Puget Sound 4K Model Version 4.0.3

Draft Model Documentation

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Trip Generation

1.0 INTRODUCTION

The trip generation model is the first of the four primary model components identified in the four-step modeling process. The trip generation models estimate the number of trips produced and attracted to each of the TAZs in the model system. The trips produced are estimated from households and their socioeconomic characteristics. The trips attracted are estimated from employment categorized by type.

The trip generation process for the Puget Sound 4K Model is similar to the process that has been in place since the mid 1990's at PSRC. Households are cross-classified by income, workers and size for home based trips and by income and either college age or school age children for college and school trips. A set of regional trip rates that are estimated from the most recent regional household travel survey are then applied to produce daily person trip ends for every TAZ in the model system. The cross-classifications for households are based on the Public Use Microdata Sample (PUMS) from the Census.

Changes made with Puget Sound 4K Model

Although the overall approach to trip generation in PSRC Model Version 1.0bb was not changed for the Puget Sound 4K Model implementation, several changes were made and include:

- Updated Trip Rates using the 2006 Puget Sound Household Travel Survey (Model Version 1.0bb was based on the 1999 Puget Sound Household Travel Survey).
- Adjustments made to trip rates to account for under-reporting of trips was based on the GPS sub-sample from the 2006 Puget Sound Household Travel Survey (Model Version 1.0bb assumed a 15% increase for all trip rates / purposes).
- Reduced the income classifications in trip generation from five (5) categories to four (4) categories to align with the income classifications in Trip Distribution and Mode Choice.
- Modifications to the income ranges for the four (4) income categories based on new income quartiles.
- Employment inputs were adjusted to align with the NAICS industrial classification codes (Model Version 1.0bb was based on SIC classification codes).
- Cross-Classifications were updated based on the 2010 PUMS data (Model Version 1.0bb was based on the 2000 PUMS data).
- Adjustment factors to total trips based on sensitivities from previous implementations of an Activity Generator have been incorporated. This only applies to future years.

1.1 OVERVIEW OF THE TRIP GENERATION PROCESS

The trip generation models are implemented within the Emme software system and are run via one master batch file. Due to the sensitivity of the employment data needed to run the trip generation process, Trip Generation can only be run by PSRC staff. The resulting trip ends that are output as a part of the trip generation process are provided to model users in the standard set of inputs needed to run the travel model. The trip generation process is shown in Figure 1. The key steps include:

1. **Read and store data in EMME databank for processing.** This step includes processing for each data file to convert text files generated from other sources into files that are formatted as input for EMME.
2. **Cross-Classification of Households.** This step classifies the households by income/worker/size for most home based trip purposes and by income/college age students and income/school age children for College and School based trips.
3. **Apply trip generation models.** This step includes the application of the trip production and trip attraction models for each of the seven major trip purposes. This step is further documented in the following sections on trip productions and trip attractions.
4. **Change productions and attractions into origin and destination matrices.** This step involves transposing the trip attractions from rows to columns and adding home-based shopping and home-based other trips together.
5. **Add special generators.** This step includes adding trips for locations that are not captured by standard trip generation inputs and rates. These include places like SeaTac Airport, Port Facilities and stadiums. This step is documented in the following section on special generators.
6. **Add external trips.** This step includes adding trips generated in the study area, but destined outside the study area, as well as trips generated outside the study area, but destined to places within the study area. This step is documented in the following section on external trips.
7. **Balance trip productions and attractions for each trip purpose.** This balancing process ensures that total trips produced and attracted in each trip purpose will match. This step is documented in the following section on trip balancing.
8. **Output trip productions and attractions for each trip purpose.** This process generates a text file for each trip purpose production and attraction for use in the Puget Sound 4K Trip Based Model. This step is documented in the following section on trip ends.

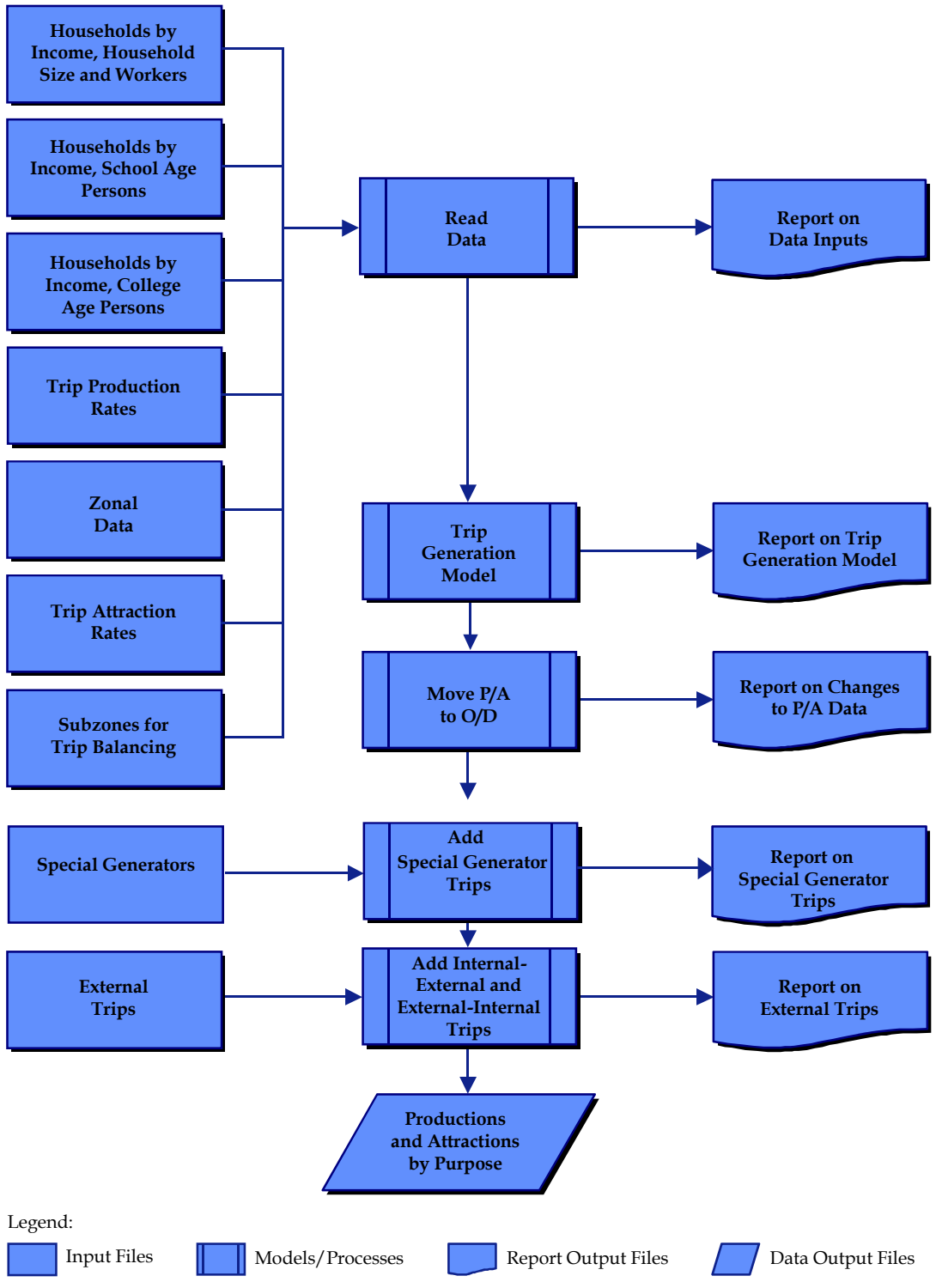

Figure 1. Trip Generation Modeling Process

1.2 TRIP PURPOSES

The trip generation models have been estimated for seven trip purposes:

1. Home-based work
2. Home-based college
3. Home-based school
4. Home-based shop
5. Home-based other;
6. Non-home-based work
7. Non-home-based other

The home-based and non-home-based trip production and attraction models were updated using the 2006 household travel surveys. Trip purposes are defined by the activities reported in the household survey at the origin and destination of each trip. If a person's trip has one end at home and one end at work with no stops in between, then this trip is defined as a home-based work trip. If a person's trip begins at home, then involves stopping at the store to buy groceries and continues on to work, this set of trips is defined as a home-based shopping trip and a non-home-based trip. Home-based other trips include activities for visiting, free-time, personal business, and appointments. Non-home-based trips include any trips that begin and end at places other than home.

1.3 HOUSEHOLD CROSS-CLASSIFICATIONS

Households are cross-classified for the estimation and application of trip rates based on household size, number of workers and income level for all home and non-home based trip purposes except college and school trips. For college trips, households are classified by income level and the number of college age persons (ages 18-24) in the household. For school based trips, households are classified by income level and the number of school age children (ages 5-17) in the household. In all, there are 52 cross-classifications for home based work, other shopping and non-home based trips, 12 cross-classifications for college trips and 16 cross-classifications for school based trips.

The cross-classification of households by traffic analysis zone (TAZ) is performed using data from the 2010 Public Use Microdata Sample (PUMS) provided by the US Census. An equivalency file relating the TAZ to PUMA is provided to distribute the PUMS classification data to all TAZ's in the region. The classification of households for each TAZ does not change in any forecast or horizon year. In all, there are 27 PUMAS in the Puget Sound Region which are shown in Figure 2. The cross-classifications by trip purpose are shown in Table 1 through Table 3. The classification of households was originally determined in the mid 1990's through analysis of trip rates in the 1988 Household Travel survey. These categorizations have been reviewed with both the 1999 and 2006 Household Travel Surveys and the distinctions amongst trip making combined with the availability of adequate sample data continue to support this cross-classification system in the Puget Sound 4K Model.

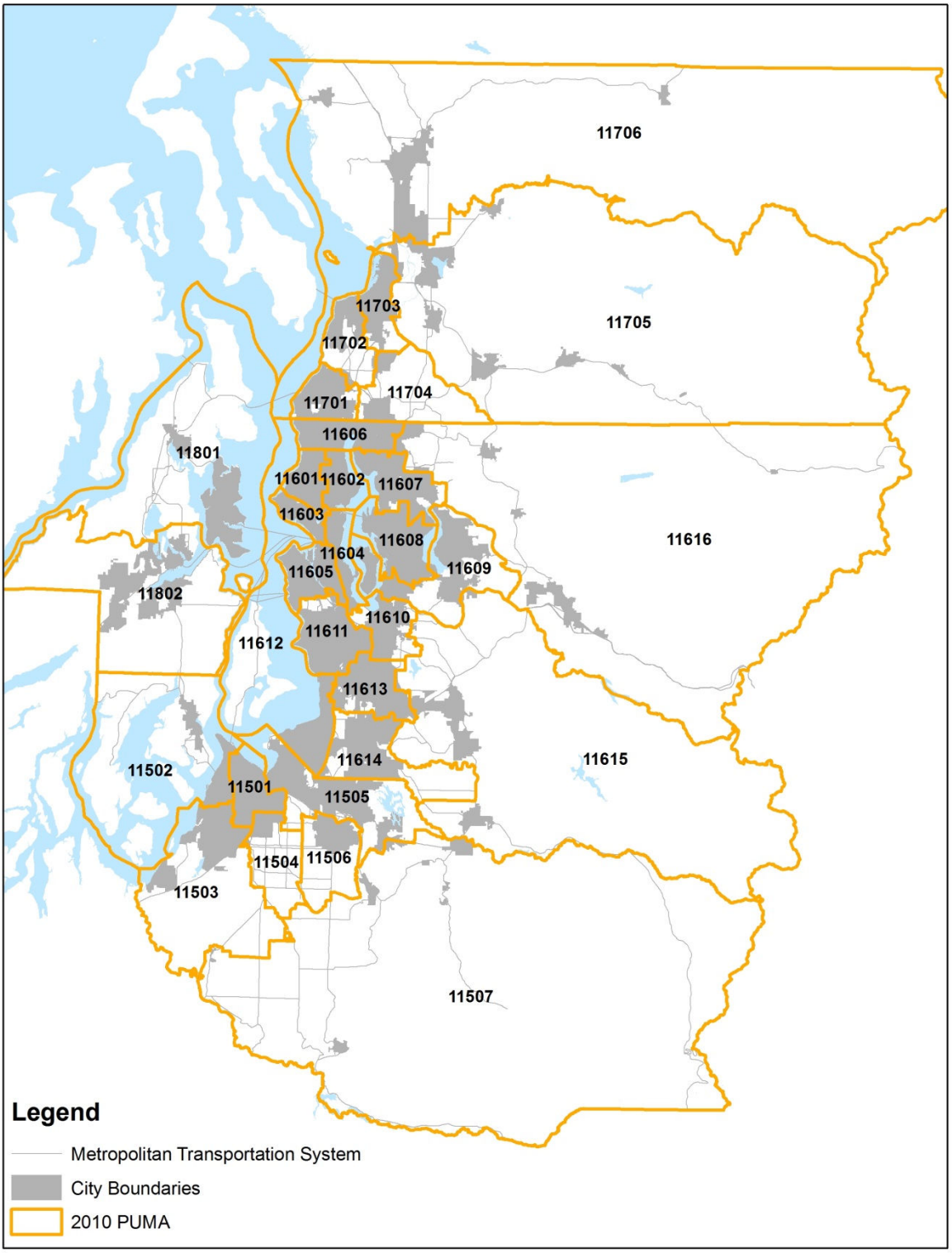

Figure 2. 2010 Census PUMA Boundaries

Table 1. Work, Other, Shopping and Non-Home Based Household Cross-Classifications

Household Size	Number of Workers in Household	Income Level			
		<$30k	$30k to $60k	$60k to $90k	>$90k
1 Person	0	✓	✓	✓	✓
	1	✓	✓	✓	✓
2 Persons	0	✓	✓	✓	✓
	1	✓	✓	✓	✓
	2	✓	✓	✓	✓
3 Persons	0	✓	✓	✓	✓
	1	✓	✓	✓	✓
	2	✓	✓	✓	✓
	3+	✓	✓	✓	✓
4+ persons	0	✓	✓	✓	✓
	1	✓	✓	✓	✓
	2	✓	✓	✓	✓
	3+	✓	✓	✓	✓

Table 2. College Based Household Cross-Classifications

# of College Age People	Income Level			
	<$30k	$30k to $60k	$60k to $90k	>$90k
0 college age people	✓	✓	✓	✓
1 college age person	✓	✓	✓	✓
2 or more college age people	✓	✓	✓	✓

Table 3. School Based Household Cross-Classifications

# of School Age Children	Income Level			
	<$30k	$30k to $60k	$60k to $90k	>$90k
0 school age children	✓	✓	✓	✓
1 school age child	✓	✓	✓	✓
2 school age children	✓	✓	✓	✓
3+ school age children	✓	✓	✓	✓

Changes made with Puget Sound 4K Model

There have been two updates to the cross-classifications in the Puget Sound 4K model.

- Reduced the income classifications in trip generation from five (5) categories to four (4) categories to align with the income classifications in Trip Distribution and Mode Choice.
- Cross-Classifications were updated based on the 2010 PUMS data.

The reduction on the number of income categories to cross-classify by was based on a review of differences in trip making between the bottom two income categories in the trip generation model and the availability of sample data. Trip rates for these two lower income categories were similar in both the 1999 and 2006 Household Travel Survey's and did not show a significant difference in trip making between one another. The V1.0bb model system had already compressed the number of income categories in Trip Distribution and Mode Choice to four (4) for these same reasons and as such a decision was made in the Puget Sound 4K model to move to a consistent four (4) income categorization for the entire model system.

The other change to the Puget Sound 4K model cross-classification was to update the distributions based on the 2010 PUMS data. This changes the distribution of households by all cross-classifications across the region. This change better aligns the base year travel model inputs to the most recent and best available data.

1.4 TRIP RATE ESTIMATION

Trip production models for home-based trips in the Puget Sound 4K Trip Generation Model were estimated using 2006 Puget Sound Household Travel Survey data. The models were estimated for each trip purpose separately and rates were derived for each cross-classification. The process of trip rate estimation was consistent between the 1999 and 2006 Household Travel Surveys.

Changes made with Puget Sound 4K Model

One major difference between the V1.0bb trip rates and those used in the Puget Sound 4K Model is the approach to account for the under-reporting of trips in household surveys. In the Version 1.0bb Model, trip rates for all purposes were increased by 15% region wide as well as adjustments for Kitsap Peninsula attraction rates. Without adjusting for underreporting, the basic survey results from the 1999 Puget Sound Household Travel Survey estimated approximately 3.48 daily trips per person. When the 15% adjustment is applied, the daily trips per person would increase to 3.97 which results in approximately 14,270,000 daily person trips in 2010.

In 2006, the Household Survey conducted a smaller subsample that included GPS tracking of trips to compare amongst other things the general level of under-reporting of trips. The trip rates in the Puget Sound 4K model were adjusted by trip purpose based on this GPS sample. Table 4 highlights the differences in trips per person by trip purpose between the Basic Survey and the GPS subsample.

Table 4. 2006 Household Survey Trips per Person with and without GPS Expansion

Trip Purpose	Trips per Person		% Change in Trips per Person
	Basic Weights	GPS Weights	
Work Trips	0.62	0.66	6%
College Trips	0.037	0.039	7%
School Trips	0.31	0.33	8%
Shopping Trips	0.31	0.36	17%
Other Trips	1.37	1.60	17%
Non-Home Work Trips	0.38	0.47	24%
Non-Home Other Trips	0.73	0.95	29%
All Purposes	3.76	4.41	17%

Overall, the total difference between the GPS weighted sample and the Basis Survey weights is 17% in the Puget Sound 4K Model trip rates, however the differences by trip purpose vary significantly. Without adjusting for underreporting of trips, the average trips per person in the 2006 Puget Sound Household Travel Survey was approximately 3.76 trips per person. With these set of adjustments, the 2010 total daily person trips in the Puget Sound 4K Model are approximately 15,484,000 total daily person trips and an average trip per person of 4.41.

The new trip rates result in approximately 8% more daily person trips than the Version 1.0bb model when the same land use inputs are run through the trip generation processes. This total difference in person trips is in line with the relative increase in trip making that occurred for the unadjusted trip rates between the 1999 and 2006 Household Travel Surveys.

Table 5. 1999 and 2006 Household Survey Trip per Person

Household Survey	Trips per Person	
	Basic Weights	Adjusted Weights
1999 Household Travel Survey	3.48	3.97
2006 Household Travel Survey	3.76	4.41
% Change 1999 to 2006 Surveys	8%	11%

1.5 TRIP PRODUCTION MODELS

As noted previously, the trip production models for home-based trips in the Puget Sound 4K Trip Generation Model were estimated using 2006 household travel survey data. The models were estimated for each trip purpose separately. Trip production rates are described separately for each trip purpose.

Home-Based Work Trips

The home-based work trip production rates are estimated for each category of households by household income, number of workers, and household size.

Table 7 presents the home-based work trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey.

Home-based-work trips are kept separate by income group throughout the modeling process, to facilitate evaluating the impacts of tolls and other pricing policies on commuters with different values of time. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories.

The home based work trip rates based on the 2006 Travel Survey are generally higher than those observed from the 1999 Survey. When the same TAZ input data is used in the two model platforms, there is an increase of approximately 168,000 home based work trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, an 8% increase. Table 6 compares the total Home Based Work trips between the V1.0bb and 4K models and the household survey.

Table 6. Comparison of 2010 Home-Based Work Trip Productions

HBW Classification	V1.0bb	4K	2006 HH Survey
Income 1	174,324	296,887	
Income 2	431,369	605,485	
Income 3	637,238	625,061	
Income 4	957,172	915,722	
Total HBW Trips	2,200,103	2,443,154	2,386,847

The total home based work productions from the Puget Sound 4K model are within 2.4% of the 2006 Household Survey targets. This compares with a -7.8% difference between the survey and the trip rates from the V1.0bb model.

Table 7. Home-Based Work Trip Production Rates per Household

Household Size	Number of Workers in Household	Household Income Level									
		Income Level 1*		Income Level 2*		Income Level 3*		Income Level 4*		Income Level 5*	
		V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
1 Person	0	0.02	n/a	0.01	0.07	0.07	0.05	0.26	0.03	0.19	0.10
	1	0.75	n/a	1.02	1.26	1.17	1.26	1.37	1.31	1.30	1.21
2 Persons	0	0.00	n/a	0.07	0.12	0.01	0.08	0.15	0.20	0.33	0.19
	1	0.08	n/a	0.41	1.20	0.62	1.35	1.06	1.47	1.24	1.43
	2	1.24	n/a	1.57	2.79	1.78	2.92	2.22	3.04	2.40	2.81
3 Persons	0	0.00	n/a	0.00	0.09	0.15	0.28	0.11	0.65	0.21	0.10
	1	0.20	n/a	0.40	1.26	0.77	1.46	0.99	1.28	1.09	1.20
	2	1.33	n/a	1.52	2.17	1.89	2.41	2.12	2.73	2.21	2.41
	3+	2.52	n/a	2.72	5.11	3.09	3.69	3.31	3.89	3.41	3.29
4+ persons	0	0.00	n/a	0.17	0.53	0.09	0.00	0.22	0.00	0.17	0.31
	1	0.47	n/a	1.10	1.44	1.02	1.26	1.15	1.60	1.10	1.44
	2	1.07	n/a	1.71	1.64	1.62	2.31	1.75	2.18	1.71	2.11
	3+	2.62	n/a	3.26	4.79	3.17	4.49	3.30	4.12	3.26	4.33

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

College Trips

College trips are made up of home-based college trips and student trips made from dormitories, represented by trips from group quarters. Since the college trip purpose is not exclusively comprised of home-based trips, we have identified this trip purpose as "college" instead of "home-based college." These two types of college trips are generated and distributed using separate model parameters to represent their unique travel characteristics, but they are combined in a single trip purpose, called college. The remaining discussion covers the home-based college portion of the trip purpose and the college dormitory trips are discussed in the section on group quarters.

Home-based college trips are estimated from the household survey data based on the number of persons aged 18 through 24 in the household. These are not adjusted in trip generation for proximity to a college or for areas of student housing, which might have an impact on home-based college trips, but these data were not available for analysis. The model does adjust the home-based college trips for proximity to a college during the trip distribution step.

Table 9 presents the home-based college trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories.

When the same TAZ input data is used in the two model platforms, there is a decrease of approximately 11,000 home based college trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 7% decrease. Table 8 compares the total Home Based College trips between the V1.0bb and 4K models and the household survey.

Table 8. Comparison of 2010 Home-Based College Trip Productions

Trip Purpose	V1.0bb	4K	2006 HH Survey
College Trips	167,892	157,627	140,677

The total home based college productions from the Puget Sound 4K model are approximately 12% higher than the 2006 Household Survey targets. This compares to an over-estimation of college trips from the V1.0bb model of approximately 19%.

Table 9. Home-Based College Trip Production Rates per Household

College Age People	Household Income Level									
	Income Level 1*		Income Level 2*		Income Level 3*		Income Level 4*		Income Level 5*	
	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
0 College Age	0.14	n/a	0.06	0.00	0.04	0.00	0.03	0.01	0.03	0.01
1 College Age	0.37	n/a	0.29	0.91	0.26	0.91	0.26	0.70	0.25	0.72
2+ College Age	0.62	n/a	0.54	3.22	0.52	3.12	0.51	1.52	0.51	0.97

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

Home Based School Trips

Home-based school trips are estimated from the household survey data based on the number of persons aged 5 through 17 in the household. As expected, home-based school trips increase with the number of person's aged 5 through 17 in the household. The survey trips for this trip purpose include some trips made by adults dropping off kids at school, and some adult education (not to colleges) trips made by adults, which explains trips per household made when there are no children in the household.

Table 11 presents the home-based school trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories.

There is a significant increase in the overall amount of school trips that were captured in the 2006 Puget Sound Household Travel Survey. Many of these trips are via school bus, walk and bike and do not involve vehicle travel. When the same TAZ input data is used in the two model platforms, there is an increase of over 324,000 home based school trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 41% increase. Table 10 compares the total Home Based College trips between the V1.0bb and 4K models and the household survey.

Table 10. Comparison of 2010 Home-Based School Trip Productions

Trip Purpose	V1.0bb	4K	2006 HH Survey
School Trips	791,094	1,115,010	1,201,653

The total home based school productions from the Puget Sound 4K model are approximately 7% lower than the 2006 Household Survey targets. This compares to an under-estimation of school trips from the V1.0bb trip rates of approximately -34%. Many of these additional trips are non-motorized and thus this large increase in school based trips has little influence on the overall vehicle miles traveled in the region.

Table 11. Home-Based School Trip Production Rates per Household

School Age People	Household Income Level									
	Income Level 1*		Income Level 2*		Income Level 3*		Income Level 4*		Income Level 5*	
	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
0 School Age	0.00	n/a	0.00	0.04	0.01	0.06	0.06	0.20	0.18	0.23
1 School Age	0.71	n/a	0.79	2.05	1.01	1.83	1.14	1.89	1.26	1.90
2 School Age	1.81	n/a	1.89	3.83	2.11	3.67	2.24	3.47	2.36	3.54
3+ School Age	3.20	n/a	3.28	5.92	3.50	6.17	3.62	6.58	3.75	5.38

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

Home-Based Shopping Trips

The home-based shopping trip production rates are estimated for each category of households by household income, number of workers, and household size.

Table 13 presents the home-based shopping trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories. For household sizes of one or two persons, home-based shopping trip rates decline as the number of workers increase. This could imply that, for smaller households, the presence of more workers indicates that more shopping is done as part of a work tour and, therefore, there are fewer home-based shopping trips made for these households. For household sizes of three or more persons, home-based shopping trips tend to increase with more workers. This is the opposite effect of the smaller households, where more workers indicate less time for shopping. In general, shopping trips increase as the number of persons and number of workers increase.

The home based shopping trip rates based on the 2006 Travel Survey are generally lower than those observed from the 1999 Survey. When the same TAZ input data is used in the two model platforms, there is a decrease of approximately -320,000 home based shopping trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 20% decrease. Many of the trips that were categorized as shopping trips in the 1999 HH Survey appear to be considered Home-Based Other trips in the 2006 Survey, a major reason for the differences in the total estimated number of trips by this purpose. Table 12 compares the total Home Based Shopping trips between the V1.0bb and 4K models and the household survey.

Table 12. Comparison of 2010 Home-Based Shopping Trip Productions

Trip Purpose	V1.0bb	4K	2006 HH Survey
Shopping Trips	1,638,350	1,313,730	1,288,978

The total home based shopping productions from the Puget Sound 4K model are within 2.0% of the 2006 Household Survey targets. This compares with a 27% difference between the survey and the trip rates from the V1.0bb model.

Table 13. Home-Based Shopping Trip Production Rates per Household

Household Size	Number of Workers in Household	Household Income Level									
		Income Level 1*		Income Level 2*		Income Level 3*		Income Level 4*		Income Level 5*	
		V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
1 Person	0	0.70	n/a	0.71	0.56	0.65	0.58	0.66	0.63	0.65	0.50
	1	0.49	n/a	0.50	0.35	0.44	0.34	0.45	0.33	0.44	0.33
2 Persons	0	1.08	n/a	1.28	1.25	1.38	1.28	1.25	1.24	1.22	1.35
	1	0.72	n/a	0.93	0.62	1.02	1.00	0.90	0.93	0.87	1.00
	2	0.60	n/a	0.80	1.68	0.90	0.55	0.77	0.67	0.74	0.73
3 Persons	0	1.58	n/a	1.54	0.47	1.78	0.58	1.79	2.76	1.78	2.02
	1	0.89	n/a	0.86	0.81	1.09	0.93	1.10	1.07	1.09	1.34
	2	0.73	n/a	0.69	0.58	0.93	0.70	0.94	1.08	0.93	0.81
	3+	0.84	n/a	0.81	1.97	1.05	1.01	1.06	1.04	1.04	1.27
4+ persons	0	0.33	n/a	1.18	0.75	1.28	0.79	1.19	0.43	1.29	1.47
	1	0.36	n/a	1.21	0.91	1.31	1.50	1.22	1.14	1.32	0.93
	2	0.42	n/a	1.27	1.63	1.36	1.56	1.27	1.00	1.37	1.06
	3+	0.61	n/a	1.46	0.82	1.55	2.30	1.46	1.66	1.56	1.45

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

Home-Based Other Trips

The home-based other trip production rates are estimated for each category of households by household income, number of workers, and household size.

Table 15 presents the home-based other trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories. This table demonstrates that home-based other trips tend to increase with household size and decrease with number of workers, except in the case of household sizes of four or more persons, where home-based other trips tend to increase with more workers. This is the opposite effect of the smaller households, where more workers indicate less time for other trips.

The home based other trip rates based on the 2006 Travel Survey are generally higher than those observed from the 1999 Survey. When the same TAZ input data is used in the two model platforms, there is an increase of approximately 674,000 home based other trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 13% increase. As noted in the section of shopping trips, many of the trips that were categorized as shopping trips in the 1999 HH Survey appear to be considered Home-Based Other trips in the 2006 Survey, a major reason for the differences in the total estimated number of trips by this purpose. The use of the GPS sub-sample also appears to account for some of the increase as it highlighted a 17% increase in HBO trip rates when the GPS data was used.

Table 14 compares the total Home Based Other trips between the V1.0bb and 4K models and the household survey.

Table 14. Comparison of 2010 Home-Based Other Trip Productions

Trip Purpose	V1.0bb	4K	2006 HH Survey
HBO Trips	5,045,379	5,719,422	5,709,688

The total home based other productions from the Puget Sound 4K model are within 0.2% of the 2006 Household Survey targets. This compares with a -12% difference between the survey and the trip rates from the V1.0bb model.

Table 15. Home-Based Other Trip Production Rates per Household

Household Size	Number of Workers in Household	Household Income Level									
		Income Level #1*		Income Level #2*		Income Level #3*		Income Level #4*		Income Level #5*	
		V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
1 Person	0	1.66	n/a	1.61	1.48	1.58	1.78	1.53	2.06	1.63	1.51
	1	1.11	n/a	1.06	0.98	1.03	0.95	0.97	0.97	1.07	0.89
2 Persons	0	3.31	n/a	3.09	3.65	3.54	3.65	3.20	4.27	3.19	4.35
	1	2.48	n/a	2.26	2.93	2.71	2.88	2.37	3.11	2.35	2.61
	2	1.99	n/a	1.78	3.46	2.22	2.09	1.89	2.21	1.87	2.23
3 Persons	0	2.88	n/a	2.39	2.79	3.34	8.98	3.16	3.50	3.41	6.57
	1	3.61	n/a	3.12	4.88	4.06	5.11	3.89	4.91	4.13	5.97
	2	2.88	n/a	2.40	3.81	3.34	4.42	3.17	5.19	3.41	4.83
	3+	2.40	n/a	1.91	1.38	2.86	3.61	2.68	3.48	2.93	3.26
4+ persons	0	2.69	n/a	3.90	8.52	4.13	6.63	4.39	9.95	4.53	13.26
	1	3.74	n/a	4.95	6.01	5.18	7.79	5.44	9.59	5.58	9.54
	2	3.67	n/a	4.88	9.52	5.11	8.47	5.37	7.35	5.51	7.69
	3+	3.66	n/a	4.87	2.60	5.10	8.94	5.36	9.21	5.50	6.52

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

Non-Home-Based Trips

Although the majority of non-home-based trips occur between employment centers in the region, trip ends are generated at the household level. Productions are not generated at household locations, but households control the number of trips that are generated and the attractions control the location. Non-home-based trips are divided into those with at least one trip end at a workplace and those with both trip ends at non-workplaces.

Table 17 and Table 18 present the non-home based trip production rates in the Puget Sound 4K Trip Generation model along with a comparison to the trip generation rates that were used in Version 1.0bb which were based on the 1999 Puget Sound Household Travel Survey. As noted previously, one key difference between the trip generation in Version 1.0bb and 4K is the use of four income categories in trip generation as well as revisions to the income levels for the 4 income categories.

The non-home based work to other trip rates based on the 2006 Travel Survey is generally higher than those observed from the 1999 Survey. When the same TAZ input data is used in the two model platforms, there is an increase of approximately 371,000 work to other trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 25% increase. The use of the GPS sub-sample appears to account for some of the increase as it highlighted a 25% increase in Work to Other trip rates when the GPS data was used.

The non-home based other to other trip rates based on the 2006 Travel Survey are generally similar to those observed from the 1999 Survey. When the same TAZ input data is used in the two model platforms, there is a slight decrease of approximately -14,000 other to other trips in 2010 using the 4K model with updated trip rates from the 2006 Survey, a 1% decrease.

Table 16 compares the total Non-Home Based trips between the V1.0bb and 4K models and the household survey.

Table 16. Comparison of 2010 Non-Home-Based Trip Productions

Trip Purpose	V1.0bb	4K	2006 HH Survey
Work to Other Trips	1,259,776	1,631,512	1,675,055
Other to Other Trips	3,165,852	3,151,618	3,416,897

The total non-home based productions from the Puget Sound 4K model are within -3% for Work to Other and -8% for Other to Other trips in the 2006 Household Survey targets. This compares to -25% and -7% differences between the survey and the trip rates from the V1.0bb model.

Table 17. Non-Home-Based Work to Other Trip Production Rates per Household

Household Size	Number of Workers in Household	Household Income Level									
		Income Level #1*		Income Level #2*		Income Level #3*		Income Level #4*		Income Level #5*	
		V1.00bb	4K	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K
1 Person	0	0.00	n/a	0.00	0.04	0.06	0.04	0.18	0.03	0.09	0.04
	1	0.48	n/a	0.55	0.66	0.73	0.80	0.86	0.74	0.76	0.99
2 Persons	0	0.11	n/a	0.01	0.01	0.00	0.04	0.00	0.13	0.41	0.23
	1	0.20	n/a	0.05	0.70	0.32	0.89	0.52	1.33	0.96	1.21
	2	0.85	n/a	0.70	0.88	0.98	1.30	1.17	1.76	1.62	1.91
3 Persons	0	0.00	n/a	0.00	0.00	0.00	0.21	0.00	0.25	0.20	0.11
	1	0.23	n/a	0.44	0.63	0.51	0.78	0.67	0.67	0.90	0.99
	2	0.67	n/a	0.89	1.28	0.95	1.92	1.11	2.60	1.34	2.06
	3+	1.00	n/a	1.22	0.55	1.29	2.81	1.44	3.21	1.68	2.46
4+ persons	0	0.00	n/a	0.00	0.52	0.00	0.00	0.00	0.00	0.28	0.37
	1	0.28	n/a	0.14	0.36	0.15	0.56	0.40	0.83	0.75	0.98
	2	0.38	n/a	0.38	2.28	0.75	1.55	1.00	2.09	1.35	2.12
	3+	0.61	n/a	0.61	0.89	0.98	3.38	1.23	2.17	1.57	2.25

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

Table 18. Non-Home-Based Other to Other Trip Production Rates per Household

Household Size	Number of Workers in Household	Household Income Level									
		Income Level #1*		Income Level #2*		Income Level #3*		Income Level #4*		Income Level #5*	
		V1.00bb	4K	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K
1 Person	0	1.22	n/a	1.20	0.79	1.10	1.39	0.98	1.37	1.11	1.24
	1	0.92	n/a	0.90	0.80	0.80	0.64	0.68	0.54	0.81	0.51
2 Persons	0	2.07	n/a	1.91	2.68	2.23	2.82	2.17	2.92	2.29	3.04
	1	1.53	n/a	1.37	1.66	1.69	1.97	1.63	2.07	1.75	2.12
	2	1.32	n/a	1.16	2.20	1.48	1.25	1.42	0.88	1.54	1.13
3 Persons	0	2.12	n/a	1.67	2.03	2.30	5.14	2.30	3.27	2.35	7.07
	1	2.37	n/a	1.92	2.35	2.55	3.50	2.56	2.80	2.60	3.23
	2	1.73	n/a	1.28	1.81	1.90	2.14	1.91	2.50	1.95	2.46
	3+	1.98	n/a	1.53	0.86	2.16	2.35	2.16	1.26	2.21	1.72
4+ persons	0	2.48	n/a	2.78	4.40	3.82	1.36	3.49	2.88	4.00	8.68
	1	1.55	n/a	1.85	3.94	2.89	3.83	2.56	5.12	3.07	4.10
	2	1.74	n/a	2.04	5.16	3.08	4.42	2.75	3.88	3.26	4.36
	3+	2.09	n/a	2.39	1.39	3.44	5.13	3.11	4.67	3.62	2.61

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

1.6 TRIP ATTRACTION MODELS

Trip attraction models in the Puget Sound region were originally developed from a 1971 household travel survey. These rates were subsequently modified in the mid 1990's and then were updated in Version 1.0bb based on analysis of the 1999 Puget Sound Household Travel Survey.

Trip attraction models in the Puget Sound 4K Trip Generation Model were analyzed and some re-estimated using 2006 Puget Sound Household Travel Survey data. The models were estimated for each trip purpose separately and rates were derived for each cross-classification. The process of trip rate estimation was consistent between the 1999 and 2006 Household Travel Surveys.

Home-Based Work

Home-based work trip rates are presented in Table 19 for employment and household classifications. For the home-based work trip purpose, the overall rates are generally unchanged from the V1.0bb update. The biggest difference is in the Manufacturing and WTCU categories which changed based on the NAICS employment classification changes. As shown, the attraction rates are divided into four income ranges based on analysis of census data for worker income by employment type.

Table 19. Home-Based Work Trip Attraction Rates per Employee

	Household Income Level							
	Income Level #1*		Income Level #2*		Income Level #3*		Income Level #4*	
Employment Type	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K	V1.00bb	4K
Retail Employment	0.23	0.21	0.32	0.30	0.48	0.45	0.54	0.50
FIRES Employment	0.20	0.19	0.26	0.24	0.37	0.35	0.52	0.49
Government Employment	0.28	0.19	0.26	0.18	0.36	0.25	0.45	0.31
Education	0.19	0.19	0.26	0.27	0.44	0.45	0.59	0.60
WTCU	0.18	0.00	0.28	0.00	0.46	0.00	0.54	0.00
Manufacturing	0.12	0.00	0.24	0.06	0.47	0.12	0.63	0.23
Households	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04

*Income Categories were changed between the Version 1.0bb and the Puget Sound 4K Trip Generation model implementation. The classifications are:

Classification	V1.0bb	4K
Income Level #1	< $15k	n/a
Income Level #2	$15k to $25k	< $30k
Income Level #3	$25k to $45k	$30k to $60k
Income Level #4	$45k to $75k	$60k to $90k
Income Level #5	> $75k	> $90k

College

College trip rates are presented in Table 20 for full-time college enrollment. These include both home-based and college dormitory trips. College attraction rates were slightly higher from observations on the 2006 Household Travel Survey.

Table 20. Home-Based College Trip Attraction Rates

Classification	V1.00bb	4K
Full Time College Enrollment	0.61	0.88

Home-Based Shopping

Prior to Version 1.0bb, home-based shopping trip attractions were derived as a subset of the home-based other trip attractions and adjusted for low-density retail employment classifications. For both V1.0bb and 4K, the density classification scheme is no longer used and home-based shopping trip attractions are based only on retail employment. Home Based Shopping rates are shown in Table 21. Shopping attraction rates are noticeably higher in the 2006 Household Survey. Although this increases the overall attractions in the model, shopping trip ends are balanced to productions so the overall increases have less impact on the overall generation of trips than the changes in production rates.

Table 21. Home-Based Shopping Trip Attraction Rates

Classification	V1.00bb	4K
Retail Employment	2.70	3.64

Home-Based Other

Home-based other trip attractions are derived from retail, FIRES, and government employment, as well as households. Similar to the home-based shopping trip purpose, the trip rates are no longer stratified by the employment density classifications. The home-based other trip attraction rates are presented in Table 22. HBO attraction rates are noticeably different in the 2006 Household Survey and the attraction rates have removed the sue of government employment. Although these changes influence the overall attractions in the model, home based other trip ends are balanced to productions so the overall changes have less impact on the overall generation of trips than the changes in production rates.

Table 22. Home-Based Other Trip Attraction Rates

Classification	V1.00bb	4K
Retail	2.41	3.76
FIRES	0.35	0.03
Government	0.35	0.00
Households	1.82	1.82

Home-Based School

Home-based school trip attractions were increased fairly significantly from the V1.0bb model. These rates are presented in Table 23 for educational employment, which is the only variable used in this model. The large increase in the number of attractions is due to the increased amount of trip activity that was observed in the 2006 Household Survey. As noted on with the trip productions, many of these trips are non-motorized in nature and have minimal impacts on overall vehicle trip making in the overall trip based model.

Table 23. Home-Based School Trip Attraction Rates

Classification	V1.00bb	4K
Educational	7.90	12.81

Non-Home-Based Trips

Non-home-based work-other trip attractions are derived from retail, FIRES, and government employment, while non-home-based other-other attractions are derived from retail and government employment. Table 24 presents the non-home-based work-other trip attraction rates, while Table 25 presents the other-other attraction rates.

While other correlations of employment may have contributed to trip attraction rates, if the employment category was not significant, it was not used in the attraction model. For example, non-home-based other trip attractions do not include FIRES employment because it was not significant in the regression model estimation. Retail and government employment have the strongest correlations for this purpose.

Trip attraction rates between the two model systems are fairly consistent. The largest change was the removal of any tractions based on government employment for the other to other employment which from the 2006 survey was strongest correlated to Retail employment.

Table 24. Non-Home Based Work Trip Attractions

Classification	V1.00bb	4K
Retail	1.02	1.65
FIRES	0.44	0.79
Government	0.28	0.28

Table 25. Non-Home Based Other Trip Attractions

Classification	V1.00bb	4K
Retail	3.42	3.55
Government	0.19	0.00

1.7 GROUP QUARTERS

Trip generation based on group quarters populations did not change between the V1.0bb and 4K models. Data on trip generation rates for each non-institutional group quarter's population was derived from a variety of sources, such as the following:

- Proposed trip rates per student in college housing are derived from a university trip model developed for the University of Michigan. This is one of the few university trip models that are developed from household survey data, including students. The results of this model indicate that there are 1.18 university trips per student on a daily basis. It is assumed that there is no work or school trips made by university trip students. Other trip purposes are assumed to be proportional to the regional average, but adjusted so that the total of non-university trip purposes matches the ITE trip generation rate for University Housing (ITE Code 550). The ITE total vehicle trip rate is 2.38 trips per student per day, converted to 3.14 person trips per student per day, using average regional auto occupancy of 1.32 persons per vehicle. The home-based college trips are held constant at 1.18 trips per student, so the total trip rate per person in college housing is 3.82 trips per person, compared to the regional average of 3.48 trips per person.
- Proposed trip rates per person in military housing are derived from a special generator model developed for the MacDill Air Force Base in Tampa Bay (Florida), and controlled to Institute of Transportation Engineers (ITE) trip generation rates for military housing (ITE Code 501). Tampa Bay is one of the few military trip models that are developed by trip purpose. The ITE total vehicle trip rate is 1.78 trips per employee per day, converted to 2.35 person trips per employee per day, using average regional auto occupancy of 1.32 persons per vehicle. This is further converted to 2.97 person trips per unit per day, using a conversion factor of 1.27 employees to population rate in Fort Lewis. The results of this model indicate that there are 2.97 trips per person from military housing on a daily basis, compared to the regional average of 3.48 trips per person.
- Proposed trip rates per person in retirement homes are derived from a retired person's model developed in Tucson (Arizona) and controlled to ITE trip generation rates for retirement homes (averaging ITE codes 250 through 253). Tucson is one of the few models that have retired person's trip rates developed by trip purpose from household survey data. The ITE average vehicle trip rate is 2.55 trips per unit per day, converted to 3.37 person trips per unit per day, using average regional auto occupancy of 1.32 persons per vehicle. This is further converted to 3.37 person trips per person per day, using a conversion factor of 1.0 person to unit rate. The results of this model indicate that there are 3.37 trips per person from retirement housing on a daily basis, compared to the regional average of 3.48 trips per person.

Table 26 summarizes the results of the trip generation rates per person by type and trip purpose.

Table 26. Non-Institutional Group Quarters Trip Rates (Per Person)

Trip Purpose	College Dormitories	Military Quarters	Retirement Homes
Home-Based Work	-	0.37	0.10
Home-Based College	1.18	-	-
Home-Based School	-	-	0.03
Home-Based Shop	0.40	0.74	0.70
Home-Based Other	1.24	1.09	1.49
Non-Home-Based	1.00	0.76	1.04
Total	3.82	2.97	3.37

1.8 SPECIAL GENERATORS

Special Generators are used in the model to account for locations that are not captured by standard trip generation inputs and rates. There are currently four (4) special generators in the travel model and include:

- SeaTac Airport (TAZ 983)
- Tacoma Dome (TAZ 3110)
- Seattle Center (TAZ 438)
- Exhibition Center (TAZ 631)

SeaTac Airport special generator trips are split as 75% home-based other and 25% non-home based work to other trips. The other three special generators are all added to the home-based other trip purpose. These special generators are all added to the overall attractions for the respective trip purpose and are included before trip balancing occurs. Since non-home based and home based other trips are balanced to productions, the impact of the special generators is not an increase in overall trips but instead a redistribution in the number of attractions to these four zones.

Changes made with Puget Sound 4K Model

In Version 1.0bb, there were several special generators added to capture hotel trips in Downtown Seattle. With revisions made to the trip production and attraction rates based on the 2006 Household Travel Survey, there was no longer a need to treat these as special generator trips and hence they have been removed from the 4K model.

1.9 EXTERNAL TRIPS

External trips can be defined as three types of trips: 1) internal-external; 2) external-internal; and 3) external-external. Of these three types, the trip generation model estimates only the internal-external and external-internal trips. The external-external trip table is estimated from a separate source and added to the trip tables prior to trip assignment.

External trips were originally derived from an external survey conducted in 1970 that covered King, Pierce, and Snohomish county borders. These external trip tables have been updated over time, based on current traffic counts and cross-sound data. There are 18 external stations around the four-county region coded as TAZs 3733 to 3750. Table 27 contains the 2010 trips by trip purpose for these internal-external and external-internal trips. External trips were updated based on the latest set of 2010 average weekday traffic counts from the Washington State Department of Transportation.

Table 27. Internal-External and External-Internal Trips by Purpose

Trip Purpose	Trips
Home-Based Work	81,849
Home-Based College	3,641
Home-Based School	4,442
Home-Based Shop	36,080
Home-Based Other	99,055
Non-Home-Based (Total)	18,623
Total	243,690

1.10 TRIP BALANCING

Trip balancing is completed prior to distribution to ensure that the same number of trip productions and attractions is created for each trip purpose. Trip balancing is determined based on the confidence one places in the derivation of the productions and attractions for each trip purpose. For instance, it is common to balance attractions to productions for home-based trip purposes, because these are typically estimated from household survey data (an observed source), when the attractions are often estimated by borrowing coefficients (an estimated source).

In this trip generation model home-based work, home-based shop, home-based other, and non-home-based trip purposes are balanced so that total attractions are adjusted to match total productions. Home-based college and home-based school trips are balanced so that total productions are adjusted to match total attractions. In the case of educational trips, it is expected that the trip rates on college enrollment and educational employment for home-based college and home-based school, respectively, are more accurate than the trip rates on persons by age group.

After balancing, non-home-based attractions are copied into the productions, so that the productions equal the attractions in every TAZ. The home-based-work productions and attractions for the four income groups are summed for ease of access, but they are kept separated through all steps of the modeling process.

Table 28. Trip Balancing by Purpose

Trip Purpose	Control for Balancing	Comments
Home-Based Work (by income group)	Productions	Lowest two groups summed after balancing
Home-Based College	Attractions	
Home-Based School	Attractions	Balance by subarea
Home-Based Shopping	Productions	
Home-Based Other	Productions	
Non-Home-Based Work	Productions	Attractions replace productions
Non-Home-Based Other	Productions	Attractions replace productions

The home-based school trips are balanced according to a series of subareas, rather than region wide, to represent school districts. These subareas are defined by TAZ.

Changes made with Puget Sound 4K Model

In Version 1.0bb, prior to trip balancing the raw productions and attractions were adjusted in two ways. The first adjustment was intended to correct for an underreporting of trips by surveyed households. In this adjustment, HB Work, Shopping, Other, NHB Work-Other, and NHB Other to Other productions were increased by 15%, while college and HB School attractions are increased by 15%. The second adjustment redistributed some of the regional trips to the Kitsap Peninsula to improve agreement with observed travel patterns across the Puget Sound. In this adjustment, HB Work, Shopping and Other attractions are increased by 15% for Kitsap County.

In Puget Sound 4K, the trip rates estimated from the 2006 Household Travel Survey already account for the under-reporting of trips using the GPS subsample so no further adjustment is made before trip balancing.

1.11 TRUCK TRIP GENERATION

The truck model in 4K is largely unchanged from the Version 1.0bb model that was originally created in the early 2000's. The truck model defines a truck based on relative weight classes and separates light, medium, and heavy trucks for analysis purposes. Medium and heavy trucks are defined to match the definitions used for collecting truck counts by the WSDOT. While these definitions rely primarily on weight, these categories also are loosely correlated to other defining characteristics of trucks for other purposes. The following general categories of trucks are used:

- Light trucks are defined as four or more tires, two axles, and less than 16,000 lbs. gross vehicle weight (this also includes non-personal use of cars and vans);
- Medium trucks are defined as single unit, six or more tires, two to four axles and 16,000 to 52,000 lbs. gross vehicle weight; and
- Heavy trucks are defined as double or triple unit, combinations, five or more axles, and greater than 52,000 lbs. gross vehicle weight.

In these definitions, the medium trucks are directly correlated to single-unit trucks collected in the WSDOT truck counts, and heavy trucks are directly correlated to double- and triple-unit trucks in the counts. The truck counts do not separate light trucks from passenger cars, so there is no truck count data available for validating the light trucks in this model. Light trucks have been included in this analysis primarily, so that all vehicles are represented in the traffic assignments. Light trucks are intended to include all commercial vehicles that are not included in the medium- and heavy-truck categories. Commercial vehicles are not included in the non-home-based trip purpose model as these represent only noncommercial vehicles.

Employment Data used for Truck Generation

The socioeconomic data used in the truck model are consistent with those data used in the passenger model, except that the employment data are stratified into more employment categories. This process provides more accuracy for truck travel and allows for a direct relationship between the commodities being estimated in the external trip model and the allocation of these commodities to TAZs within the region. The employment categories used in the truck model are:

- Agriculture/Forestry/Fishing
- Mining
- Construction
- Manufacturing (Products and Equipment)
- Transportation/Communication/Utilities
- Wholesale
- Retail
- FIRES
- Education and Government

Truck Trip Rates

Truck trip production rates for internal truck travel were developed separately for the three different truck types: light, medium, and heavy. These are presented in Table 29. Truck trip consumption rates are the equivalent of truck trip attraction rates, and are provided in Table 30 by truck type and industry.

Table 29. Truck Trip Production Rates

	Truck Type		
Employment Category	**Heavy**	**Medium**	**Light**
Agriculture/Forestry/Fishing	0.2366	0.0889	0.4102
Mining	0.3405	0.0889	0.4102
Construction	0.0856	0.0998	0.4102
Manufacturing – Products	0.2661	0.0858	0.3466
Manufacturing – Equipment	0.0953	0.0858	0.3466
TCU	0.1075	0.2079	0.3466
Wholesale	0.1337	0.2552	0.3466
Retail Trade	0.0463	0.1637	0.3281
FIRES	0.0044	0.0434	0.1615
Education and Government	0.0068	0.0297	0. 1615
Households	0.0031	0.0358	0.0928

Table 30. Truck Trip Attraction Rates

	Truck Type		
Employment Category	**Heavy**	**Medium**	**Light**
Agriculture/Forestry/Fishing	0.0988	0.2831	1.3161
Mining	5.0897	14.8073	47.9052
Construction	0.0290	0.0876	0.2585
Manufacturing – Products and Equipment	0.0208	0.0538	0.2581
TCU	0.0378	0.0998	0.5082
Wholesale	0.0087	0.0352	0.1464
Retail Trade	0.0032	0.0123	0.0501
FIRES	0.0088	0.0375	0.1591
Education and Government	0.0073	0.0160	0.0966
Households	0.0071	0.0385	0.1732

Truck Special Generators

Special generator trips were developed for the following five generators:

- SeaTac Airport;
- Port of Seattle;
- Port of Everett;
- Port of Tacoma; and
- Warehouses and distribution centers in the SR 167 corridor.

In the case of the three ports, the port activities are included in several TAZs. All special generator truck trips from the ports are heavy trucks. Port truck trips were estimated by subtracting the truck traffic generated by existing employment in the zone from the total truck traffic expected in each TAZ. Warehouse and distribution centers in the SR 167 corridor were estimated from a truck survey conducted in February 2006. Truck trips coded as special generators are presented in Table 31.

Table 31. Truck Special Generators

	Daily Truck Trips		
Area	**Light Trucks**	**Medium Trucks**	**Heavy Trucks**
SR 167 Warehouses	320	460	990
Port of Seattle	-	-	5,890
Port of Tacoma	-	-	1,960

Truck Refactoring

The trip rates for trucks are based on a variety of data sources including both local and national data. Due to the variability of data availability locally and the strong differences between truck travel by region, a set of regional adjustment factors were calculated for truck production and attraction rates. These adjustments were developed iteratively and are based on observed truck counts across the region. These factors remain unchanged in 4k and are include in Table 32

Table 32. Truck Trip Adjustment Factors

	Daily Truck Trips Adjustments		
Area	**Light Trucks**	**Medium Trucks**	**Heavy Trucks**
Productions	0.554	0.309	0.413
Attractions	0.749	0.500	1.375

1.12 SUMMARY OF TRIP ENDS WITH 4K MODEL

The results of the trip generation model are trip ends by purpose and TAZ. These are referred to as trip ends, because the trip productions represent the end of the trip where it is generated, and the trip attractions represent the end of the trip where it is attracted. During trip distribution, these trip ends are connected to produce trips between the production zones and the attraction zones. Table 33 presents the trip ends by trip purpose before and after trip balancing. These trip ends include internal trips, special generators and external trips.

Table 34 presents the implied average trip rates per household, person, and employee for all trip purposes for V1.0bb and the 4K model. These trip rates are based on the following demographic data for 2010:

- Total persons are 3,690,948;
- Total households are 1,454,695
- Total employment is 1,865,414.

Table 33. 2010 Daily Regional Productions and Attractions

Trip Purpose	Before Trip Balancing		After Trip Balancing	
	Productions	Attractions	Productions	Attractions
Home-Based Work	*2,443,154*	*2,115,098*	*2,443,154*	*2,443,153*
Income less than $30,000	296,887	306,500	296,887	296,887
Income $30,000-$60,000	605,485	404,834	605,485	605,484
Income $60,000-$90,000	625,061	605,589	625,061	625,060
Income more than $90,000	915,722	798,174	915,722	915,722
Home-Based College	227,227	157,627	157,627	157,627
Home-Based School	1,241,422	1,115,011	1,115,011	1,115,011
Home-Based Shop	1,313,730	1,138,597	1,313,730	1,313,737
Home-Based Other	5,719,422	5,486,879	5,719,422	5,719,421
Non-Home-Based Work	1,631,509	1,472,218	1,631,509	1,631,509
Non-Home-Based Other	3,151,616	3,052,161	3,151,616	3,151,616
Light Trucks			317,167	317,166
Medium Trucks			56,956	56,956
Heavy Trucks			34,016	34,016
Total Trips	15,728,079	14,537,590	15,940,212	15,940,214

Table 34. Total Average Person Trips Rates

Trip Purpose	Trips per Household		Trips per Person		Trips per Employee	
	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
Home-Based Work	1.55	1.67	0.61	0.66	1.13	1.31
Home-Based College	0.08	0.11	0.03	0.04	0.06	0.08
Home-Based School	0.69	0.85	0.27	0.34	0.51	0.67
Home-Based Shopping	1.11	0.90	0.44	0.35	0.82	0.70
Home-Based Other	3.44	3.93	1.35	1.55	2.53	3.06
Non-Home-Based Work	0.88	1.12	0.34	0.44	0.65	0.87
Non-Home-Based Other	2.16	2.17	0.85	0.85	1.59	1.69
Total Person Trips	9.91	10.75	3.89	4.24	7.29	8.38

Trip Distribution

2.0 INTRODUCTION

The trip distribution model is the second of the four primary model components identified as part of the four-step modeling process. The trip distribution models estimate the number of trips from each TAZ to each other TAZ. The trips are estimated as a function of the travel impedance from one zone to another. For all purposes, traditional doubly constrained gravity models are used. This means that the model iterates until the trips produced from and attracted to each zone are consistent with the input assumptions on trips as a result of trip generation.

For home-based work trips, individual gravity models were developed for each of the income quartiles. These models were developed using the 2006 Household Travel Survey, weighted using appropriate data from the year 2010 Census, and applied using year 2010 network and trip generation data developed by PSRC. Traditional area-specific adjustment factors in the gravity model, commonly known as K-factors, are not used in this model.

Changes made with Puget Sound 4K Model

Although the overall approach to trip distribution in PSRC Model Version 1.0bb was not changed for the Puget Sound 4K Model implementation, several changes were made and include:

- Updated friction factors using the 2006 Puget Sound Household Travel Survey (Model Version 1.0bb was based on the 1999 Puget Sound Household Travel Survey).
- The full Generalized Cost and distance skims are used for trip distribution. In Model Version 1.0bb, a percentage of the cost was applied in trip distribution.
- Truck Trip Distribution uses bi-directional cost and distance skims. In Model Version 1.0bb, the AM skims were used.
- Friction factors for all trip purposes are based on a gamma function. In Model Version 1.0bb, Work Tips used logsums from mode choice.

2.1 TRIP PURPOSES

The trip distribution models are applied for seven trip purposes:

- Home-based work;
- Home-based college;
- Home-based school;
- Home-based shop;
- Home-based other;

- Non-home-based work
- Non-home-based other.

For home-based work trips, unique distribution models are used for each of the four income groups. The following section provides an overview on the general form applied for trip distribution.

2.2 GRAVITY MODELS

The gravity model is used to distribute trips from each origin zone to each destination zone in the region. It is based on Newton's law of gravity, which describes the gravitational force between two bodies. The gravitational force in transportation models is a function of the attractiveness of a zone and the impedance:

$$T_{ij} = \frac{P_i * (A_j * F_{ij} * K_{ij})}{SUM\ (A_j * F_{ij} * K_{ij})}$$

Where:

T_{ij} = The number of trips produced in Zone i and attracted to Zone j;

P_i = The number of trips produced in Zone i;

A_j = The number of trips attracted to Zone j;

F_{ij} = A friction factor, which is a function of the impedance of travel from i to j that represents the disutility of travel between i and j; and

K_{ij} = The zone-to-zone adjustment factor, which takes into account the effect of undefined socioeconomic linkages not otherwise incorporated in the gravity model.

The gravity model in this application will apportion the trips produced at each origin among destinations, according to the attractiveness of each destination and the disutility of travel for each trip interchange. This application is doubly constrained, which means that the program will iterate until the trips produced from and attracted to each zone are consistent with the input assumptions on trips.

Friction Factors

The basic functional formula for the friction factors for both work and non-work trips is given by the gamma function as follows:

$$f(t) = \exp(\beta t)t^{\gamma} = \exp(\beta t + \gamma \ln t)$$

Where:

Beta and gamma = Parameters to be calibrated; and

t = the impedance.

As noted previously, the previous version of the model used logsums from mode choice for work based trips. In the Puget Sound 4K Model, all friction factors are based on gamma functions and their parameters were estimated using the 2006 Puget Sound Household Travel Survey. The coefficients in the friction factor functions are provided in Table 35 by trip purpose.

Table 35. Trip Distribution Coefficients

Trip Purpose	Beta		Gamma		Impedance	
	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
Home Based Work Income #1	1.696	-0.0858	n/a	0	Log Sum	AM Cost/Dist
Home Based Work Income #2	1.337	-0.0775	n/a	0	Log Sum	AM Cost/Dist
Home Based Work Income #3	1.298	-0.0740	n/a	0	Log Sum	AM Cost/Dist
Home Based Work Income #4	1.173	-0.0629	n/a	0	Log Sum	AM Cost/Dist
Home-Based College	-0.12	-0.1382	0	0	AM Cost	AM Cost/Dist
Home-Based School	-0.25	-0.2290	1	0	MD Cost	MD Cost/Dist
Home-Based Shopping	-0.5	-0.2223	-4	0	MD Cost	MD Cost/Dist
Home-Based Other	-0.19	-0.1423	-1	0	MD Cost	MD Cost/Dist
Non-Home-Based Work	-0.023	-0.0910	-2.6	0	MD Cost	MD Cost/Dist
Non-Home-Based Other	0.11	-0.1493	1.6	0	MD Cost	MD Cost/Dist

The impedance used in the friction factors is based on the combination of the generalized cost and distance. The distance matrices are used to estimate the cost of vehicle operation using a combination of the auto operating cost and the value of time.

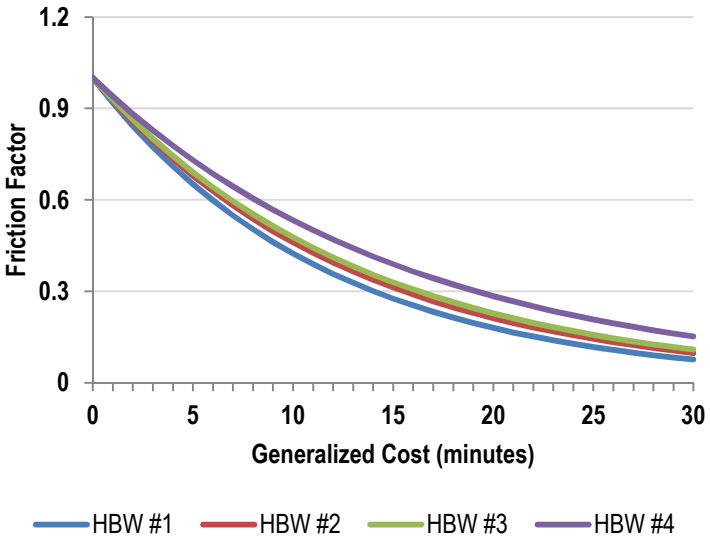

Figure 3. Home Based Work Friction Factors

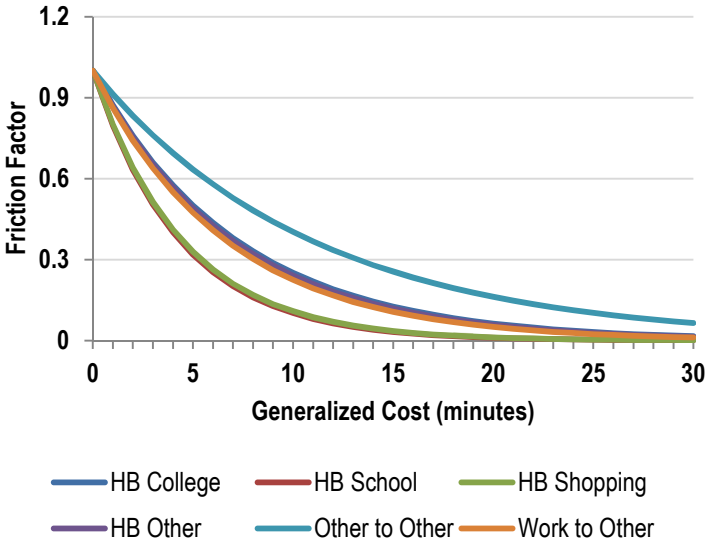

Figure 4. Non-Work Friction Factors

2.3 COLLEGE TRIPS

The distribution of college trips differs from the other trip purposes in that it treats the distribution of college trips for students that do not live in group quarters differently than those students who do. The distribution of college trips is a two-step process as follows:

- Identify the number of students living in group quarters that are within walking distance of a college. These trips are then linked directly to the college attractions without a gravity model.
- Distribute the remaining home-based college using a traditional gravity model formulation.

The total number of dormitory college trips (represented by the group quarters) is removed from the total college trips produced in trip generation before these home-based college trips are distributed to avoid double-counting.

2.4 TRUCK TRIP DISTRIBUTION

The distribution of truck trips relies upon an exponential friction factor for trip distribution. The skims utilized in truck trip distribution are the bi-directional generalized cost and distance skims for trucks. The bidirectional skims are calculated using the AM and transposed PM peak period skims from the assignment and skimming process. Table 36 shows the parameters used in truck trip distribution.

Table 36. Truck Trip Distribution Coefficients

Trip Purpose	Alpha		Beta		Impedance	
	V1.0bb	4K	V1.0bb	4K	V1.0bb	4K
Light Commercial	3.75	0	-0.08	-0.04585	AM Cost	AM/PM Cost/Dist
Medium Trucks	2.1	0	-0.005	-0.0053	AM Cost	AM/PM Cost/Dist
Heavy Trucks	4.0	0	-0.05	-0.00001	AM Cost	AM/PM Cost/Dist

The friction factors for trucks shown in Figure 5.

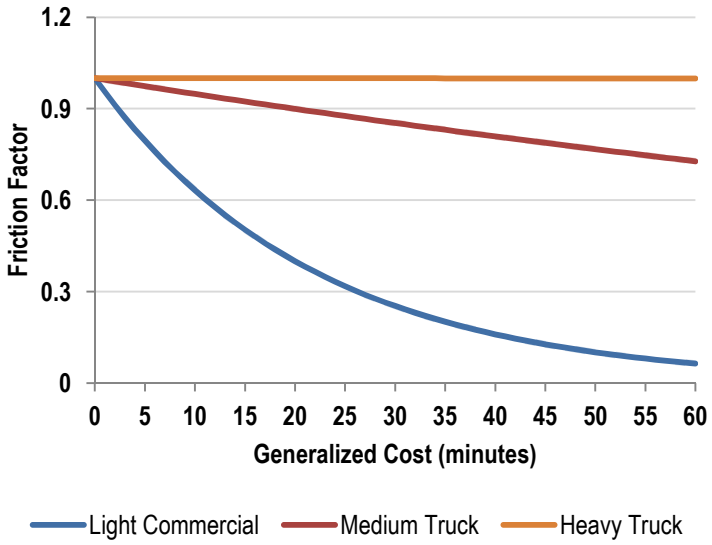

Figure 5. Truck Friction Factors

2.5 EXTERNAL TRIPS

External trips involve classifying external trips into three types of trips and two vehicle types, as follows:

- Internal-external trips by auto (I-E auto);
- External-internal trips by auto (E-I auto);
- External-external trips by auto (E-E auto);
- Internal-external trips by truck (I-E truck);
- External-internal trips by truck (E-I truck); and
- External-external trips by truck (E-E truck).

These classifications are made based on the origin and destination of trips traveling through external stations around the four-county region. Origins and destinations are defined based on whether they are inside or outside the region. There are 18 external stations in the Puget Sound region.

Total trips are based on traffic counts at the external stations and are scaled by trip purposes based on observed data for internal trips and census data. Traffic counts were obtained for a majority of the external stations from the Washington State Department of Transportation for the latest set of base year data available.

The primary source of data for external truck trips is the TRANSEARCH commodity flow data for the year 1997, which is converted to truck trips. The TRANSEARCH data were converted from annual truck trips to daily truck trips by dividing by 264 days of operation per year. Since the TRANSEARCH data did not include all of the data needed to develop comprehensive truck trip tables, some adjustments were made to these sources to fill in the gaps in the data source. The external truck trips converted to the year 2000 and updated using the SFTA data and have not been updated for the 2010 base year.

Through trips (classified as E-E trips) are those trips that begin and end outside the region, but travel through the region at some point. These trips were originally created from an origin-destination survey conducted in 1961, and then updated in 1971 during a model update process. Since that time, the external trips have remained reasonably constant, while the overall traffic at external stations has grown to match external station counts. A through trip table is used to represent external-to-external trip interchanges.

Table 37 shows the initial daily auto inputs for the external stations prior to the trip balancing that occurs in the model stream and Table 38 shows the total heavy truck trips. The resulting external trip volumes compared to external station counts are included in Table 39.

Table 37. External auto trip inputs prior to balancing

TAZ	External Location	Internal to External	External to Internal	External to External	Total Auto External Trips
3733	I-5 to Olympia	59,083	80,560	1,261	140,904
3734	SR 507 to Yelm	5,097	21,923	51	27,071
3735	SR 7 to Morton	1,378	1,931	27	3,336
3736	SR 706 to Longmire	268	2,409	27	2,704
3737	SR 123 S. of Cayuse Pass	0	0	53	53
3738	SR 410 E. of Cayuse Pass	148	532	109	789
3739	I-90 @ Snoqualmie Pass	17,992	19,543	853	38,388
3740	SR 2 to Stevens Pass	982	1,629	409	3,020
3741	SR 92 to Monte Carlo	0	0	0	0
3742	SR 530 N. of Darrington	687	1,359	191	2,237
3743	SR 9 N. of Arlington	554	1,980	215	2,749
3744	I-5 to Mount Vernon	27,500	35,917	1,614	65,031
3745	SR 530 N. of Stanwood	5,699	7,442	26	13,167
3746	SR 532 to Camano Island	9,100	22,391	26	31,517
3747	Ferry to Whidbey Island	2,606	4,986	65	7,657
3748	Hood Canal Bridge	4,645	16,978	952	22,575
3749	SR 3 to Belfair	10,245	16,386	45	26,676
3750	SR 302 to Shelton	1,314	5,158	57	6,529
Total		147,298	241,124	5,981	394,403

Table 38. Daily external heavy truck trips prior to balancing

TAZ	External Location	Internal to External	External to Internal	External to External	Total Truck External Trips
3733	I-5 to Olympia	5,600	5,100	800	11,500
3734	SR 507 to Yelm	0	0	0	0
3735	SR 7 to Morton	0	0	0	0
3736	SR 706 to Longmire	0	0	0	0
3737	SR 123 S. of Cayuse Pass	0	0	0	0
3738	SR 410 E. of Cayuse Pass	0	0	0	0
3739	I-90 @ Snoqualmie Pass	2,200	3,100	400	5,700
3740	SR 2 to Stevens Pass	100	200	100	400
3741	SR 92 to Monte Carlo	0	0	0	0
3742	SR 530 N. of Darrington	0	0	0	0
3743	SR 9 N. of Arlington	0	0	0	0
3744	I-5 to Mount Vernon	2,200	2,700	900	5,800
3745	SR 530 N. of Stanwood	0	0	0	0
3746	SR 532 to Camano Island	0	0	0	0
3747	Ferry to Whidbey Island	0	0	0	0
3748	Hood Canal Bridge	0	0	0	0
3749	SR 3 to Belfair	0	0	0	0
3750	SR 302 to Shelton	100	0	0	100
Total		10,200	11,100	2,200	23,500

Table 39. External daily volumes compared to counts after trip balancing

TAZ	External Location	Observed	4K	% Difference	Delta
3733	I-5 to Olympia	114,600	114,400	0%	-200
3734	SR 507 to Yelm	21,400	21,400	0%	0
3735	SR 7 to Morton	2,500	2,400	-4%	-100
3736	SR 706 to Longmire	2,100	2,200	5%	100
3737	SR 123 S. of Cayuse Pass	600	150	-75%	-450
3738	SR 410 E. of Cayuse Pass	700	700	0%	0
3739	I-90 @ Snoqualmie Pass	35,000	34,700	-1%	-300
3740	SR 2 to Stevens Pass	3,300	3,250	-2%	-50
3741	SR 92 to Monte Carlo	90	200	122%	110
3742	SR 530 N. of Darrington	1,700	1,700	0%	0
3743	SR 9 N. of Arlington	2,100	2,000	-5%	-100
3744	I-5 to Mount Vernon	52,300	52,400	0%	100
3745	SR 530 N. of Stanwood	9,100	9,100	0%	0
3746	SR 532 to Camano Island	22,500	22,500	0%	0
3747	Ferry to Whidbey Island	5,800	5,900	2%	100
3748	Hood Canal Bridge	15,300	15,500	1%	200
3749	SR 3 to Belfair	17,900	17,900	0%	0
3750	SR 302 to Shelton	4,500	4,500	0%	0
Total		311,490	310,900	0%	-590

2.6 SUMMARY OF RESULTS

Trip distribution model results are the trip tables by purpose. These can be summarized by the average trip length in both miles (distance) and minutes (travel time). Table 40 presents a summary of the trip distribution results for person trips and Table 41 present the summary for truck trips. Average speeds are calculated from the distance and travel time for each purpose. Changes in trip distance reflect changes in chosen routes due to congestion, and changes in travel time reflect changes in chosen routes, as well as changes in time caused by the congestion.

The average trip lengths by purpose between the model and Travel Survey are generally consistent with the largest differences for school and non-home based work trips. For trucks, the survey data is based of national freight research, not local survey data. There is general alignment for medium and heavy trucks with fairly large differences for light trucks. This is most likely due to the inclusion of non-truck vehicles in the model's light truck trip tables since this truck type also includes any vehicle used for commercial trip purposes and is not restricted to trucks.

Table 40. Average trip length and time by purpose

Trip Purpose	Daily Trips	Average Model Trip Length (miles)	Average Model Trip Time (minutes)	Average Survey Trip Length
Home Based College	157,700	7.8	23.0	8.1
Home Based Other	5,717,800	5.7	16.7	5.5
Home Based Shopping	1,313,200	4.5	14.7	4.6
Home Based School	1,115,200	3.3	11.6	4.4
Non-Home Other to Other	3,151,600	4.8	15.0	4.6
Non-Home Work to Other	1,631,300	7.8	20.5	6.2
Home Based Work Income #1	296,800	9.4	24.4	11.4
Home Based Work Income #2	605,400	11.7	28.6	
Home Based Work Income #3	624,900	13.0	30.9	
Home Based Work Income #4	915,600	13.8	32.1	
Total Trips	15,529,500	6.6		6.4

Table 41. Average trip length and time by truck type

Truck Type	Daily Trips	Length (miles)	Time (minutes)	Average Survey Trip Length
Light Trucks	317,200	15.4	28.5	26.3
Medium Trucks	57,000	28.8	48.5	27.6
Heavy Trucks	34,000	30.7	50.7	31.6
Total Truck Trips	408,200	18.6	33.1	

Home Based Work Trip Length Frequency Distribution

Figure 6 compares the frequency of home based work trips by their length with the 2006 Household Travel Survey. The 4K model is generally matching the survey results but tends to have slightly longer trips than the survey.

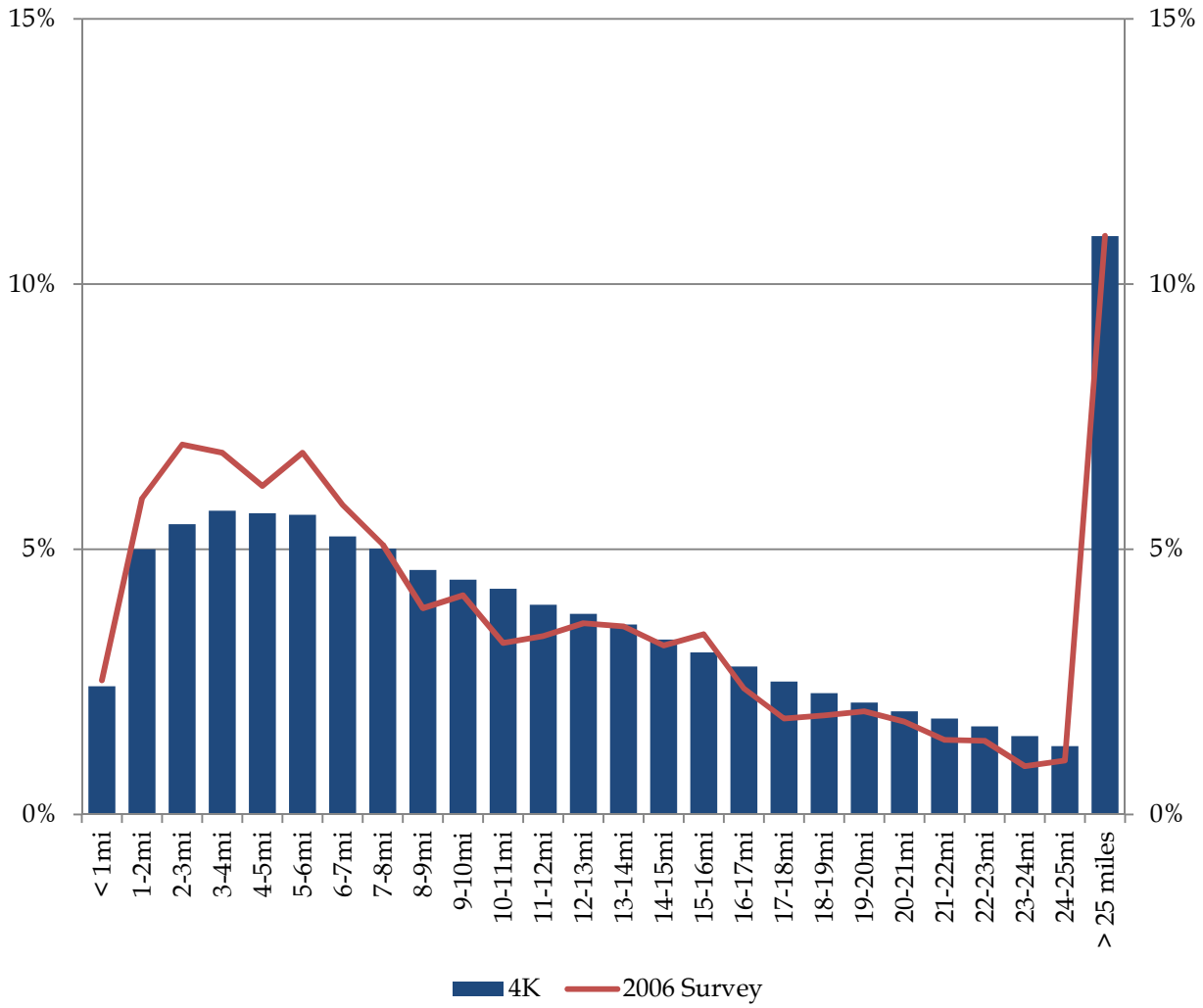

Figure 6. Home Based Work Trip Length Frequency

Home Based College Trip Length Frequency Distribution

Figure 7 compares the frequency of home based college trips by their length with the 2006 Household Travel Survey. The 4K model generally matches the average trip length for college trips as shown in Table 40 but shows variation compared to trips lengths by frequency. One reason for this variation is the fairly small sample size (320 trips) for College Trips in the 2006 Household Travel Survey.

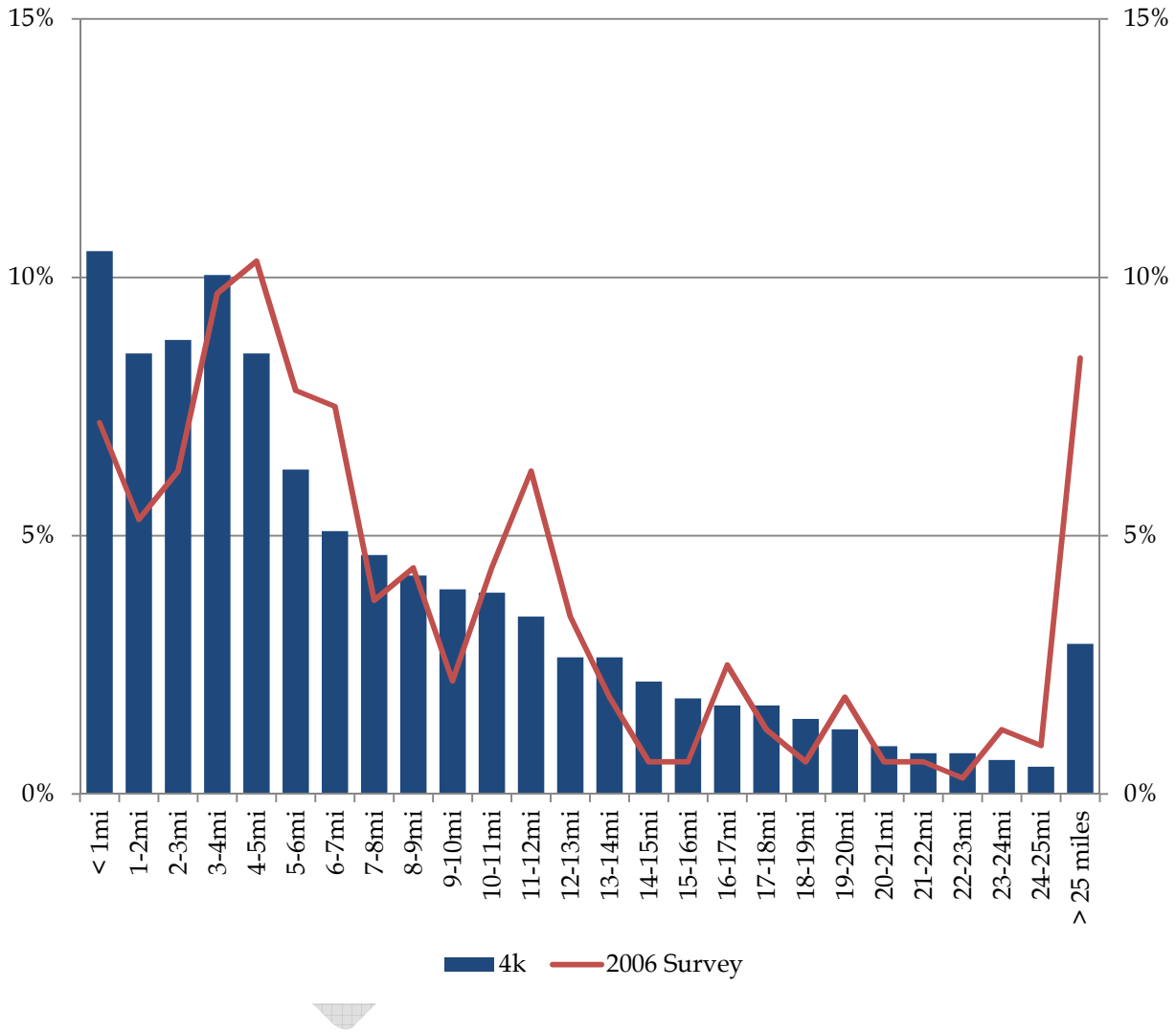

Figure 7. Home Based College Trip Length Frequency

Home Based Other Trip Length Frequency Distribution

Figure 8 compares the frequency of home based other trips by their length with the 2006 Household Travel Survey. The 4K model generally matches the average trip length for HBO trips as shown in Table 40 but slightly fewer trips in the loess than 2 mile category which leads to a slightly longer average trip length for home based other trips in the 4K model.

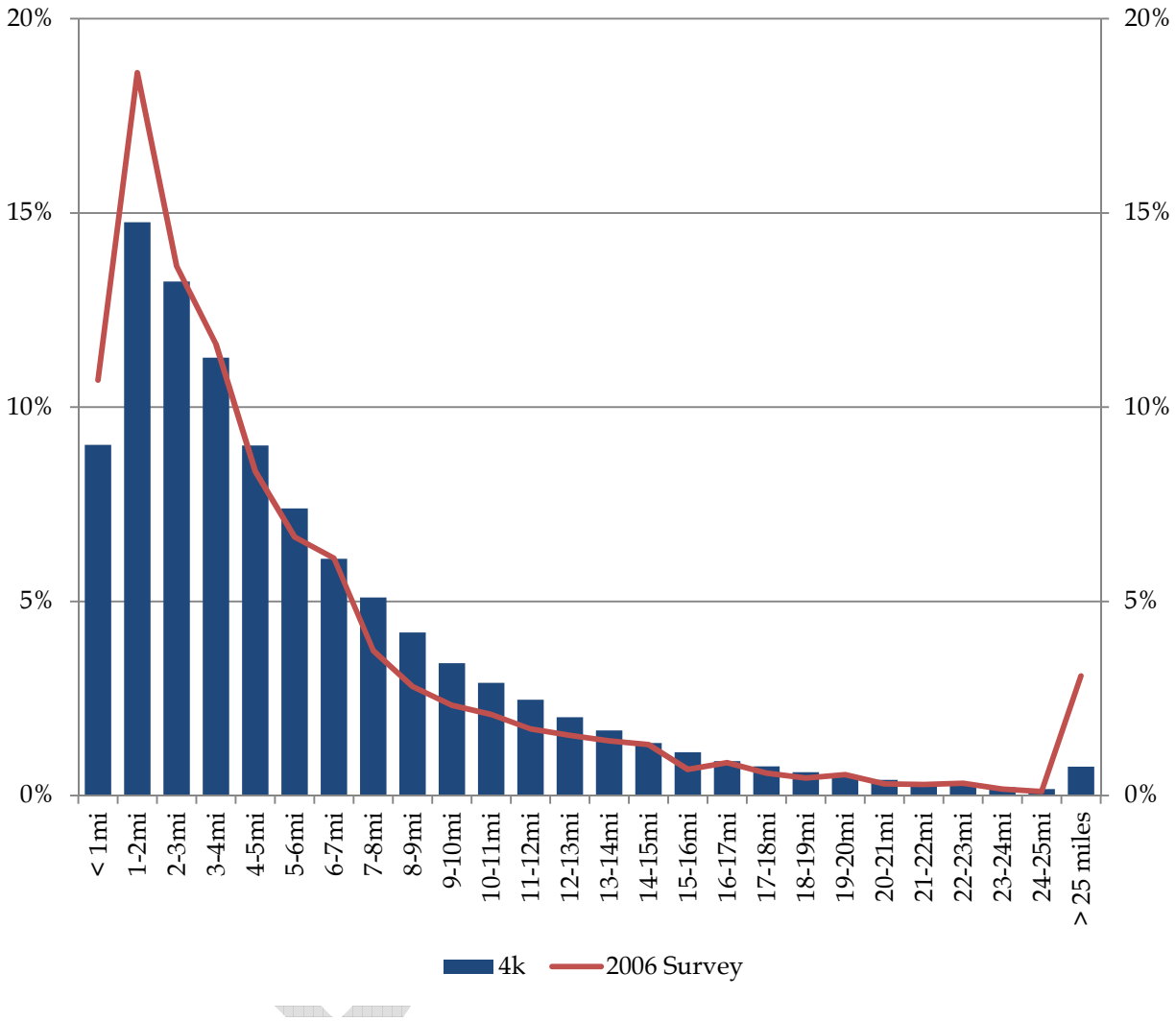

Figure 8. Home Based Other Trip Length Frequency

Home Based Shopping Trip Length Frequency Distribution

Figure 9 compares the frequency of home based shopping trips by their length with the 2006 Household Travel Survey. The 4K model matches the average trip length for shopping trips well and generally captures the distribution of trips in all distance categories.

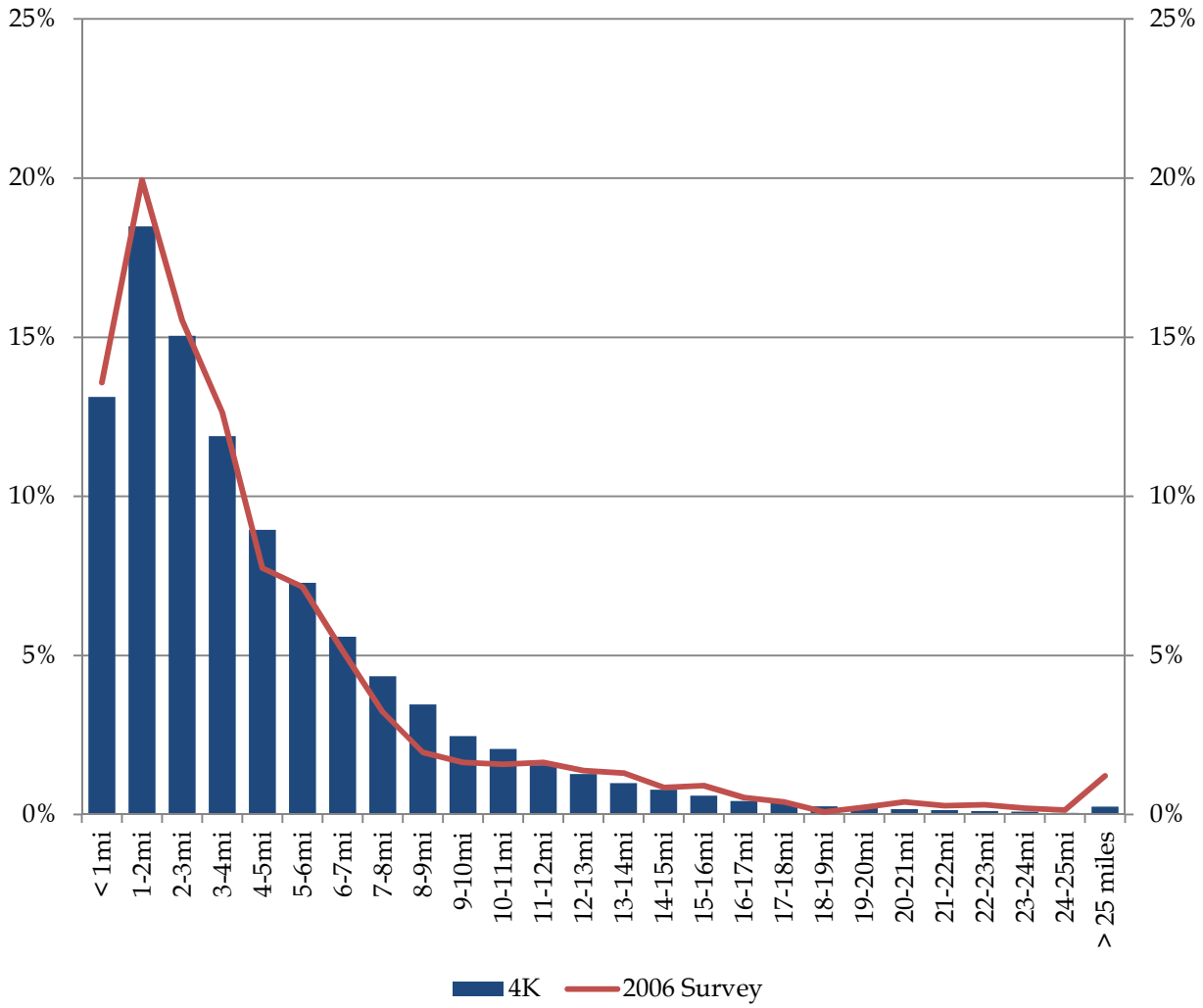

Figure 9. Home Based Shopping Trip Length Frequency

Home Based School Trip Length Frequency Distribution

Figure 10 compares the frequency of home based school trips by their length with the 2006 Household Travel Survey. The 4K model generally over-estimates the number of trip less than 1 mile in length and under-estimates the average trip length of school trips on average as shown in Table 40.

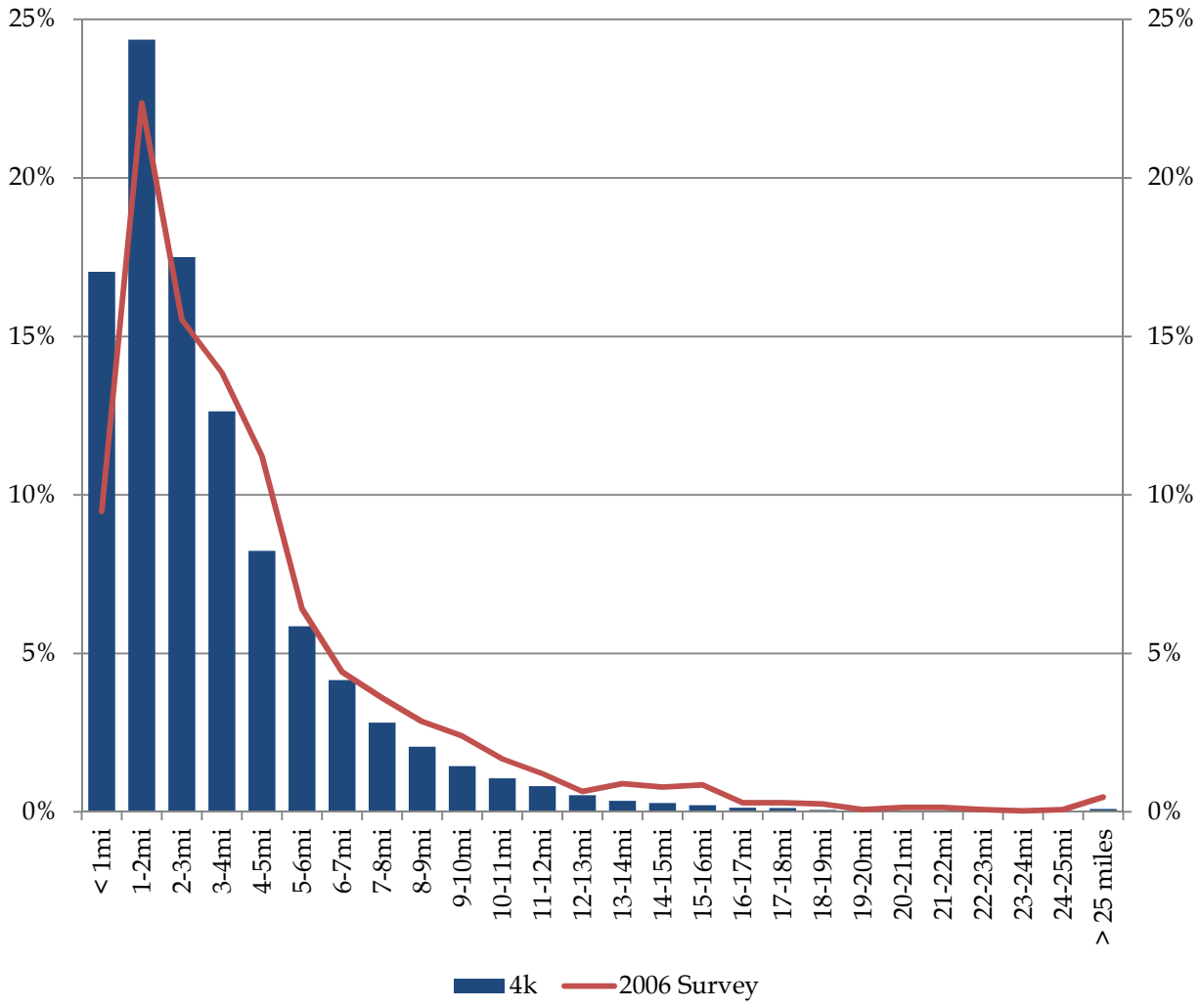

Figure 10. Home Based School Trip Length Frequency

Non-Home Based Other Trip Length Frequency Distribution

Figure 11 compares the frequency of non-home based other trips by their length with the 2006 Household Travel Survey. The 4K model generally over-estimates the length of trips for non-home based other trips as shown in Table 40. The largest differences occur in the less than 2 miles in length trips. The overall difference in average trip length is around 0.2 miles (4.8 vs 4.6 miles).

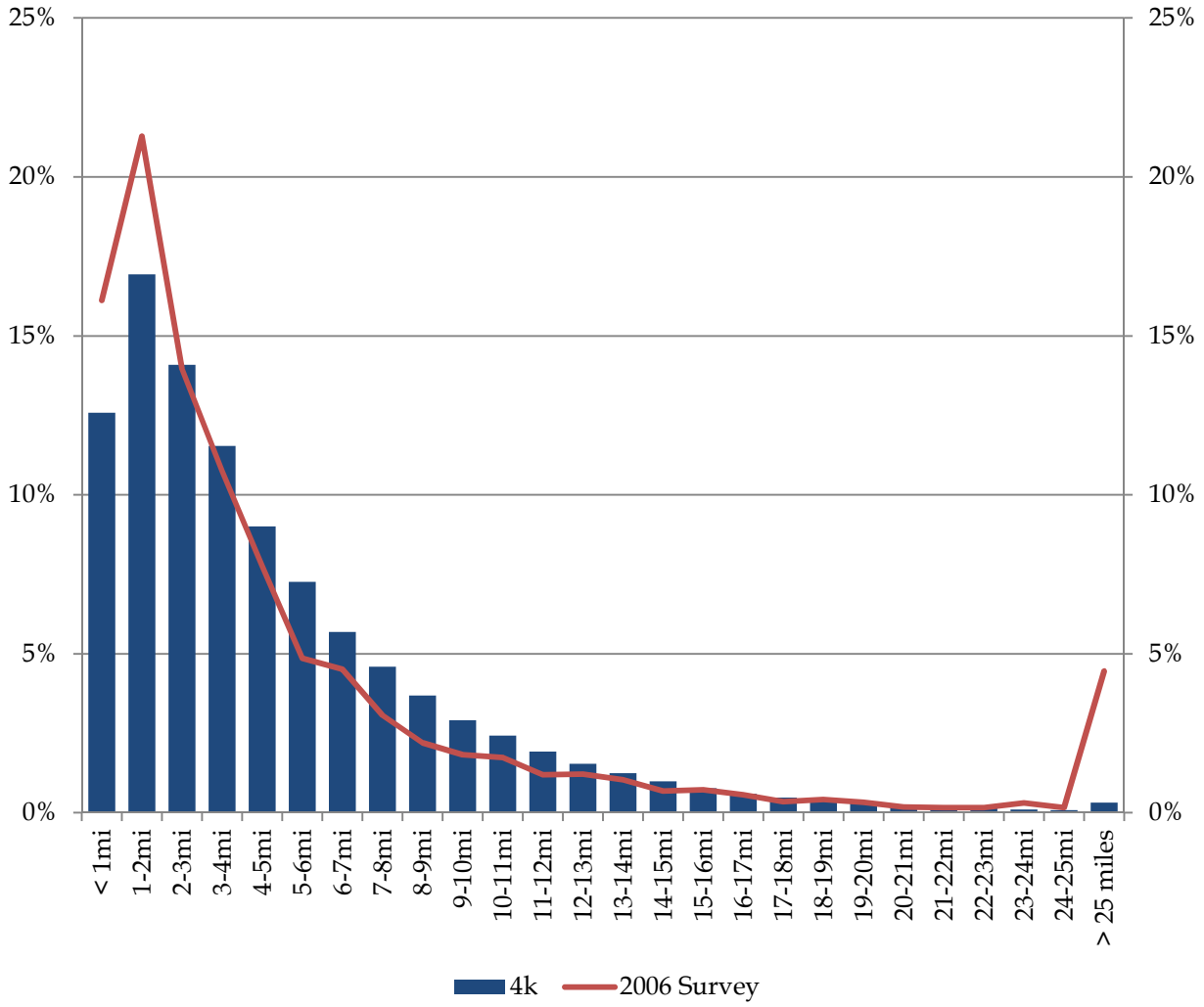

Figure 11. Non-Home Based Other Trip Length Frequency

Non-Home Based Work Trip Length Frequency Distribution

Figure 12 compares the frequency of non-home based work trips by their length with the 2006 Household Travel Survey. The 4K model under-estimates the number of trip less than 3 miles in length which leads to an overall over-estimate of the average trip length of non-home based work trips on average as shown in Table 40. The overall difference in trip lengths for non-home based work trips is the largest of all trip purposes. Despite this, the overall VMT in the model replicates the regional totals fairly well.

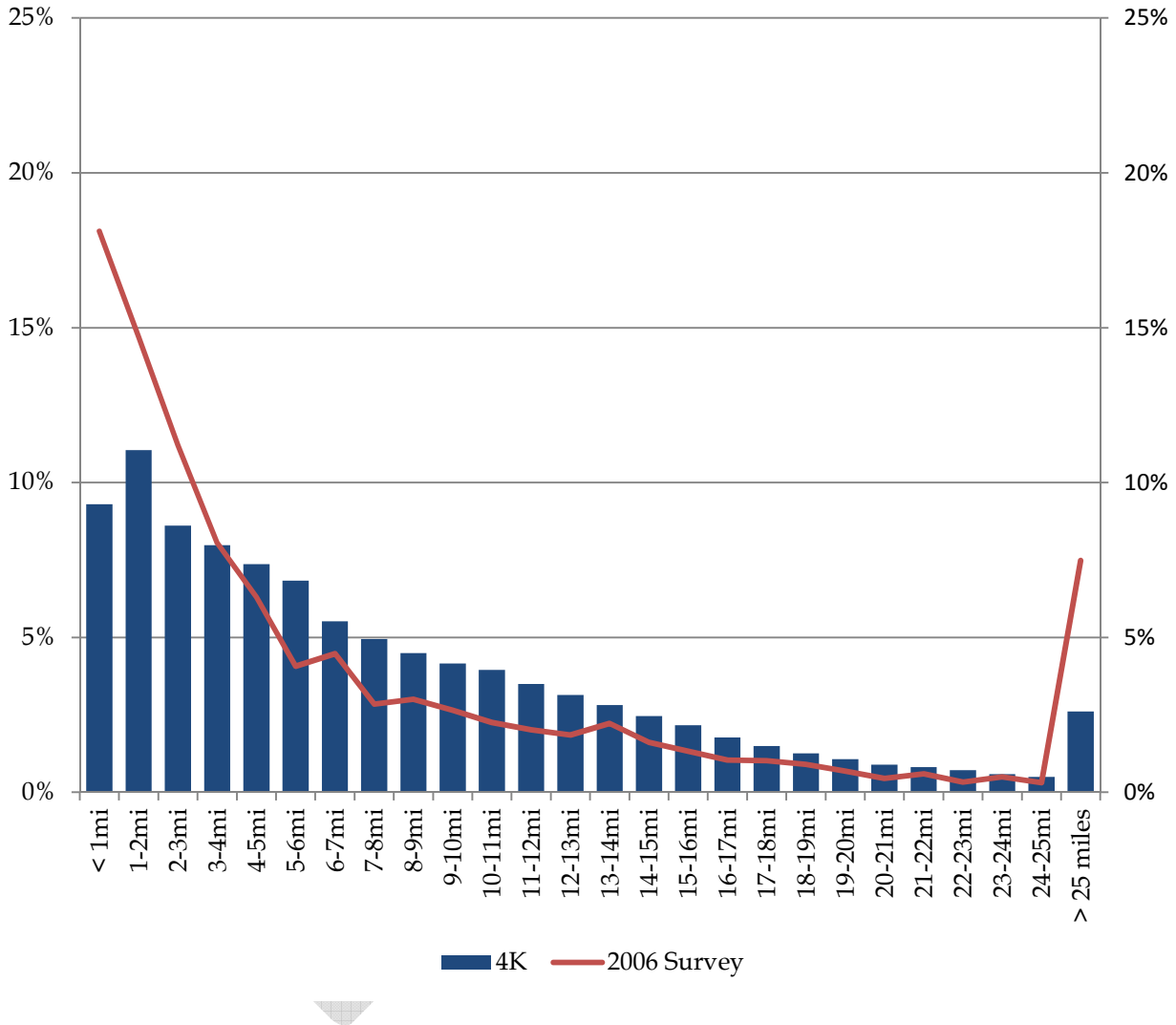

Figure 12. Non-Home Based Work Trip Length Frequency

Mode Choice

3.0 INTRODUCTION

The mode choice model is the third stage of the four-step travel demand modeling process. Productions and attractions of the trip generation model are linked in trip distribution, creating zone-to-zone person-trip movements. These trips are then apportioned to the available travel modes through the application of the mode choice model.

Mode choice models are used in the analysis of policy-oriented transportation planning scenarios and in examining the effects of various policy measures, as well as changes in the socioeconomic composition of an urban area on transportation-related social and environmental issues. A wide range of transportation policies can be evaluated through the application of the behavioral-based mode choice models. Examples include scenarios evaluating the effectiveness of high-occupancy vehicle (HOV) lanes, toll-ways, fixed guideway transit, exclusive bus lanes, and parking pricing.

Changes made with Puget Sound 4K Model

There were several changes made between the PSRC Model Version 1.0bb and the Puget Sound 4K Model implementation and include:

- Removal of the nested logit structure for Home Based Work Mode Choice and its replacement with a multinomial logit formulation.
- Estimation of all mode choice parameters from the 2006 Household Travel Survey (Version 1.0bb was a combination of the 1999 Household Travel Survey and assertion of national variables).
- Removal of market segmentation from Home Based Work and Home Based Non-Work mode choice.
- School trip mode choice is performed for all modes (Version 1.0bb estimated choice for vehicle and non-vehicle trips).

3.1 MODEL STRUCTURE

PSRC's mode choice model uses the multinomial logit formulations, a model structure widely used in urban travel demand analysis estimating the probabilities of a decision-maker's choice of travel modes among a finite set of alternatives. In a logit mode choice setting, the choice among travel modes is determined by the following factors:

- Characteristics of the trip maker (e.g., income, gender, age, household size, auto availability);
- Characteristics of the modes of travel available to the trip maker (e.g., travel time, cost of travel); and
- Characteristics of the trip itself (e.g., work versus non-work trips).

The probability of a trip maker choosing a mode of travel is a function of the "utility"of that mode versus the aggregate utility of all available modes. A utility function measures the amount of satisfaction one receives from the consumption of a certain good; in this case, the use of a particular mode of travel. The linear utility function of each mode is composed of variables describing the characteristics of the alternative and those of the decision-maker. Descriptor variables in utility equations of alternatives also depend on the characteristics of the trip itself, as different variables may be introduced for different trip purposes.

The probability of choosing an alternative is defined by the following relationship (the logit formulation):

$$P_m = \frac{e^{U_m}}{\sum_k e^{U_k}}$$

Where:

P_m = the probability of choosing mode *m*.

U_m = the utility of mode *m* in the following form:

$$U_m = aX + bZ + d$$

Where:

X and Z = Vectors of attributes of the alternatives and decision-makers, respectively;

a and b = Vectors of parameters; and

d = A constant capturing the unmeasured attributes.

k = the set of all available modes.

For example, the utility of traveling using an automobile may be described as:

$U_{Auto} = a * Time + b * Cost + c * Income + d$

Multinomial logit functions require the presence of distinct alternatives with no correlation in the choice set. This requirement, known as the Independence of Irrelevant Alternatives (IIA), ensures that the model calculates the correct share for each mode, and that there is no unreasonable shifting of shares among alternatives. Similarity of alternatives in a choice set can violate this assumption and result in the calculation of incorrect probabilities for various alternatives. Special statistical tests can determine the violation of the IIA assumption within a particular model. The best approach in alleviating this problem is the use of nested logit formulation, where the decision-maker is faced with a hierarchy of distinct sets of alternatives.

Home-Based College Mode Choice Model

The home-based college mode choice model is of the multinomial logit form with a choice set comprised of the following alternatives:

- Drive alone – Single-occupancy auto trips
- Shared ride 2 – Auto trips with two occupants
- Shared ride 3+ – Auto trips with three or more occupants
- Transit – Walk access
- Walk
- Bicycle

The home-based college model specifies driving alone in a car and carpooling as distinct alternatives. There is no market segmentation is used in the structure of the home-based college mode choice model. Table 42 presents the structure of the mode choice model for the home-based college trips. The cost for driving includes the auto operating cost of a vehicle as well as any parking costs at the destination. Transit costs include the fare between the origin and destination of the trip. Out of vehicle time for transit includes estimates of the walk access, wait, boarding and transfer times associated with the transit trip. The mode choice parameters in the 4K model were estimated using the 2006 Household Travel Survey for the region. All costs are expressed in 2010 dollars.

Table 42. Home-Based College Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-	-
Walk Time	-	-	-	-	-0.1592	-
Bike Time	-	-	-	-	-	-0.1181
Travel Cost (cents)	-0.0018	-0.0018	-0.0018	-0.0018	-	-
Value of Time ($) (2010 $'s)	$8.33	$8.33	$8.33	$8.33	-	-
Alternative Specific Constants	-	-2.3600	-3.1299	-0.1297	3.1095	-0.6332

Home-Based Non-Work Mode Choice Model

The home-based non-work mode choice model is also of the multinomial logit form with a choice set comprised of the following alternatives:

- Drive alone – Single-occupancy auto trips
- Shared ride 2 – Auto trips with two occupants
- Shared ride 3+ – Auto trips with three or more occupants
- Transit – Walk access
- Walk
- Bicycle

The home-based non-work model consolidates both shopping and other trips and there is no market segmentation is used in the structure of the home-based non-work mode choice model. Table 43 presents the structure of the mode choice model for the home-based non-work trips. The cost for driving includes the auto operating cost of a vehicle as well as any parking costs at the destination. Transit costs include the fare between the origin and destination of the trip. Out of vehicle time for transit includes estimates of the walk access, wait, boarding and transfer times associated with the transit trip. The mode choice parameters in the 4K model were estimated using the 2006 Household Travel Survey for the region. All costs are expressed in 2010 dollars.

Table 43. Home-Based Non-Work Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Walk	Bike
In-Vehicle Time	-0.0150	-0.0150	-0.0150	-0.0150	-	-
Out of Vehicle Time	-	-	-	-0.0300	-	-
Walk Time	-	-	-	-	-0.0923	-
Bike Time	-	-	-	-	-	-0.0342
Travel Cost (cents)	-0.0015	-0.0015	-0.0015	-0.0015	-	-
Value of Time ($) (2010 $'s)	$6.00	$6.00	$6.00	$6.00	-	-
Alternative Specific Constants	-	-0.3985	-0.5327	-2.2497	1.8960	-3.4304

The 4K non-work mode choice model differs from Model Version 1.0bb in that it no longer includes any reference to market segmentation or vehicle ownership in the mode choice model specifications.

Home-Based School Mode Choice Model

The home-based school mode choice model in 4K includes a multinomial logit form with a choice set comprised of the following alternatives:

- Drive alone – Single-occupancy auto trips
- Shared ride 2 – Auto trips with two occupants
- Shared ride 3+ – Auto trips with three or more occupants
- Transit – Walk access
- Walk
- Bicycle

Table 44 presents the structure of the mode choice model for the home-based school trips. There are no cost co-efficients for the school choice models. This reflects that transit use is generally school bus. All costs are expressed in 2010 dollars.

Table 44. Home-Based School Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Walk	Bike
In-Vehicle Time	-0.0050	-0.0050	-0.0050	-0.0050	-	-
Out of Vehicle Time	-	-	-	-0.0500	-	-
Walk Time	-	-	-	-	-0.0698	-
Bike Time	-	-	-	-	-	-0.1182
Travel Cost (cents)	-	-	-	-	-	-
Value of Time ($) (2010 $'s)	-	-	-	-	-	-
Alternative Specific Constants	-	1.2168	1.6059	-0.0315	3.5358	0.5797

The 4K school mode choice model differs from Model Version 1.0bb in that it estimates choices for all modes compared to the simplified vehicle / non-motorized choice set used for Version 1.0bb.

Home-Based Work Mode Choice Model

The home-based work mode choice model is no longer a nested model in 4K and was moved back to a multinomial logit form with a choice set comprised of the following alternatives:

- Drive alone – Single-occupancy auto trips
- Shared ride 2 – Auto trips with two occupants
- Shared ride 3+ – Auto trips with three or more occupants
- Transit – Walk access
- Transit - Drive access
- Walk
- Bicycle

The home-based work model is broken out by the four income classes in the model. There is no market segmentation is used in the structure of the home-based work mode choice model. Table 45 through Table 48 present the structure of the mode choice models for the home-based work trips. The cost for driving includes the auto operating cost of a vehicle as well as any parking costs at the destination. Transit costs include the fare between the origin and destination of the trip. Out of vehicle time for transit includes estimates of the walk access, wait, boarding and transfer times associated with the transit trip. Auto access to transit includes both the time in a car and the operating cost from the origin as well as any costs at the park and ride lot and the wait and transfer times on the transit system. The mode choice parameters in the 4K model were estimated using the 2006 Household Travel Survey for the region. All costs are expressed in 2010 dollars.

Table 45. Home-Based Work Income #1 Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Drive to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-0.0500	-	-
Walk Time	-	-	-	-	-	-0.0318	-
Bike Time	-	-	-	-	-	-	-0.0258
Travel Cost (cents)	-0.0040	-0.0040	-0.0040	-0.0040	-0.0040	-	-
Value of Time ($) (2010 $'s)	$3.75	$3.75	$3.75	$3.75	$3.75	-	-
Alternative Specific Constants	-	-2.2303	-4.3741	-0.6911	-2.9349	-0.6436	-4.7651

Table 46. Home-Based Work Income #2 Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Drive to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-0.0500	-	-
Walk Time	-	-	-	-	-	-0.1139	-
Bike Time	-	-	-	-	-	-	-0.0675
Travel Cost (cents)	-0.0030	-0.0030	-0.0030	-0.0030	-0.0030	-	-
Value of Time ($) (2010 $'s)	$5.00	$5.00	$5.00	$5.00	$5.00	-	-
Alternative Specific Constants	-	-2.8267	-4.7142	-1.4712	-3.0075	1.4831	-2.2035

Table 47. Home-Based Work Income #3 Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Drive to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-0.0500	-	-
Walk Time	-	-	-	-	-	-0.1104	-
Bike Time	-	-	-	-	-	-	-0.0521
Travel Cost (cents)	-0.0023	-0.0023	-0.0023	-0.0023	-0.0023	-	-
Value of Time ($) (2010 $'s)	$6.52	$6.52	$6.52	$6.52	$6.52	-	-
Alternative Specific Constants	-	-3.0411	-4.6849	-1.9304	-3.0053	0.9008	-2.7140

Table 48. Home-Based Work Income #4 Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Drive to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-0.0500	-	-
Walk Time	-	-	-	-	-	-0.0885	-
Bike Time	-	-	-	-	-	-	-0.0480
Travel Cost (cents)	-0.0018	-0.0018	-0.0018	-0.0018	-0.0018	-	-
Value of Time ($) (2010 $'s)	$8.33	$8.33	$8.33	$8.33	$8.33	-	-
Alternative Specific Constants	-	-3.0284	-4.7987	-1.9340	-2.8608	0.7207	-2.7707

As noted above, previous versions of the Home Based Work mode choices models were nested logit models that broke down auto into drive alone and auto access transit. The larger difference in model structure related to the use of market segmentation differences based on auto availability and number of workers. These market segmentation differences were removed in the 4K model estimation and the structure of the model was returned to a multi-nominal logit formulation. These changes were made based on observations in the 2006 Household Travel Survey.

Non-Home Based Mode Choice Model

The non-home based mode choice model is also of the multinomial logit form with a choice set comprised of the following alternatives:

- Drive alone – Single-occupancy auto trips
- Shared ride 2 – Auto trips with two occupants
- Shared ride 3+ – Auto trips with three or more occupants
- Transit – Walk access
- Walk
- Bicycle

The non-home based model consolidates both non-home work and non-home other trips and there is no market segmentation is used in the structure of mode choice model. Table 43 presents the structure of the mode choice model for the home-based non-work trips. The cost for driving includes the auto operating cost of a vehicle as well as any parking costs at the destination. Transit costs include the fare between the origin and destination of the trip. Out of vehicle time for transit includes estimates of the walk access, wait, boarding and transfer times associated with the transit trip. The mode choice parameters in the 4K model were estimated using the 2006 Household Travel Survey for the region. All costs are expressed in 2010 dollars.

Table 49. Non-Home Based Mode Choice Model Parameters

Variable	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Walk	Bike
In-Vehicle Time	-0.0250	-0.0250	-0.0250	-0.0250	-	-
Out of Vehicle Time	-	-	-	-0.0500	-	-
Walk Time	-	-	-	-	-0.1333	-
Bike Time	-	-	-	-	-	-0.0273
Travel Cost (cents)	-0.0025	-0.0025	-0.0025	-0.0025	-	-
Value of Time ($) (2010 $'s)	$6.00	$6.00	$6.00	$6.00	-	-
Alternative Specific Constants	-	-0.7953	-1.0424	-2.2680	2.2288	-4.3750

The 4K non-home mode choice model is similar in structure to Model Version 1.0bb in the mode choice model specifications.

3.2 SUMMARY RESULTS

The mode choice model produces trips by various modes. The outputs of the model in the format of zone-to-zone travel movements by transit and highway modes are then assigned onto the highway and transit network for further analysis. A regional summary of trips by various modes and trip purposes produced by the mode choice model for 2010 conditions is shown in Table 50.

Table 50. 2010 Mode Choice Results by Trip Purpose

Trip Purpose	Drive Alone	HOV 2	HOV 3+	Transit Walk	Transit Drive	Walk	Bike
Home Based College	58%	7%	4%	18%	0%	9%	4%
Home Based Other	37%	27%	25%	2%	0%	9%	1%
Home Based School	8%	27%	40%	3%	0%	19%	3%
Non-Home Based	45%	24%	20%	1%	0%	9%	1%
Home Based Work Income #1	61%	11%	2%	15%	2%	8%	1%
Home Based Work Income #2	74%	7%	2%	9%	3%	3%	3%
Home Based Work Income #3	80%	6%	2%	5%	3%	2%	2%
Home Based Work Income #4	82%	6%	1%	4%	3%	2%	2%
Total Daily Internal Trips	43.6%	22.9%	20.8%	2.6%	0.5%	8.7%	1.0%
2006 HH Survey	42.4%	21.6%	20.1%	2.8%	0.8%	8.6%	0.9%

The 4K mode choice model generally aligns with the 2006 Household Survey. The model overstates HOV volumes slightly compared to the survey results but overall traffic volumes align fairly well to traffic counts.
Table 51

Table 52and highlights the estimates of mode shares by a group of Regional Growth Centers. As shown in the tables, the 4K model generally captures the attractiveness of non-auto modes for both work and n on-work trips to Regional Growth Centers. For work based trips, transit shares in these centers are significantly higher than non-centers.

Table 51. Work Mode Shares to Select Regional Centers

Trip Mode	Bellevue	Everett	Seattle Downtown	Tacoma Downtown	All Centers	Non-Center
SOV	49%	67%	26%	71%	62%	83%
HOV (2+)	14%	9%	9%	9%	9%	8%
Transit	30%	14%	47%	12%	20%	5%
Walk and Bike	7%	10%	18%	8%	9%	4%
Total	100%	100%	100%	100%	100%	100%

Table 52. Non-Work Mode Shares to Select Regional Centers

Trip Mode	Bellevue	Everett	Seattle Downtown	Tacoma Downtown	All Centers	Non-Center
SOV	21%	27%	20%	28%	28%	30%
HOV (2+)	61%	58%	59%	57%	58%	61%
Transit	2%	2%	3%	3%	2%	1%
Walk and Bike	16%	13%	18%	12%	11%	8%
Total	100%	100%	100%	100%	100%	100%

Time of Day

4.0 INTRODUCTION

The time-of-day model is not one of the four primary model components identified as part of the four-step modeling process, but occurs in this case after mode choice and before trip assignment. The time-of-day model estimates the number of trips from each TAZ to each other TAZ in each time period. There are 32 time periods in the time of day model, every 30 minutes between 5:00 a.m. and 8:00 p.m. and additional periods for evening (8:00 p.m. to 11:00 p.m.) and night (11:00 p.m. to 5:00 a.m.).

The time-of-day model is comprised of three different steps:

1. **Divide auto access to transit trips into the auto portion and transit portions of the trip.** This step involves separating the transit trips that use park-and-ride lots into their individual modal components. The portion of the trip that is using the roadway system (from the production zone to the park-and-ride lot) is separated from the portion of the trip using the transit system (from the park-and-ride lot to the attraction zone), so that these modes can be assigned separately.
2. **Develop daily single-occupancy vehicle (SOV), HOV2 and HOV3+, Trucks and transit trip tables.** This step involves adding trips by purpose and the external-external trip table to produce a set of daily trip tables, and converting these trip tables from a production-attraction format to an origin-destination format.
3. **Develop carpool, non-carpool, truck and transit trip tables by time period.** This step involves applying the time-of-day models for auto trips and peaking factors for truck and transit trips and converting these trip tables from a production-attraction format to an origin-destination format.

There are two primary types of models used to estimate peak-period travel: 1) peaking factor models; and 2) choice models. The use of peaking factor models that produce trips by time period have been common practice for a long time, but these models are not able to evaluate the impacts of different alternatives on trips by time period since the factors are fixed over time. Choice models that produce trips by time period are not as common in practice, but use traditional logit choice estimation techniques to apportion trip tables by purpose to various time periods. Choice models spread the number of trips that occur in the peak period based on an assessment of congestion, level of service, purpose, and socioeconomic or density variables.

The objective of the time-of-day choice models is to provide sensitivity to temporal decisions with respect to sociodemographic and trip characteristics. This sensitivity to temporal decision-making is expected to have significant impacts on forecasting results, as peak-period travel is more likely to be occurring in saturated conditions. Fixed time period factors provide realistic estimates of peaking characteristics under current conditions, but are not sensitive to changes in travel behavior as congestion increases or demographics shift.

The time-of-day choice models are applied to produce probabilities that auto trips will occur in one of the 32 time periods. These probabilities are then applied to auto trip tables for each purpose to produce trip tables by time period and purpose. This process is very similar to how

mode choice models are estimated and applied. The sum of the resulting time period trip tables will equal the total daily trips.

Changes made with Puget Sound 4K Model

There were no changes made to the time of day structure between the PSRC Model Version 1.0bb and the Puget Sound 4K Model implementation in respect to the time of day models. Documentation of the time of day process is included to help understand and validate how the 4K model is performing compared to existing information. The only change was:

- Updated Time of Day factors using the 2006 Puget Sound Household Travel Survey (Model Version 1.0bb was based on the 1999 Puget Sound Household Travel Survey).

4.1 TIME PERIODS

The time-of-day models produce shares by mode for five time periods of the day:

- A.M. peak (6:00 a.m. to 8:59 a.m.);
- Midday (9:00 a.m. to 2:59 p.m.);
- P.M. peak (3:00 p.m. to 5:59 p.m.);
- Evening (6:00 p.m. to 9:59 p.m.); and
- Night (10:00 p.m. to 5:59 a.m.)

These five time periods are used for all modes, auto, transit, and external trips. The auto modes are calculated for 32 time periods as described below and aggregated to the five time periods for assignment purposes.

4.2 AUTO ACCESS TRANSIT

Park-and-ride lots present a special situation for the travel demand model, because these trips are comprised of two modes, both of which need to be assigned to modal networks. These trips are estimated in the mode choice model from production to attraction zones. Prior to the application the time-of-day model, these auto access to transit trips are split into two separate trip tables so that each portion of the trip can be assigned separately to the highway and transit networks. This is based on the portion of the trip from the production zone to the park-and-ride lot (for highway trip tables), and the portion of the trip from the park-and-ride lot to the attraction zone (for transit trip tables). For each zone pair (p,q) in the auto access to transit trip table, the trips are routed through one or more park-and-ride lots using a logit model with the following utility for each park-and-ride lot (k).

$Utility_{pkq}$ = exp(generalized auto $cost_{pk}$) + exp(total transit $time_{kq}$)

4.3 FIXED TIME OF DAY FACTORS

The time-of-day models for transit, truck and non-motorized travel are developed and applied as a set of fixed factors by trip purpose, mode, direction and time period. Time of day factors for SOV, HOV 2 and HOV 3+ vehicles are also created using fixed time of day factors for College, School and Non-Home Based trip purposes. The remaining trip purpose time of day factors are based on logit modeling and are descried in Section 4.4.

Factors by time period, purpose, and direction are provided in Table 53 through Table 61. Direction is determined as a function of the productions (P) and attractions (A) in each zone. The total daily factors are calculated first to balance the total trip-making for each purpose over the 24-hour day. The time-of-day models were estimated by calculating time-of-day factors from the 2006 PSRC Household Travel Survey.

Table 53. Time of Day Factors – Walk Trips

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.453	0.547	0.310	0.000	0.571	0.506	0.118	0.286	0.000	0.208	0.000	0.000
HBO	0.501	0.499	0.202	0.124	0.320	0.262	0.284	0.281	0.181	0.297	0.014	0.037
School	0.437	0.563	0.878	0.000	0.109	0.503	0.002	0.494	0.011	0.002	0.000	0.002
Shop	0.398	0.602	0.065	0.036	0.314	0.312	0.273	0.295	0.326	0.335	0.022	0.023
OtO	0.500	0.500	0.055	0.055	0.521	0.521	0.244	0.244	0.164	0.164	0.016	0.016
WtO	0.500	0.500	0.086	0.086	0.725	0.725	0.135	0.135	0.051	0.051	0.003	0.003
HBW #1	0.488	0.512	0.371	0.107	0.455	0.175	0.033	0.507	0.000	0.186	0.142	0.025
HBW #2	0.496	0.504	0.498	0.000	0.335	0.283	0.157	0.268	0.010	0.237	0.000	0.221
HBW #3	0.486	0.514	0.554	0.000	0.373	0.258	0.034	0.418	0.039	0.271	0.000	0.053
HBW #4	0.493	0.507	0.619	0.000	0.247	0.080	0.066	0.571	0.027	0.322	0.041	0.027

Table 54. Time of Day Factors - Bike Trips

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.482	0.518	0.133	0.000	0.867	0.363	0.000	0.387	0.000	0.250	0.000	0.000
HBO	0.521	0.479	0.202	0.065	0.228	0.162	0.340	0.253	0.222	0.507	0.009	0.013
School	0.507	0.493	0.788	0.000	0.212	0.429	0.000	0.571	0.000	0.000	0.000	0.000
Shop	0.355	0.645	0.145	0.000	0.606	0.264	0.191	0.532	0.058	0.147	0.000	0.057
OtO	0.500	0.500	0.038	0.038	0.473	0.473	0.301	0.301	0.178	0.178	0.010	0.010
WtO	0.500	0.500	0.190	0.190	0.275	0.275	0.328	0.328	0.184	0.184	0.023	0.023
HBW #1	0.690	0.310	0.611	0.000	0.389	0.343	0.000	0.000	0.000	0.657	0.000	0.000
HBW #2	0.465	0.535	0.500	0.000	0.406	0.060	0.085	0.293	0.000	0.647	0.009	0.000
HBW #3	0.529	0.471	0.597	0.014	0.207	0.190	0.063	0.533	0.012	0.218	0.122	0.044
HBW #4	0.501	0.499	0.633	0.061	0.225	0.107	0.000	0.565	0.000	0.267	0.142	0.000

Table 55. Time of Day Factors – Walk to Transit Trips

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.514	0.486	0.717	0.000	0.216	0.305	0.015	0.490	0.052	0.205	0.000	0.000
HBO	0.542	0.458	0.412	0.015	0.440	0.472	0.073	0.241	0.065	0.204	0.010	0.068
School	0.503	0.497	0.828	0.000	0.108	0.416	0.064	0.584	0.000	0.000	0.000	0.000
Shop	0.391	0.609	0.063	0.000	0.838	0.512	0.019	0.368	0.080	0.086	0.000	0.034
OtO	0.500	0.500	0.095	0.095	0.544	0.544	0.230	0.230	0.098	0.098	0.034	0.034
WtO	0.500	0.500	0.143	0.143	0.343	0.343	0.437	0.437	0.070	0.070	0.006	0.006
HBW #1	0.511	0.489	0.538	0.069	0.242	0.214	0.064	0.464	0.037	0.248	0.118	0.005
HBW #2	0.550	0.450	0.772	0.004	0.114	0.070	0.013	0.719	0.004	0.155	0.097	0.051
HBW #3	0.545	0.455	0.720	0.000	0.111	0.115	0.000	0.789	0.000	0.081	0.168	0.014
HBW #4	0.528	0.472	0.824	0.011	0.073	0.050	0.004	0.735	0.004	0.134	0.095	0.070

Table 56. Time of Day Factors – Drive to Transit Trips (Transit Portion of Trip)

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
HBW #1	0.477	0.523	0.557	0.000	0.223	0.309	0.000	0.531	0.000	0.047	0.220	0.114
HBW #2	0.554	0.446	0.726	0.000	0.075	0.031	0.000	0.834	0.000	0.029	0.199	0.106
HBW #3	0.515	0.485	0.688	0.000	0.005	0.065	0.000	0.875	0.015	0.060	0.293	0.000
HBW #4	0.571	0.429	0.725	0.000	0.009	0.049	0.006	0.763	0.000	0.188	0.260	0.000

Table 57. Time of Day Factors – Commercial Vehicles

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
Light	0.500	0.500	0.194	0.194	0.346	0.346	0.240	0.240	0.126	0.126	0.094	0.094
Medium	0.500	0.500	0.208	0.208	0.417	0.417	0.204	0.204	0.095	0.095	0.076	0.076
Heavy	0.500	0.500	0.209	0.209	0.468	0.468	0.189	0.189	0.071	0.071	0.063	0.063

Table 58. Time of Day Factors – Shared Ride 2

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.604	0.396	0.430	0.000	0.387	0.425	0.158	0.082	0.026	0.493	0.000	0.000
HBO	0.506	0.494	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
School	0.637	0.370	0.851	0.001	0.125	0.429	0.014	0.510	0.008	0.058	0.003	0.003
Shop	0.383	0.617	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
OtO	0.500	0.500	0.064	0.064	0.459	0.459	0.267	0.267	0.200	0.200	0.010	0.010
WtO	0.500	0.500	0.145	0.145	0.390	0.390	0.319	0.319	0.113	0.113	0.034	0.034
HBW #1	0.502	0.498	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #2	0.529	0.471	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #3	0.538	0.462	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #4	0.549	0.451	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD

Table 59. Time of Day Factors – Shared Ride 3+

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.669	0.331	0.245	0.000	0.316	0.187	0.426	0.125	0.013	0.688	0.000	0.000
HBO	0.488	0.512	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
School	0.569	0.431	0.836	0.000	0.123	0.303	0.007	0.639	0.011	0.057	0.023	0.001
Shop	0.408	0.592	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
OtO	0.500	0.500	0.091	0.091	0.386	0.386	0.295	0.295	0.215	0.215	0.014	0.014
WtO	0.500	0.500	0.130	0.130	0.515	0.515	0.268	0.268	0.071	0.071	0.017	0.017
HBW #1	0.759	0.241	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #2	0.549	0.451	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #3	0.512	0.488	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #4	0.698	0.302	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD

Table 60. Time of Day Factors – Drive Alone

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
College	0.514	0.486	0.399	0.000	0.415	0.516	0.123	0.190	0.043	0.269	0.020	0.026
HBO	0.479	0.521	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
School	0.556	0.444	0.830	0.004	0.097	0.681	0.039	0.202	0.009	0.113	0.024	0.000
Shop	0.365	0.635	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
OtO	0.500	0.500	0.080	0.080	0.552	0.552	0.229	0.229	0.132	0.132	0.007	0.007
WtO	0.500	0.500	0.183	0.183	0.438	0.438	0.298	0.298	0.064	0.064	0.016	0.016
HBW #1	0.520	0.480	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #2	0.538	0.462	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #3	0.529	0.471	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
HBW #4	0.532	0.468	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD	TOD
Thru	0.500	0.500	0.142	0.142	0.359	0.359	0.220	0.220	0.173	0.173	0.106	0.106

Table 61. Time of Day Factors – Drive to Transit Trips (Auto Portion of Trip)

Trip Purpose	Share of Trips		AM Peak Factors		Midday Factors		PM Peak Factors		Evening Factors		Overnight Factors	
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P
HBW #1	0.477	0.523	0.557	0.000	0.223	0.309	0.000	0.531	0.000	0.047	0.222	0.114
HBW #2	0.554	0.446	0.726	0.000	0.075	0.031	0.000	0.834	0.000	0.029	0.199	0.106
HBW #3	0.515	0.485	0.688	0.000	0.005	0.065	0.000	0.875	0.015	0.060	0.293	0.000
HBW #4	0.571	0.429	0.725	0.000	0.009	0.049	0.006	0.763	0.000	0.188	0.260	0.000

4.4 CHOICE BASED TIME OF DAY MODEL

Auto trips for Work, Shopping and Home Based Other are further subdivided into 32 time periods as shown in Table 62. The auto time-of-day model uses highway travel times from each of the 5 time periods to predict travel for 30-minute time periods. When estimating the time-of-day models, the chosen time period for each trip was based on the midpoint between the reported trip departure time and trip arrival time. The home-work time period is based on the arrival time of the home-work trip and the work-home time period is based on the departure time of the work-home trip. All other purpose time periods are based on departure time of the trip.

Table 62. Choice Based Time of Day Model Time Periods

AM Peak	Midday	PM Peak	Evening	Night
5:00-5:29 am	10:00-10:29 am	3:00-3:29 pm	8:00-10:59 pm	11:00pm-4:59 am
5:30-5:59 am	10:30-10:59 am	3:30-3:59 pm		
6:00-6:29 am	11:00-11:29 am	4:00-4:29 pm		
6:30-6:59 am	11:30-11:59 am	4:30-4:59 pm		
7:00-7:29 am	12:00-12:29 pm	5:00-5:29 pm		
7:30-7:59 am	12:30-12:59 pm	5:30-5:59 pm		
8:00-8:29 am	1:00-1:29 pm	6:00-6:29 pm		
8:30-8:59 am	1:30-1:59 pm	6:30-6:59 pm		
9:00-9:29 am	2:00-2:29 pm	7:00-7:29 pm		
9:30-9:59 am	2:30-2:59 pm	7:30-7:59 pm		

Trip tables are developed for each time period, purpose, mode, and direction. These are applied to networks by mode and time period in the trip assignment model. The 32 time periods estimated in the time-of-day models are aggregated into the five time periods used in assignment. Multinomial logit choice models were estimated for fourteen home-based trip purpose/direction combinations:

- Home to work (separate model for each of four income groups)
- Work to home (separate model for each of four income groups)
- Home to shop
- Shop to home
- Home to other
- Other to home

Two main features were added to the time-of-day models to make them more sensitive to congestion pricing:

- First, the three periods where congestion occurs (a.m. peak, midday, p.m. peak) were further divided into 30-minute sub-periods in order to model peak-spreading behavior. Because it would be impractical to also perform a separate traffic assignment for each 30-minute period, the distribution of trips across the sub-periods was based on travel times for the same 5 periods that are included in the current model. As the congested travel time in the "peak of the peak" increases relative to the free-flow travel time, the peak tends to flatten, and a higher percentage of peak travelers will travel in the shoulders of the peak. Generally, this type of effect is not symmetric, because there are different constraints for traveling earlier as opposed to traveling later. In the a.m. peak, for example, we expect more workers to shift toward the earlier shoulder of the peak,

rather than the later shoulder, because many workers have to arrive at work before a specific time.

- Second, in addition to auto travel time variations between periods, the model is sensitive to auto travel cost differences between periods, for instance from time-of-day-specific congestion pricing. Because we have no data on such cost differences in the household survey, it is necessary to infer the sensitivity to travel cost by using the sensitivity to travel time multiplied by the appropriate value of time for each income group/travel purpose. We use the same values of time that are used in the mode choice models.

Multinomial logit models were estimated for the 6 trip purpose/direction combinations using a set of 32 alternatives. Compared to the remainder of the modeling system, the am and pm "peak" periods are both expanded to include wider shoulder periods. The am peak, midday, and pm peak periods are set to be 5 hours long and contain 10 one-half-hour sub-periods. The evening and night periods remain as single periods, spanning three and six hours, respectively. In estimation, we use both period-specific variables, as well as "shift" variables, to move trips earlier or later within each of the three larger periods. The shift variables are nonlinear; for example, it may take more than twice as much am peak congestion to get someone to shift their departure time 30 minutes earlier than it does to get the same person to shift 60 minutes earlier. The following variables were used in the models:

- Sociodemographic
    - Household Income
    - Household Size.
- O-D/level of service
    - Auto in-vehicle travel time during each of the five periods
    - Bridge dummy variable

Variables that were tested but not included in the final models related to employment accessibility variables. A description of the variables retained in the final models and the impact of these variables on the temporal choice behavior of travelers are as follows:

- **Household Income** – The dummy variable that indicates high-income group has a significant coefficient specific to pm peak period in the 'Work to Home' model whereas in the 'Home to Work' model, the coefficient is significant in the a.m. peak period. This indicates that commuters from higher-income households are more likely to travel to work during the am peak period and less likely to travel during the p.m. peak period than other time periods. This result is further corroborated in the 'Work to Home' model where the income coefficient for the a.m. period was insignificant (and not included) suggesting that commute trips from higher-income households are not as likely to be destined to home during the morning peak period. The income coefficients for the pm time period are greater than for other time periods in the 'Work to Home' model, indicating that higher-income commuters are more likely to return home during the pm peak period. The lower-income variable has a negative coefficient in the am peak period of the 'Home to Work' model, probably because the lower-income jobs have

more irregular hours than high-income jobs and are more likely to occur in off-peak time periods.

- **Household Size –** Larger households are less likely to travel to work in am peak than smaller households, as indicated by the negative and significant household size coefficient in the 'Home to Work' model. It may be that larger household sizes indicate the presence of children or more complicated household structures, which, combined with multiple workers in the household, lead to flexible or extended work schedules resulting in more reverse direction work trips. By contrast, smaller households are more likely to return home from work in the pm peak period, as indicated by the negative and significant coefficient in the 'Work to Home' model. It is possible that smaller households have fewer outside constraints on work hours and schedules, and work trips can occur in more traditional work hours.
- **Carpool Dummy –** If a work to home trip is made using the carpool mode of travel, then this variable is equal to one; otherwise, it equals zero. The coefficient of this variable is very significant and positive in the 'Home to Work' model, and very significant and negative in 'Work to Home' model. This coefficient is negative in the 'Work to Home' model, indicating that carpool trips from work to home are less likely to occur, and it is hypothesized that there are fewer opportunities for casual carpooling from work to home than there are from home to work. For non-work trips, this variable is significant and positive in both directions of the trip except for trips returning home during a.m. peak period where it is negative owing to the fact that carpooling is usually not an option from a non-home non-work location.
- **Bridge Dummy –** If a trip is made using one of three bridges in the Puget Sound region (namely Tacoma Narrows, I-90, and SR 520), then this variable is equal to one; and, if not, it is zero. In the 'Home to Work' model, this coefficient was significant and positive in the am peak period, indicating that there is a higher likelihood that trips across the bridge will be made during morning peak hours solely for work-related purposes. These coefficients were more significant in the midday and pm peak periods of the 'Work to Home' model indicating a higher likelihood of trips across bridges in the reverse work commute direction. This variable was found to be significant and positive in the non-work models during the midday period indicating the propensity of non-work travelers to opt for uncongested periods to perform non-work activities.
- **Congestion Level –** The level of congestion or delay is measured by the difference in generalized cost (in minutes) for am, midday, pm, and evening time periods and the generalized cost for night time period. This variable is found to be negative and significant in all the models, indicating that delay affects travel decisions by time-of-day choice significantly. The size of the coefficient in the 'Home to Work' model is less negative than in the 'Work to Home' model, indicating a stronger negative effect on travel decisions for trips from work to home during the congested periods.
- **Shift Variables –** Two kinds of 'Shift' variables are computed, namely, 'Shift Early' and 'Shift Later', which measure the difference between the time period indicator (on a scale from 1 through 24 with 0.5 increments) and the midpoint of the first three time periods (am, midday and pm peak periods). 'Shift Early' is used when the time period indicator is less than the midpoint whereas 'Shift Later' is used when it is greater. The square of these variables also is used in the models to see the impact of very short and very long

delays on temporal choice behavior. During model estimation, these 'Shift' variables are multiplied by the delay variable as well as other variables to see the combined effect on time-of-day choice. The coefficients for the delay variables multiplied by 'Shift Early' and 'Shift Later' are significant and positive while on the other hand these are negative when multiplied by the square of 'Shift Early' and 'Shift Later'. This indicates that there is more likelihood of travelers switching their time choice when undertaking trips that might generate either very short or very long delays.

For each time period (am peak, midday, pm peak, and evening) the delay is equal to the generalized time for that period minus the generalized time for the night period, with a minimum value of 0 (no negative delays). There was a problem in application with delays much greater than 20 minutes, which only occur for cross-sound trips. But, the estimation data did not include delays in this range, and the peak-spreading functions were too sensitive for large delays. As a result, we dampened delay values so they have less impact in the models for high values, based on the following formula:

D' = 3.557 * D^0.489

Where D is the originally calculated delay value.

These revised delay values are only used in the peak shift variables. For the other delay variables that apply to entire large time periods (am peak, midday, pm peak, and evening), the models are not as sensitive, so using the unadjusted delay values was reasonable.

4.5 THROUGH TRIPS

Through trips are those trips that begin and end outside the region, but travel through the region at some point. These trips were originally created from an origin-destination survey conducted in 1961, and then updated in 1971 during a model update process. Since that time, the external trips have remained reasonably constant, while the overall traffic at external stations has grown. Table 63 presents a summary of the through trip table.

Table 63. Through Trips

TAZ	External Location	Productions	Attractions	Total Through Trips	% of External Trips
3733	I-5 to Olympia	1261	1986	1624	1.2%
3734	SR 507 to Yelm	51	50	51	0.2%
3735	SR 7 to Morton	27	25	26	0.8%
3736	SR 706 to Longmire	27	21	24	0.9%
3737	SR 123 S. of Cayuse Pass	53	79	66	4.0%
3738	SR 410 E. of Cayuse Pass	109	161	135	17.1%
3739	I-90 @ Snoqualmie Pass	853	856	855	2.2%
3740	SR 2 to Stevens Pass	409	604	507	16.8%
3741	SR 92 to Monte Carlo	0	164	82	2.9%
3742	SR 530 N. of Darrington	191	44	118	5.3%
3743	SR 9 N. of Arlington	215	63	139	5.1%
3744	I-5 to Mount Vernon	1614	1481	1548	2.4%
3745	SR 530 N. of Stanwood	26	50	38	0.3%
3746	SR 532 to Camano Island	26	9	18	0.1%
3747	Ferry to Whidbey Island	65	58	62	0.8%
3748	Hood Canal Bridge	952	169	561	2.5%
3749	SR 3 to Belfair	45	100	73	0.3%
3750	SR 302 to Shelton	57	61	59	0.9%
Total		5981	5981	5986	1.5%

4.6 SUMMARY RESULTS

Table 64 provides a summary of the trips by time period. These trips are used as input to trip assignment which impact mode choice and trip distribution.

Table 64. Share of Trips by Time of Day

Time of Day	Observed	Model
AM Peak Period	18%	14%
Midday Period	35%	38%
PM Peak Period	26%	23%
Late Evening Period	16%	21%
Overnight Period	6%	5%
Total	100%	100%

Trip Assignment

5.0 INTRODUCTION

The trip assignment model is the last of the four primary model components identified as part of the four-step modeling process. The trip assignment model estimates the volume on each link in the transportation system for both highway and transit modes. In addition, the trip assignment model generates specific performance measures, such as the congested speed or travel time on a highway link or the boardings and alightings on a transit route. Trip assignment is performed separately for each mode (auto and transit) and time period (am peak, midday, pm peak, evening, and night).

There are two primary objectives to using the trip assignment model. The first objective is to assign trip tables and produce measures of impedance for both trip distribution and mode choice models. The second objective is to assign the trip tables and produce volumes for auto and transit networks. These are described separately in the following sections. The remainder of this section describes the trip assignment model in detail.

Changes made with Puget Sound 4K Model

There were a few changes made between the PSRC Model Version 1.0bb and the Puget Sound 4K Model implementation in respect to the trip assignment models. These changes include:

- Inclusion of an estimate of intersection delay for arterials throughout the region.
- Inclusion of the bus vehicles on the highway links in the vehicle assignment.
- Capacity constrained transit assignments are no longer used in 4K.

5.1 TIME PERIODS

The trip assignment model is applied separately for each of the five time periods, which supports the three primary objectives of producing impedance measures, producing volumes by mode and to produce data for the time-of-day model. The following list describes the five time periods and uses for generating impedance measures and volumes:

- A.M. Peak assignments are used to produce both impedance measures and volumes by mode. Three-hour trip tables are assigned using an hourly factor of 0.350 and one-hour capacities to estimate volume and delay for the networks.
- Midday assignments are used to produce both impedance measures and volumes by mode. Six-hour trip tables are assigned using an hourly factor of 0.184 and one-hour capacities to estimate volume and delay for the networks.
- P.M. Peak assignments are used to produce both impedance measures and volumes by mode. Three-hour trip tables are assigned using an hourly of 0.350 and one-hour capacities to estimate volume and delay for the networks.

- Evening assignments are used to produce volumes by mode. Four hour trip tables are assigned using an hourly factor of 0.354 and one-hour capacities to estimate volume and delay for the networks.
- Night assignments are used to produce volumes by mode. Eight-hour trip tables are assigned using an hourly factor of 0.255 and one-hour capacities to estimate volume and delay for the networks.

For mid-day, evening, and night the hourly factors reflect the portion of each time-period's trips that occur during the highest-volume hour. The free-flow travel time is required as input to each of the time period assignments

5.2 HIGHWAY IMPEDANCE

Highway measures of impedance include travel time for each time period. The parameters used to develop these assignments are described in the following section of this report.

Highway travel time is comprised of three components:

- In-vehicle travel time for each origin-destination zone pair
- Terminal time for each origin zone
- Terminal time for each destination

The in-vehicle travel times are measured in minutes and estimated as a function of free-flow travel time and volume delay. Delay is determined as a function of the volume to capacity ratio for the time period being estimated. These functions are described in the Highway Assignment portion of this section.

Terminal times represent the time it takes to travel from one's origin to one's vehicle and from one's vehicle to one's final destination. This would typically be higher in denser urban areas, where it is necessary to park further away from the final destination. Terminal times are fixed by traffic analysis zone and range from one to six minutes for internal zones, and are set at 30 minutes for external zones. They are a function of area type.

Intra-zonal travel times cannot be calculated in the same way because the modeled trips do not use the roadway network and the time within a zone would be calculated as zero. As a result, intra-zonal travel times are calculated as follows:

Intra-zonal Time = 60 min/hr * average-intra-zonal-trip-length / speed

Where:

Average-intrazonal-trip-length (in miles) = 0.75 * SQRT (area (in sqmi))

Speed is in miles per hour.

For mode choice, AM and PM auto generalized costs and times are averaged in order to consider the return trip when calculating mode shares. For instance, autos traveling south on

the Narrows Bridge will pay $3.00, while autos traveling north will pay nothing. The average "bidirectional" cost per trip is $1.50.

Travel Cost and Values of Time

The highway assignment model relies on separate estimates of values-of-time in the calculation of generalized costs, which serve as the basis of the skimming and path-building. Since the model system uses the assigned network generalized costs as inputs to trip distribution, mode choice, and time-of-day modeling, the assumed value-of-time in the highway assignment affects the model system in many ways. Based on a review of local and regional research connected with value of time, we reached the following conclusion on the consistency of the value of time in the model system:

- Recent research on auto travelers with access to toll facilities indicates that auto travelers' values-of-time in making route choices is significantly higher than the values-of-time measured in mode choice models. Therefore, it is reasonable that the PSRC highway assignment generalized costs be based on different values-of-time than the mode choice model's time values.

The value of time assumed for route and mode choice are highlighted in Table 65. The VOT for HOV vehicles varies by time of day and is based on the relative share of work and non-work trips using the HOV modes by the models five time periods.

Table 65. Value of Time Comparison between Mode Choice and Route Assignment

Trip Purpose	Mode Choice Model	Assignment Models
HBW Income #1	$3.75	$12.10
HBW Income #2	$5.00	$22.30
HBW Income #3	$6.52	$32.61
HBW Income #4	$8.33	$42.25
Nonwork SOV	$6.00	$19.80
HOV 2	$6.00	$24.39 - $38.22 (varies by TOD)
HOV 3+	$6.00	$26.91 - $48.00 (varies by TOD)
Vanpools	n/a	$74.07 - $127.66 (varies by TOD)
Light Trucks	n/a	$50.42
Medium Trucks	n/a	$57.14
Heavy Trucks	n/a	$63.16

5.3 TRANSIT IMPEDANCE

Transit impedance is measured in components of travel time and number of boardings. Transit travel time is estimated for the same peak and off-peak conditions as the highway travel times, using am peak period and midday assignments. Transit travel impedance is comprised of seven components:

- In-vehicle travel time
- Auxiliary travel time for both access and egress combined
- Total wait time
- Boarding time for transfers
- Initial wait time
- Number of boardings
- Total transit time

These measures are calculated separately for the two primary modes of transit: 1) walk access; and 2) auto access. There are a series of parameters that will affect the development of transit travel times presented in Table 66. These reflect constraints on travel time (such as the maximum time to wait), as well as factors that account for different perceptions of time (such as the difference in perception between time spent waiting for a bus compared to time spent riding a bus). Travel surveys have shown that time spent waiting for a transit vehicle is more onerous that time spent riding on a transit vehicle.

Table 66. Transit Travel Time Parameters

Parameter	Value
Maximum Effective Headways	no set maximum
Boarding Time	4 minutes
Wait Time Weight	0.5
Auxiliary Time Weight	2.0
Boarding Time Weight	1.0

There is no longer a capacity constrained process for transit assignments. The waiting time at a given transit stop is based on the combined frequency of the routes that serve a particular origin and destination. This provides lower waiting times for areas with frequent service to account for the fact that travelers will choose to board the first bus that arrives (assuming it serves the travelers destination).

Time spent walking to access, transfer, or egress from the transit system is determined using a walking speed of three miles per hour and the distance along the links used. This includes distances on centroid connectors to begin or end the trip.

Park-and-Ride (Auto Access to Transit)

Auto access to transit trips is distributed to various park-and-ride lots based on the combined auto and transit travel times. Auto access utilities are determined using a function of the highway travel time, as follows:

*Auto Access Utility = exp (-0.199*Highway Time)*

This will, in effect, encourage travelers to choose park-and-ride lots closer to the origin of the trip with good transit service rather than choosing park-and-ride lots closer to the destination of the trip. Transit in-vehicle utilities for drive-to-transit trips are determined using a similar function, as follows:

*Transit In-Vehicle Utility = exp (-0.034*Total Transit Time)*

Travel time for these drive-to-transit trips is then determined by the sum of the auto access time to a particular park-and-ride lot and the transit in-vehicle time to the destination. The path is determined by isolating the first part of the trip from the origin to the park-and-ride lot, and the second part of the trip from the park-and-ride lot to the destination, and then merging these into a single trip record. This is an application of Matrix Convolutions in the EMME software.

5.4 HIGHWAY ASSIGNMENT

The highway assignment uses an equilibrium procedure to assign carpool and non-carpool trips to the roadway network for different time periods. This is a user optimal procedure that is based on the assumption that each traveler chooses a route that is the shortest time path. The highway assignment is performed in the Emme software and utilizes the gradient based path analysis.

Vehicle Classes

There are 11 classes of trips assigned in the multi-class assignment, based on mode, income group, trip purpose and vehicle type, as follows:

- Home-Based Work Single-Occupant Vehicle (SOV) in each of four income groups and separately for non-work SOV (s);
- All 2-person carpools (h);
- All 3+ person carpools (i);
- All vanpools (j);
- Light trucks (v);
- Medium trucks (u); and
- Heavy trucks (t).

The first five classes of trips are all SOV, based on the income group and purpose designation listed above. The remaining classes are based on vehicle type and mode.

Volume-Delay Functions

The highway assignment procedure is applied in an iterative fashion, where travel times are updated after each iteration to reflect congestion occurring on the network. These updates to travel time are based on a volume-delay function for each link, which is presented in Table 67. The majority of roads use a derivative of the volume-delay function originally developed by the Bureau of Public Roads (BPR). The free-flow time is based initially on the network data provided for each link and then updated in each iteration to represent the travel time from the last iteration. This process continues until "equilibrium" is reached, based on achieving one of the following criteria:

- The best relative gap is less than 0.01% (0.001). This is the difference between the current assignment and a perfect equilibrium assignment.
- The normalized gap or trip time difference is less than 0.001. This is the difference between the mean trip time of the current assignment and the mean minimal trip time.

Table 67. Volume Delay Functions

Volume-Delay Function	Definition	Function
fd 9	Centroid Connectors	Congested Time = (length * 60) / Free-Flow Speed
fd 1, 11	Freeways	Congested Time = Free-Flow Time * (1 +0.72 * (TPF*(Volume/Capacity))$^{7.2}$
fd 3	Expressways	Congested Time = Free-Flow Time * (1 +0.56 * (TPF*(Volume/Capacity))$^{6.0}$
fd 5	Urban Arterials	Congested Time = Free-Flow Time * (1 +0.60 * (TPF*(Volume/Capacity))$^{5.8}$
fd 7	Rural Arterials	Congested Time = Free-Flow Time * (1 +0.60 * (TPF*(Volume/Capacity))$^{5.6}$
fd 31,32	Auto Ferry Delay	Congested Time = Free-Flow Time/2 + 10 + [(TPF*Volume/Lane Capacity) / Lanes – 1] * (60/Lanes)
fd 40	Auto Ferry Crossing Link	Congested Time = Free-Flow Time/2

All volume-delay functions use a time period factor (TPF) to convert daily volume to capacity ratios to time period specific ratios. The time period factors used for all modes are as follows:

Table 68. Time Period Factors for Highway Assignment

A.M Peak	Midday	P.M. Peak	Evening	Night
0.350	0.184	0.350	0.354	0.255

The terminal wait links associated with ferries have a different volume-delay function associated with them to account for the additional time spent waiting for a ferry. This volume-delay function is applied to specific links coded with a volume-delay function (VDF) of 31 and 32. The other ferry links that have volume-delay function of 40, the total free-flow time is used to compute congested travel times.

Turn Penalties

Turn penalties are included in the trip assignment model to either prohibit certain turn movements or to penalize certain turn movements. Examples of different types of turn penalty functions are listed in Table 69. These are included in the model by identifying specific turn movements by their node numbers, and then coding the penalty function that will apply to these turn movements. The current model includes turn penalty functions to prohibit turns that cannot be made under "real world" conditions and to prohibit direct access from interchanges to HOV lanes where direct access ramps do not exist.

Table 69. Turn Penalty Functions

Penalty Function	Definition	Function	Range of Delay
tp 1	Fixed Delay	Turn Delay = Delay/100	0.1-1.5
tp 2	Prohibited Turns	Turn Delay = 0	0