-0.008	0.425	-0.02
	18:00-18:30	-1.142	0.667	-1.714	0.258	0.437	0.589
Travel Time		-0.001	0.003	-0.332	-0.002	0.002	-0.712
Congestion Measure	15:30-16:00	-0.509	3.719	-0.137	0.944	2.634	0.359
	16:00-16:30	2.675	2.830	0.945	0.189	2.223	0.085
	16:30-17:00	2.733	2.460	1.111	-0.377	2.163	-0.174
	17:30-18:00	-2.913	3.636	-0.801	0.485	1.987	0.244
	18:00-18:30	0.968	3.540	0.273	-1.796	2.537	-0.708

- *Auto travel time between origin and destination zones.* This parameter is an alternative-specific variable which was defined as the average of the eight travel time observations for each time period. Travel time has a negative effect on the utility, though the effect is not statistically significant.
- *Congestion measure.* In general, congestion effects reduced the possibility of choosing later time periods, which suggests people tend to leave early to account for additional travel time due to congestion. This holds for HBW trips. For other purposes, preference among time periods other than just before the peak (5:00 PM – 5:30 PM) and the shoulder period after 6:00 PM was not very distinct, implying a behavior attempting to avoid the peak without deferring non-work activities too far into the evening.

In rounds of effort to refine the current models, sixteen additional model specifications were tested, including models with:

- employment and population density at trip origins,
- demographic variables such as vehicle ownership, presence of kids, and household income,
- interaction between travel times and income, and
- alternative definitions of congestion measure.

The estimation results of these models did not show significant improvement in model explanatory power. The specifications presented in **Table 8.6** were preferred due to ease of interpretation and applicability.

Application of time of day require special attention in application. As mentioned in Section 8.2, a limited sample for model estimation was used. Active military force, people who mainly take modes other than auto or taxi to work were excluded. In addition, schedule flexibility was only inferred for a population group that had an access to a work benefit.

The model estimation results should only be applied to trips made by people with schedule flexibility. Household Travel Survey based estimates of the shares of trips made by individuals with flexible schedules were provided in **Table 8.7.** These factors should be refined, if a more reliable data source is available.

In addition, implied shifts between the peak-period time slices should be monitored carefully to assure that the traffic counts are matched reasonably well.

Finally, the models can be refined by using stated preference data that can capture individuals stated choice behavior under more realistic scenarios that can be defined by policy decisions.

Table 8.7 Observed and Estimates Shares of Individuals with Flexible Schedules

		Observed		Estimated	
	Flexible Work Schedule	No of Trips	Percentage	Flexible	Non-Flexible
HBW	Not Offered	317	57.74%		
	Offered, but I don't use	72	13.11%		
	Offered, and I use	117	21.31%		
	I don’t know	28	0.05%		
	NA	15	7.79%		
	TOTAL	**549**	**100.00%**	**66.0%**	**34.0%**
Other Purposes	Not Offered	658	33.90%		
	Offered, but I don't use	125	6.44%		
	Offered, and I use	266	13.70%		
	I don’t know	57	2.94%		
	NA	835	43.02%		
	TOTAL	**1,941**	**100.00%**	**68.0%**	**32.0%**