The Updated Whatcom Model

Project Final Report Draft

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The Whatcom Council of Governments

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Introduction

The Whatcom Council of Governments (WCOG) in Washington State initially undertook the development of a regional travel demand model for Whatcom County in order to support countywide planning applications and to provide necessary model data to support the Cascade Gateway travel demand model. The Whatcom County regional travel demand model was developed initially by Cambridge Systematics Inc., using a countywide network and county-level analysis zones. This model was built for the 2000 base year and was being used by WCOG and other local entities to complete regional and sub-regional forecasting and analyses for purposes, including growth management planning, transportation planning, project prioritization, and analyses of build out scenarios.

The Whatcom County regional travel demand model estimates passenger demand from socioeconomic and network data developed for both existing conditions and future year forecasts. The original model was estimated using the National Household Travel Survey (NHTS) data on travel behavior and identifies demand throughout Whatcom County by trip purpose; origin-destination patterns; temporal variations (time of day, day of week, and seasons); and local routes for all passenger demand.

The WCOG regional travel demand model was originally constructed within the Emme/2 software framework. While this model provided adequate service with respect to the analysis of travel patterns within the county, it became apparent to WCOG staff that the software platform could not entirely meet the goals of a fully integrated GIS-based travel demand modeling program. Further, enhanced functionality within a more user-friendly software modeling environment became an important priority with the advent of recent advances in technology. After careful evaluation by the county staff, the TransCAD software platform was chosen to host the WCOG regional travel demand model in 2008. Subsequently, Caliper Corporation transferred the model to the TransCAD platform.

The Whatcom council of governments also acquired access to the 2008 North Sound Travel Survey data put together by NuStats for the three county regions of Whatcom, Skagit and Island counties. The WCOG then contacted Caliper to re-estimate the travel demand model components using the recent survey data, update the base year to 2008 and create a well calibrated model that the WCOG could confidently use to pursue the aforementioned goals of the regional model.

The model stream described in this document also represents a fresh start in terms of the modeling procedures as well. In this model update, the entire modeling process is based on data provided in the survey. Using the survey in its entirety, models for Trip Generation, Trip Distribution, Mode Choice, Time of Day Analysis, and Traffic Assignment were estimated. The functionality of the model has also been greatly enhanced in many areas. One notable area is in the estimation of models for four time periods (AM Peak, PM Peak, Mid-day, and Night) throughout the typical fall weekday, providing the Whatcom Council of Governments with the ability to analyze potential infrastructure (highway and transit) projects in the context of the time period most affected.

Another advantage in the choice of TransCAD platform is the inherent interactive nature of the software. Routine analysis using complex model utilities such as select link analysis and subarea analysis can be completed by Whatcom staff quickly and interactively, without the need to hire outside consultancy services or hours of programming as in the previous model platform. Included with the delivery of this model, is a customized user interface that automates the planning process through the use of a macro. This interface also includes a scenario manager that enables the user to manage alternatives by providing immediate access to the input and output files used by the model.

Caliper Corporation is pleased to deliver this model to Whatcom and to continually support them in its application to ensure success. Please do not hesitate to contact us with any concerns or questions regarding the model's structure or assumptions. We are also delighted to have worked closely with Whatcom staff, especially Andres Gomez, in delivering a product that we believe all of us can be satisfied with. The calibration of this model and its integrity with respect to replicating the survey is at the highest level.

Model Framework

A flowchart showing the model process for the updated Whatcom model is shown in Figure 1.1

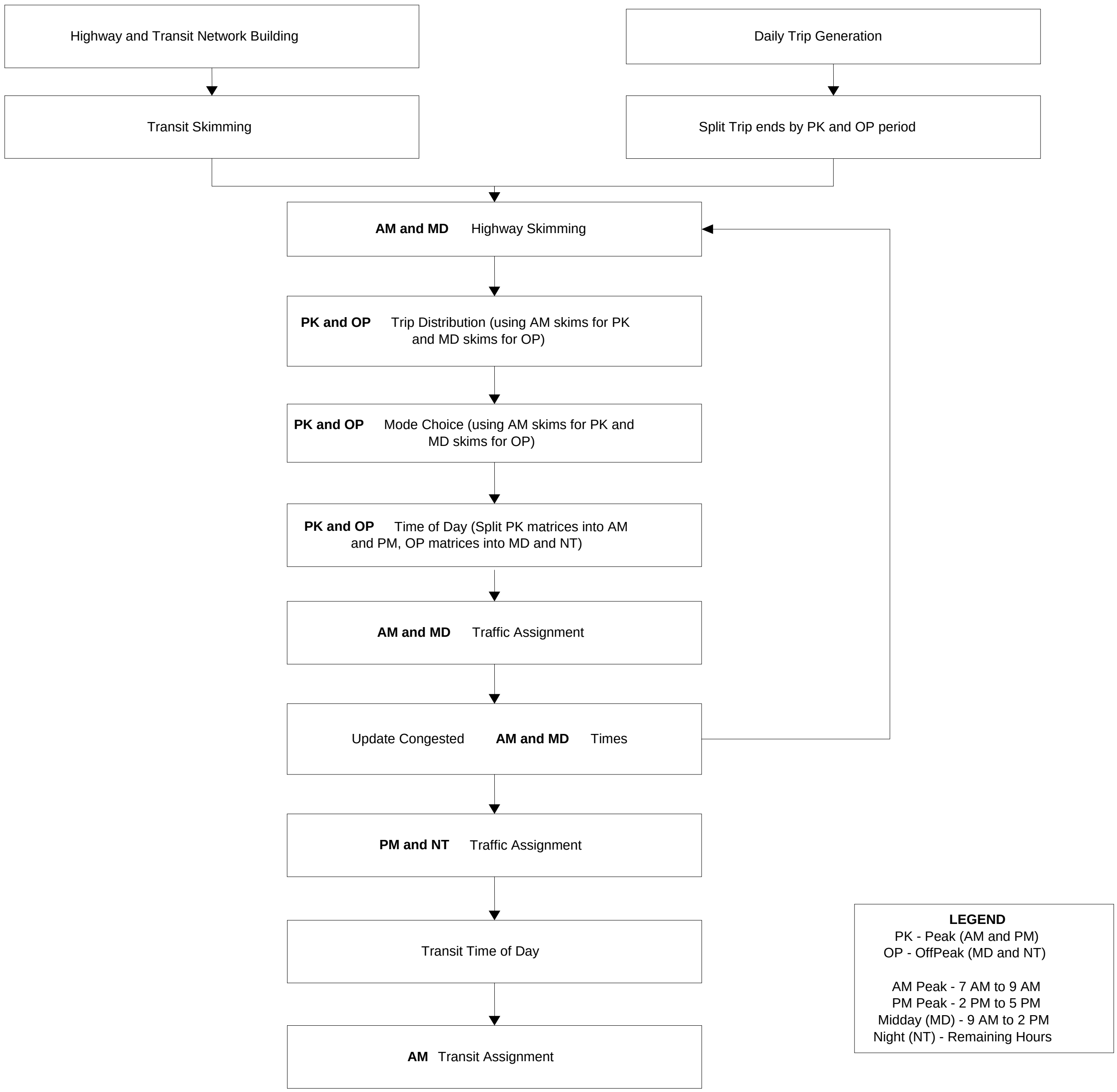

Figure 1.1: Whatcom Model Flowchart

The model was developed based on the Tri-County Travel Survey comprising of Whatcom, Island and Skagit counties and is an update of the previous version on the Planning model. The model is a traditional four-step travel demand model, with time of day components and with a feedback loop structure. A brief summary of the processes in the model are described below:

The highway and transit **initialization routines** process the highway and the route system database. The highway database is processed to make sure that link functional classes, area types and lanes are present for all the links. Based on a lookup table, the link free flow speeds, link capacities and the attributes for the Volume Delay function are filled in.

Links designated for walk are marked in the database and link walking times are computed.

The Route System is attached to the current line layer and transit times on the network links are computed. Transit skims for the AM and the Midday (MD) periods are computed based on the Pathfinder algorithm.

The **Trip Generation** algorithm predicts daily productions and attraction by trip purpose. Eight trip purposes are considered in the model (Home Based Work, Home Based College, Home Based School, Home Based Shop, Home Based Other, Non Home Based Work, Non Home Based Other and Truck Trips). For the Home based trip purposes, the trip production ends are deemed to be the home zones and trip attraction ends are deemed to the non-home zone. For the Non Home Based purpose, the trip production is the origin end and the trip attraction is the destination end. The trip productions are based on household trips and the trip attractions are based on employment and enrollment estimates.

Daily Trip Productions rates for the Home Based Work (HBW) purpose are based on the number of workers in the household, the income level of the household, and on the Household or residence region. Daily Trip Production rates for the Home Based Non Work purposes are based on the household size, on the household income type and on the household residence region. The trip making characteristics were found to be different in Bellingham, WA as compared to the rest of the region. Localized variations in the rest of the region were also considered. Trip Production rates for the Non-Home Based purposes and Daily Trip Attractions rates are based on employment by NAICS code (office, industrial, retail, arts employment etc.), school enrollment (for school trips), college enrollment, households and household population. Special generators were added for primary shopping mall areas or zones with high retail employment.

Truck Productions and Attractions were not separately developed and the truck models were obtained from the earlier version of the Whatcom Model.

The daily trip productions and attractions are split into Peak (PK) and Off-Peak (OP) productions and attractions by using splits for each purpose obtained from the survey. The PK period comprises of the AM and the PM peaks and the OP period comprises of the Midday (MD) and

Night (NT) periods. External trips are added to the PK and OP trip productions and attractions. Finally, trip balancing is performed for the PK and the OP Production and Attraction tables.

The **Highway Skimming** Process generates estimates of zone to zone travel times for the AM and the MD time periods. The link travel times input to the procedure are read from congested AM and MD time fields in the highway database. In the case of a feedback run, free flow times may be input for use in the first iteration.

The **Trip Distribution** is a doubly constrained gravity model and is applied to generate PK and OP Production Attraction matrices. During the model application, the AM skims are used as a proxy for the PK skims and the MD skims are used as a proxy for the OP period. Gamma Friction factor curves calibrated from the survey are used as inputs to the process.

The **Mode Choice** routine is likewise applied to the PK and OP trip distribution PA matrices. The mode choice is a Nested Logit Model (NLM), with one model developed for each period (PK or OP) and each purpose, excepting the truck purpose. In addition to the TAZ database, the PK mode choice model utilizes AM highway and transit skims and the OP mode choice model utilizes MD highway and transit skims. Several modes are considered during the process including Drive Alone, Carpool, Walk, Bike and Transit modes. The mode choice procedure returns Production-Attraction (PA) trips by purpose, period and mode.

The **Time of Day** procedure is used to further split the PK mode choice output matrices into AM and PM matrices and to split the OP mode choice output matrices into MD and NT matrices. The procedure also converts person trips to auto trips and converts the PA matrices into OD matrices. The time of day procedure yields Auto and Truck OD matrices by the four sub-time periods (AM, PM, MD and NT). Likewise, the transit time of day component (that is outside the feedback loop) generates AM, PM, MD and NT transit OD matrices. External highway trips are added to the Auto/Truck modes.

The **Traffic Assignment** within the feedback loop process assigns the AM and the MD trips onto the network. The assignment is based on the Origin User Equilibrium method using the BPR (Bureau of Public Roads) function. The assignment generates congested AM and MD link travel times.

In order to achieve model consistency, there is a **feedback** component in the model, wherein the congested AM and MD link travel times are used to re-compute highway skims and re-run the trip distribution, mode choice, time of day and traffic assignment. This process is shown by the feedback arrow in the model. The feedback loop can be run until a fixed point solution is obtained. Note that transit skimming is not part of the loop.

Finally, the PM and MD traffic assignments and the transit assignment for all the periods are run.

Chapter 2: Determination of Survey Weights for the North Sound 2008 Travel Survey

The updated Whatcom model for the base year 2008 was calibrated based on the 2008 North Sound Travel Survey. The North Sound Travel Survey 2008 is comprised of data from Whatcom, Skagit and Island counties in Washington State. These expansion weights typically are required so that the survey can be expanded to match the characteristics for the survey region. Critically, these weights are used in the estimation of trip generation, trip distribution, mode choice and time of day models. The availability of survey weights or expansion factors, especially for household records in Whatcom County, is critical.

However, the survey provided to Caliper Corporation had a generic expansion factor that was provided for all the records by NuStats. These expansion factors were not different by county, local regions or by household demographic market segments. In general, expansion factors that vary by region and demographic market segments greatly improve estimation of trip generation, trip distribution, mode choice and time of day models and improve the accuracy of the model. The objective of this task was hence to come up with a set of weights for the survey Household database so that the survey is representative of all the households in the three-county region and which would yield better estimation results.

Survey Background

The North Sound Travel Survey data was conducted by NuStats, a survey research firm that designed, executed, and analyzed the survey data. The 2008 North Sound Household Travel Survey collected data from a total sample of 1,500 households between July and December 2008. A socioeconomic stratification was used to define the sample of households to ensure that the study captured the diversity of the population according to specific factors affecting travel behavior in the three-county region. The stratification scheme was based on two household characteristics:

- Household Size – Total number of persons in the household (1, 2, 3, 4+ persons), and
- Household Income Level – Total annual household income from 2007.

The survey consisted of 750 households in Whatcom County, 385 in Skagit County and 366 in Island County. The number of households in the survey was proportional to the total number of households based on the Census 2000 estimates.

Further, an attempt was made to stratify the survey as per the household size and income splits for each county. The socioeconomic splits were obtained from the 2006 American Community Survey (ACS) data which were projected to 2008. The projections are reproduced below:

Household Income	Whatcom – Household Size				Total
	1	2	3	4+	
Less than $25,000	17.9%	5.4%	1.3%	3.4%	27.8%
$25,000–$49,999	7.3%	12.8%	2.5%	4.4%	27.0%
$50,000–$74,999	1.8%	7.3%	4.2%	4.8%	18.1%
$75,000 or more	1.6%	11.6%	5.9%	7.9%	27.0%
Total	28.6%	37.1%	13.8%	20.5%	100.0%
Household Income	Island and Skagit – Household Size				Total
	1	2	3	4+	
Less than $25,000	13.2%	5.8%	0.8%	2.1%	22.0%
$25,000–$49,999	8.2%	9.9%	3.3%	5.1%	26.5%
$50,000–$74,999	3.7%	11.4%	2.4%	4.7%	22.3%
$75,000 or more	2.8%	13.4%	6.2%	6.9%	29.3%
Total	27.9%	40.5%	12.7%	18.8%	100.0%

Table 2.1 – Household Stratifications Source: 2008 North Sound Travel Survey Final Report

Due to the varied response rate, however, some of the above targets in terms of the number of households could not be met as documented in the 2008 North Sound Travel Survey Report.

Weighting Methodology

The stratification scheme that was used to design the survey presents a natural methodology to weight the survey records. For the purposes of developing a travel demand model for Whatcom County, a secondary objective can be to match the number of households within each sub-region of Whatcom County.

Additionally, we were provided with 2008 Land Use Data by the Whatcom Council of Governments that contained for each TAZ in Whatcom County the household stratifications by household size and household income and household stratifications by number of workers in the household and household income. It is conceivable that the latest 2008 land use estimates are fairly representative at the aggregate level and hence this data can potentially be used to augment the weights.

The following sections present the attempted weighting mechanism for Whatcom County and Skagit/Island County records.

Whatcom County Survey Records – Weighting Scheme

Based on the available data and the survey design objective, we developed a couple of methods to perform the weighting for Whatcom county survey records.

Method 1

The first method uses the NuStats target percentages by household size and household income (based on the projected ACS 2006 data) to come up with an initial set of weights for Whatcom County records. Then based on the total Household numbers for sub-regions in Whatcom County, the initial weights are adjusted. The mechanism is illustrated below:

Whatcom County household records in the survey were tabulated by household size and income and the number of survey records in each category was determined. The number of households in each category was calculated using the total households in the region and category splits based on the projected 2006 ACS data. This was divided by the number of records in the survey to produce an initial weight. These initial weights are shown in the Table below:

HHSize	Annual HH Income	Num Records In Survey	Pct HH ACS 2006	Projected HHs ACS 2006	HH Weight
1	**< 25K**	58	17.9	13,353	**230.22**
1	**25K-50K**	78	7.3	5,445	**69.81**
1	**50K-75K**	19	1.8	1,343	**70.67**
1	**>75K**	16	1.6	1,194	**74.60**
2	**< 25K**	26	5.4	4,028	**154.93**
2	**25K-50K**	87	12.8	9,548	**109.75**
2	**50K-75K**	112	7.3	5,445	**48.62**
2	**>75K**	135	11.6	8,653	**64.10**
3	**< 25K**	3	1.3	970	**323.25**
3	**25K-50K**	24	2.5	1,865	**77.70**
3	**50K-75K**	37	4.2	3,133	**84.68**
3	**>75K**	36	5.9	4,401	**122.25**
4+	**< 25K**	3	3.4	2,536	**845.41**
4+	**25K-50K**	23	4.4	3,282	**142.70**
4+	**50K-75K**	47	4.8	3,581	**76.18**
4+	**>75K**	46	7.9	5,893	**128.11**

Table 2.2: Initial Weights for Whatcom County

In the above table for example, the percentage of one person households with an income less than 25,000 dollars is 17.9% or 13,353 out of 74,670 households in Whatcom County. The survey has 58 records in this category, thereby yielding a weight of 13353/58 or 230.22. Note that the total number of households for Whatcom County is 74,670 based on the 2008 Land Use data provided by WCOG.

The second step to adjust the weights for each sub-area of the region. For this purposes, the Metropolitan County Division (MCD) database was used to define the sub-areas. Each household record in the database was tagged to the MCD to which it belonged using TransCAD's GIS capabilities. Similarly, each TAZ record was tagged to the corresponding MCD. A theme showing the MCD sub-areas for the Whatcom County is shown in Figure 2.1 below. The legend indicates the nine sub-regions along with a number that indicates the number of TAZs that fall within the MCD. The nine sub-regions are:

Bellingham, WA (276 TAZs)
Ferndale, WA (140 TAZs)
Blaine, WA (137 TAZs)
Lynden, WA (60 TAZs)
East Whatcom, WA (18 TAZs)
Sumas, WA (46 TAZs)
Lummi Reservation, WA (9 TAZs)
Lummi Island, WA (1 TAZ)
Point Roberts, WA (1 TAZ)

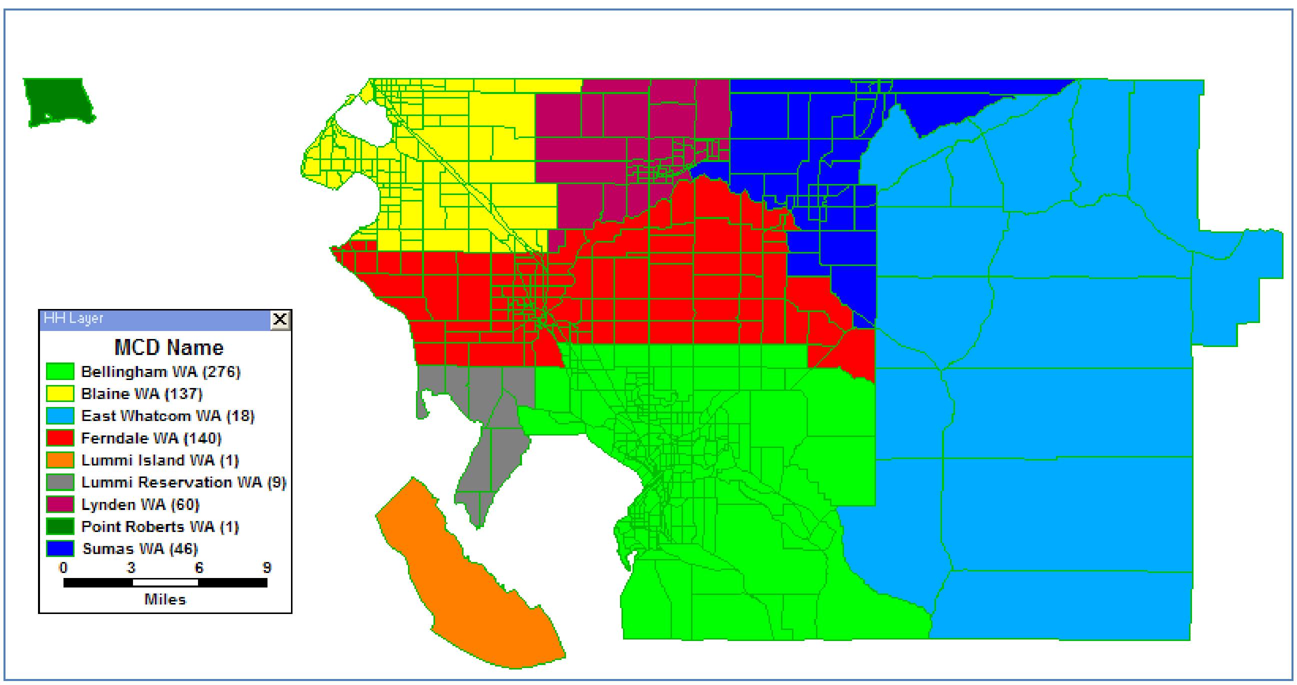

Figure 2.1: MCD Sub-Areas for Whatcom County

The land use data for the year 2008 was then aggregated to provide estimates of the total households in each of the nine sub-regions. One issue, however, is that the survey does not contain households in certain categories for specific regions. For example, there are no one person households with income between 50,000 and 75,000 dollars in the survey for the Blaine MCD region. Thus, while computing control household totals for each sub-region from the land use data, care has to be taken to not include households that have no representation in the survey.

The weights developed using the ACS percentages by household size and income was then adjusted for each of the nine sub-areas to match the total number of households to match the control totals.

The final weights developed using this approach match the sub-region totals and also adhere to the ACS 2006 stratifications by household size and income. Tables 2.3 and 2.4 illustrate this. Note that in table 3, the sub-region target is adjusted to account for certain stratifications that do not exist in the survey. Thus the total number of target households is 70,356 as opposed to 74,670.

Sub Region	Number TAZs	Number HH Landuse 2008	Number HH from survey (using Weights)
Bellingham	276	43,327	43,327
Ferndale	140	9,412	9,412
Blaine	137	5,877	5,880
Lynden	60	4,866	4,863
East Whatcom	18	3,859	3,858
Sumas	46	2,004	2,000
Lummi Reservation	9	401	398
Lummi Island	1	283	279
Point Roberts	1	326	325

Table 2.3: Survey Weights Comparison for the sub-regions

HHSize	Annual HH Income	Pct HH ACS 2006	PCT HH using Survey with Weights
1	**< 25K**	17.9	**17.9**
1	**25K-50K**	7.3	**7.4**
1	**50K-75K**	1.8	**1.7**
1	**>75K**	1.6	**1.6**
2	**< 25K**	5.4	**5.6**
2	**25K-50K**	12.8	**12.4**

2	**50K-75K**	7.3	**7.2**
2	**>75K**	11.6	**11.7**
3	**< 25K**	1.3	**1.3**
3	**25K-50K**	2.5	**2.6**
3	**50K-75K**	4.2	**4.3**
3	**>75K**	5.9	**6.1**
4+	**< 25K**	3.4	**3.3**
4+	**25K-50K**	4.4	**4.1**
4+	**50K-75K**	4.8	**4.7**
4+	**>75K**	7.9	**8.1**

Table 2.4: Survey Weights Comparison with ACS 2006 projected data

This method for weighting provides a reasonable set of weights for the Whatcom county records. The caveat associated with this method is that the percentage splits by HHSize and Income from the land use data vary slightly from the percentage splits from the projected ACS 2006 data, which are themselves only estimates and subject to considerable sampling error. As a result, some of the totals for a specific household size and income category differ from those obtained from the 2008 Land Use database. Further, significant differences are found if the weights are summed for a given household size and income and for a specific sub-area (e.g a large MCD such as Bellingham) and then compared to the aggregated Land Use 2008 numbers.

Method 2, which is described in the next section attempts to remove these discrepancies. As will be discussed, a different set of weights were estimated using aggregate statistics from the 2008 Land Use database without using the ACS percentages. Further, the weighting was expanded to match other socio-economic characteristics as well.

Method 2

Method 2 uses aggregated statistics from the 2008 land use database entirely to determine the weights. The land use 2008 database contains the cross classification of households by income and size and also another cross classification based on household income and number of workers in the household. This rich classification can be used to develop a set of weights. The method relies on the fact that aggregated 2008 land use numbers by county (and by large sub-regions) are reasonably accurate.

The essential steps in the method are listed below and described in greater detail:

Obtain an initial set of weights that satisfy the percentage of households by household size and income for the entire Whatcom region.

Adjust the initial set of weights to match sub-region household totals for each of the nine sub-regions. This is only an additional step, since the final correction after the third step (below) automatically achieves this objective.

Generate a final set of weights using an iterative procedure. This is done by first adjusting the weights to match the household size by income categories and then subsequently adjusting the weights to match the household income by number of workers in the household. These dual adjustments are performed in a loop until a specific threshold is met. During the adjustment, care is taken to further ensure that cross classification totals for certain large sub-regions are also maintained. Optionally, a final weight adjustment to match the sub-region totals can be redone.

The **first step** in the process is similar to the previous method (Table 2), except that the percentages of households in each household size and income category for the entire county are obtained from the 2008 Land Use database. This is shown in Table 5. Also included in this table are the percentage splits from the projected 2006 ACS data that was used in the previous method. It can be seen that the percentage splits are different for a few categories such as for households with size 2 and income greater than $75,000, where the ACS estimate is 11.6% and the estimate from the 2008 Land Use database is 7.4%.

As noted earlier, there are no records in the survey for certain sub-regions for a specific cross classification. Thus, while computing the percentage splits for the weight calculations, the appropriate households in that cross classification for the sub-region were not included. Therefore, it can be seen that the total of the Households from the Land Use 2008 database in the table below add up to 70,356 and not 74,670.

HHSize	Annual HH Income	Num Records In Survey	Pct HH ACS 2006	Pct HH Landuse 2008	Projected HHs Landuse 2008	HH Weight
1	**< 25K**	58	17.9	**16.8**	11,849	**204.28**
1	**25K-50K**	78	7.3	**8.2**	5,784	**74.16**
1	**50K-75K**	19	1.8	**1.7**	1,176	**61.90**
1	**>75K**	16	1.6	**1.2**	870	**54.38**
2	**< 25K**	26	5.4	**9.1**	6,417	**246.82**
2	**25K-50K**	87	12.8	**12.7**	8,960	**102.99**
2	**50K-75K**	112	7.3	**7.7**	5,399	**48.21**
2	**>75K**	135	11.6	**7.4**	5,221	**38.68**
3	**< 25K**	3	1.3	**2.0**	1,393	**464.35**
3	**25K-50K**	24	2.5	**5.1**	3,622	**150.92**
3	**50K-75K**	37	4.2	**3.5**	2,455	**66.35**
3	**>75K**	36	5.9	**3.0**	2,093	**58.14**
4+	**< 25K**	3	3.4	**2.7**	1,875	**625.03**
4+	**25K-50K**	23	4.4	**7.0**	4,903	**213.18**
4+	**50K-75K**	47	4.8	**6.3**	4,450	**94.68**
4+	**>75K**	46	7.9	**5.5**	3,887	**84.50**

Table 2.5: Initial weights using the 2008 Land Use Database

The **second step** is to adjust the weights to match the total number of households in each of the 9 sub-regions. The control totals and method to adjust the weights are identical to those used in Method 1.

The **third and iterative step** is to re-adjust the weights to match cross classifications by household size and income and by household income and number of workers in the household. This is done as follows:

The land use data is tabulated by sub-region and by the household size and income classification. Likewise the survey records are tabulated using the latest estimate of the weights. For any of the major sub-regions (i.e. all regions except Lummi Reservation, Lummi Island and Point Roberts), the total households computed from the survey are compared with the total households from the land use database for a specific cross classification. If this difference is significant (based on a certain threshold or a percentage), then the weights for this sub-region and cross classification are adjusted. The adjustment procedure was done only if the number of households for that specific cross classification is greater than 500 and only if the absolute difference between the land use numbers and the aggregated weight exceeds 5%.

A similar procedure is done by tabulating the survey and the land use data by household income and number of workers in the household for each sub-region. Note that the land use data contains 4 income classes and 5 worker classes (i.e. HH with 0, 1, 2, 3 or 4+ workers).

The above two steps are run one after another in a loop. After a few iterations, the set of weights reasonably satisfy all the requirements.

A final adjustment is done for each sub-region to match the total sub-region totals.

A macro was written using GISDK to compute these final set of weights. The final weights satisfy the following objectives, when aggregated:

The percentage splits of households by income and household size for entire Whatcom County are met. This was also the key survey design objective.

The total number of households in each sub-region is met.

For any of the large sub-regions (such as Bellingham), the number of households for a specific household size and income are within 5% households of the aggregated Land Use numbers for the same category.

For any of the large sub-regions (such as Bellingham), the number of households for a specific household income category and number of household workers category are within 5% of the appropriate aggregated 2008 Land Use numbers. The results after several such loops are shown in the tables to follow:

Sub Region	Number TAZs	Number HH Landuse 2008	Number HH from survey (using Weights)
Bellingham	276	43,327	43,325
Ferndale	140	9,412	9,410
Blaine	137	5,877	5,880
Lynden	60	4,866	4,870
East Whatcom	18	3,859	3,860
Sumas	46	2,004	2,000
Lummi Reservation	9	401	400
Lummi Island	1	283	280
Point Roberts	1	326	325

Table 2.6: Survey Weights Comparison for the sub-regions

HHSize	Annual HH Income	Pct HH Landuse 2008	PCT HH using Survey with Weights
1	< 25K	16.8	17.2
1	25K-50K	8.2	8.9
1	50K-75K	1.7	1.6
1	>75K	1.2	1.2
2	< 25K	9.1	9.6
2	25K-50K	12.7	12.6
2	50K-75K	7.7	7.7
2	>75K	7.4	7.2
3	< 25K	2.0	2.0
3	25K-50K	5.1	4.6
3	50K-75K	3.5	3.4
3	>75K	3.0	2.8
4+	< 25K	2.7	2.7
4+	25K-50K	7.0	6.7
4+	50K-75K	6.3	6.8
4+	>75K	5.5	5.0

Table 2.7: Survey Weights Comparison by HHSize and Income

Num Workers In HH	Annual HH Income	Pct HH Landuse 2008	PCT HH using Survey with Weights
0	< 25K	15.4	15.9
0	25K-50K	7.1	7.3
0	50K-75K	2.2	2.2
0	>75K	1.2	1.2
1	< 25K	12.4	12.9
1	25K-50K	13.2	13.8
1	50K-75K	5.4	5.0

1	>75K	4.5	4.5
2	< 25K	3.1	2.6
2	25K-50K	11.0	9.8
2	50K-75K	10.0	10.3
2	>75K	8.2	8.5
3	< 25K	-	No representation in survey
3	25K-50K	1.3	1.3
3	50K-75K	1.3	1.3
3	>75K	1.6	1.4
4+	< 25K	0.2	0.2
4+	25K-50K	0.5	0.6
4+	50K-75K	0.7	0.7
4+	>75K	0.6	0.6

Table 2.8: Survey Weights Comparison by Num of Workers in HH and Income

Further, from tables 2.9 and 2.10, it can be seen that the aggregated weights also respect the cross classification for large sub-regions (especially Bellingham). Only classifications where the number of households in that classification is greater than 1000 are shown below.

Sub Region	HHSize	Income	Num HH Land Use 2008	Num HH using Survey Weights
Bellingham	1	< 25K	7,504	7,296
Bellingham	1	25K-50K	3,274	3,311
Bellingham	2	< 25K	4,237	4,383
Bellingham	2	25K-50K	4,986	4,792
Bellingham	2	50K-75K	3,033	3,116
Bellingham	2	>75K	3,075	3,110
Bellingham	3	< 25K	1,294	1,309
Bellingham	3	25K-50K	2,151	2,171
Bellingham	3	50K-75K	1,564	1,602
Bellingham	3	>75K	1,263	1,269
Bellingham	4+	< 25K	1,750	1,770
Bellingham	4+	25K-50K	2,822	2,760
Bellingham	4+	50K-75K	2,728	2,761
Bellingham	4+	>75K	2,272	2,266
East Whatcom	1	< 25K	1,063	1,228
Ferndale	1	< 25K	1,284	1,405
Ferndale	2	25K-50K	1,154	1,258

Table 2.9: Key Comparisons by Sub-region, HHSize and Income Classification

Sub Region	Num Workers	Income	Num HH Land Use 2008	Num HH using Survey Weights
Bellingham	0	< 25K	7,107	7,001
Bellingham	0	25K-50K	3,313	3,234
Bellingham	0	50K-75K	1,010	1,021

Bellingham	1	< 25K	5,901	6,127
Bellingham	1	25K-50K	5,594	5,533
Bellingham	1	50K-75K	2,329	2,450
Bellingham	1	>75K	2,088	2,047
Bellingham	2	< 25K	1,610	1,628
Bellingham	2	25K-50K	3,738	3,780
Bellingham	2	50K-75K	4,143	4,075
Bellingham	2	>75K	3,378	3,545
Blaine	1	25K-50K	1,041	1,031
East Whatcom	0	< 25K	1,000	1,044
Ferndale	0	< 25K	1,202	1,184
Ferndale	1	< 25K	1,007	992
Ferndale	1	25K-50K	1,295	1,275
Ferndale	2	50K-75K	1,139	1,108

Table 2.10: Key Comparisons by Sub-region, Num Workers and Income Classification

Skagit/Island County Weights

The Skagit/Island county regions are external to the Whatcom model and it is not necessary to develop weights that replicate the cross classification by sub-region and it sufficient to develop weights that respect the cross classification used to stratify the original survey.

Therefore, a simple weighting procedure is adopted that matches the region wide Household percentages by income and household size.

Household Income	Island and Skagit – Household Size				Total
	1	2	3	4+	
Less than $25,000	13.2%	5.8%	0.8%	2.1%	22.0%
$25,000–$49,999	8.2%	9.9%	3.3%	5.1%	26.5%
$50,000–$74,999	3.7%	11.4%	2.4%	4.7%	22.3%
$75,000 or more	2.8%	13.4%	6.2%	6.9%	29.3%
Total	27.9%	40.5%	12.7%	18.8%	100.0%

Table 2.11: Skagit/Island ACS 2006 projections by Income and HHSize

The number of projected households for 2008 for these counties (based on ACS 2007) data are 44,037 for Skagit County and 31,359 for Island County. For each county, based on Table 2.12, the number of households in each cross-classification can be determined and this divided by the number of corresponding records in the survey provides the weight. Tables 2.12 and 2.13 show the final weights developed for these counties:

HHSize	Annual HH Income	Num Records In Survey	Pct HH ACS 2006	Projected HHs ACS 2006	HH Weight
1	< 25K	29	13.2	5,813	**200.44**
1	25K-50K	37	8.2	3,611	**97.60**
1	50K-75K	16	3.7	1,629	**101.84**
1	>75K	10	2.8	1,233	**123.30**
2	< 25K	13	5.8	2,554	**196.47**
2	25K-50K	52	9.9	4,360	**83.84**
2	50K-75K	63	11.4	5,020	**79.69**
2	>75K	61	13.4	5,901	**96.74**
3	< 25K	0	0.8	352	**Not in Survey**
3	25K-50K	15	3.3	1,453	**96.88**
3	50K-75K	12	2.4	1,057	**88.07**
3	>75K	19	6.2	2,730	**143.70**
4+	< 25K	2	2.1	925	**462.39**
4+	25K-50K	18	5.1	2,246	**124.77**
4+	50K-75K	21	4.7	2,070	**98.56**
4+	>75K	17	6.9	3,039	**178.74**

Table 2.12: Weights for Skagit County Records

HHSize	Annual HH Income	Num Records In Survey	Pct HH ACS 2006	Projected HHs ACS 2006	HH Weight
1	< 25K	22	13.2	4,139	**188.15**
1	25K-50K	30	8.2	2,571	**85.71**
1	50K-75K	13	3.7	1,160	**89.25**
1	>75K	9	2.8	878	**97.56**
2	< 25K	11	5.8	1,819	**165.35**
2	25K-50K	46	9.9	3,105	**67.49**
2	50K-75K	77	11.4	3,575	**46.43**
2	>75K	62	13.4	4,202	**67.78**
3	< 25K	4	0.8	251	**62.72**
3	25K-50K	5	3.3	1,035	**206.97**
3	50K-75K	20	2.4	753	**37.63**
3	>75K	15	6.2	1,944	**129.62**
4+	< 25K	3	2.1	659	**219.51**
4+	25K-50K	8	5.1	1,599	**199.91**
4+	50K-75K	19	4.7	1,474	**77.57**
4+	>75K	22	6.9	2,164	**98.35**

Table 2.13: Weights for Island County Records

The final survey weights as per Method 2 above were used for the estimation of the travel demand model components. The final weights are populated in a field WeightFinal_LU in the survey database.

Chapter 3: Travel Analysis Zone (TAZ) Layer and Network Development

The network and TAZ data structures used in the updated model and described below refer to a 2008 Base Year.

TAZ Layer Development

The Whatcom county region is divided into 696 TAZs, including 8 external zones that permit flow into and out of the Whatcom region from various gateways such as from Canada in the north. Each TAZ contains detailed land use information provided by the Whatcom Council of Governments. These demographics are used to generate trip ends in the Trip Generation process. The 688 internal TAZs encompass numerous districts designated by metropolitan county divisions (MCDs) comprising of Bellingham, Ferndale, Lynden, Blaine, East Whatcom, Lummi Reservation, Lummi Island, Point Roberts, and Sumas. These districts form logical boundaries exhibiting similar travel behavior and exploited for this reason in various stages of the planning process. Further, these MCDs were used to develop weights for the travel survey described in Chapter 2.

Table 3.1 shows a summary of TAZ Structure by Metropolitan County Division:

MCD	NUMBER OF TAZs
Bellingham	276
Blaine	137
East Whatcom	18
Ferndale	140
Lummi Island	1
Lummi Reservation	9
Lynden	60
Point Roberts	1
Sumas	46
External Stations	8
TOTAL	***696***

Table 3.1: Number of TAZs based on Metropolitan County Divisions

The development of the TAZ database was completed by Whatcom staff. The TAZ boundaries are consistent with roadway geography, never bisected by major roadways, and generally exhibit homogeneous land use characteristics. Further, as expected TAZ boundaries tend to be smaller in the more densely populated regions of the county. TAZ boundaries are represented in the network using centroid nodes, which are connected to the main network via centroid connectors.

The demographics used in this model and calculated at the TAZ level are shown in Table 3.2 below. These fields are in the land use database file.

DEMOGRAPHIC NAME	VARIABLE
Low Income Households with no workers	0WLINC
Low-Medium Income Households with no workers	0WLMINC
Medium-High Income Households with no workers	0WMHINC
High Income Households with no workers	0WHINC
Low Income Households with 1 worker	1WLINC
Low-Medium Income Households with 1 worker	1WLMINC
Medium-High Income Households with 1 worker	1WMHINC
High Income Households with 1 worker	1WHINC
Low Income Households with 2 workers	2WLINC
Low-Medium Income Households with 2 workers	2WLMINC
Medium-High Income Households with 2 workers	2WMHINC
High Income Households with 2 workers	2WHINC
Low Income Households with 3 workers	3WLINC
Low-Medium Income Households with 3 workers	3WLMINC
Medium-High Income Households with 3 workers	3WMHINC
High Income Households with 3 workers	3WHINC
Low Income Households with 4+ workers	4WLINC
Low-Medium Income Households with 4+ workers	4WLMINC
Medium-High Income Households with 4+ workers	4WMHINC
High Income Households with 4+ workers	4WHINC
1 Person Low Income Households	1HHLINC
1 Person Low-Medium Income Households	1HHLMINC
1 Person Medium-High Income Households	1HHMHINC
1 Person High Income Households	1HHHINC
2 Person Low Income Households	2HHLINC
2 Person Low-Medium Income Households	2HHLMINC

2 Person Medium-High Income Households	2HHMHINC
2 Person High Income Households	2HHHINC
3 Person Low Income Households	3HHLINC
3 Person Low-Medium Income Households	3HHLMINC
3 Person Medium-High Income Households	3HHMHINC
3 Person High Income Households	3HHHINC
4+ Persons Low Income Households	4HHLINC
4+ Persons Low-Medium Income Households	4HHLMINC
4+ Persons Medium-High Income Households	4HHMHINC
4+ Persons High Income Households	4HHHINC
Government Employment	GOVT_EMP
Finance, Insurance and Real Estate Employment	FIRE_EMP
Services Employment	SERVICE_EMP
Retail Employment	RETAIL_EMP
Wholesale Employment	WHLSL_EMP
Manufacturing Employment	MANUF_EMP
Construction Employment	CONST_EMP
Educational Employment	EDU_EMP
Agricultural Employment	OTHER_EMP
Mining Employment	MINING_EMP
Total Households	TOTALHH
Household Population	HHPOP
Grade School Enrollment	GRADE
Middle School Enrollment	MIDDLE
High School Enrollment	HIGH
College Enrollment	COLLEGE

Table 3.2: TAZ Demographic Variables

Roadway Network Development

The roadway network represents the available roadway supply for accommodating the estimated travel demand for the base year. Typically, the supply in a travel demand model includes all roadways of collector class and higher along with some important higher-volume local roads. Most travel demand models exclude local streets links since they tend not to be influential in analyzing travel patterns at a regional level, are largely uncongested, and tend to lack connectivity with the main network. The roadway network for the Whatcom was developed from existing GIS data sources, including centerlines and aerial photographs.

Centroid connectors connect the TAZ centroids to the roadway network. These links replace the local street network within a TAZ. Centroid connector placement is critical to properly representing the spread of flow across the network. The centroid connectors for the Whatcom model was created by Whatcom staff using their local knowledge of the region and by using aerial photography. During the course of model calibration and validation, a few connector locations were modified. Centroid connectors in the Whatcom model exhibit unlimited capacity and constant speeds of 25 mph.

There are several primary types of links in the Whatcom network. These include highways, ramps, major and minor arterials, major and minor collectors, transit only links, and centroid connectors. Based on the area type of the network links, further classifications within these link types are made, since links in the rural regions typically have greater speeds. These additional classifications also exhibit significant variance in the available capacity for the link. The values of speed and capacity based on link type and area type are illustrated in Table 3.3. These values were determined during the model calibration phase. In addition, certain local sections of a particular road experience changes in speeds and sometimes have a posted speed that is quite different from the speed determined from Table 3.3. In such case, these speeds on certain local sections of the roads were over-ridden to match posted speeds.

Type	Class	AreaType	Speed	Lane Capacity
1	Freeway	1 - Urban	62	1700
1	Freeway	2 - Suburban	65	1850
1	Freeway	3 - Rural	70	2000
2	Major Arterial	1 - Urban	33	900
2	Major Arterial	2 - Suburban	37	1000
2	Major Arterial	3 - Rural	45	1100
4	Minor Arterial	1 - Urban	30	800
4	Minor Arterial	2 - Suburban	35	900
4	Minor Arterial	3 - Rural	40	1000
5	Major Collector	1 - Urban	28	600
5	Major Collector	2 - Suburban	31	650
5	Major Collector	3 - Rural	37	700
6	Minor Collector	1 - Urban	25	600
6	Minor Collector	2 - Suburban	30	650
6	Minor Collector	3 - Rural	35	700
7	Ramp	1 - Urban	30	900
7	Ramp	2 - Suburban	30	1000
7	Ramp	3 - Rural	30	1100
9	Centroid Connector	1 - Urban	25	9999
9	Centroid Connector	2 - Suburban	25	9999
9	Centroid Connector	3 - Rural	25	9999

Table 3.3: Speeds and Capacities by functional class and area type

During the initialization phase of the model, the free flow speeds are assigned based on the above classification and the over-riding speeds are applied. The lane capacity is obtained from the above table, multiplied by the number of lanes and a capacity reduction factor to yield the hourly capacity. The hourly capacities are in turn multiplied by 2, 3, 4.5 and 6 to obtain AM, PM, MD and NT period capacities respectively. A map of the network is shown in Figure 3.1.

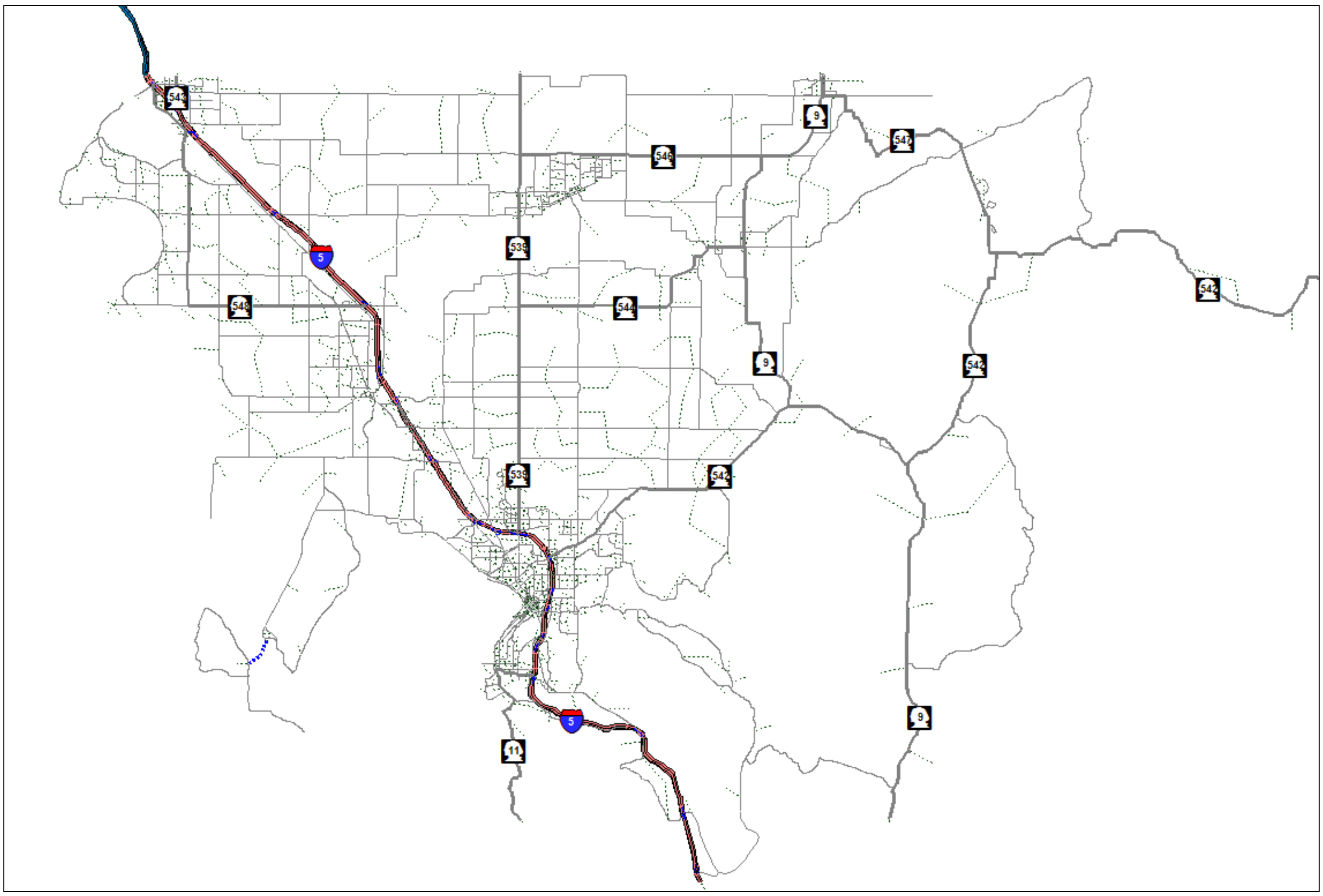

Figure 3.1: Highway Network

Transit Network Development

Utilizing the Whatcom roadway network as the underlying geography, Whatcom staff and Caliper Corporation developed a geographically accurate Transit Network. This transit network provides an inventory of available routes and stops. The Transit Network is used for determining the possible transit paths across the Whatcom region that is critical for input into the mode choice model. Once an origin-destination matrix for transit trips is calculated, the trips are then assigned to the Transit Network.

The route inventory should be a geographically accurate representation of the route alignments. The alignment of a route is dependent on the availability of suitable underlying links in the roadway network to traverse. There are several instances in the Whatcom network where links are utilized only by transit vehicles and consequently designated as transit-only links and are not available to other modes. In the updated model, we utilize the same route system for each time period of the model (AM Peak, PM Peak, Off-Peak, and Night) and select only the applicable routes and attributes for that period from which to build the transit network. Stop locations at near/far side of intersections and mid-block locations are also geographically represented. Proper geographic placement of stops helps facilitate better replication of transit accessibility behavior through walking. The travel time between stops in the transit network is a function of the highway travel times between the stops. The transit travel time on a link is assumed to be 1.2 times the highway travel time.

Three park and ride locations are used in the model, one for Lincoln Creek station, Ferndale Transit Center and for the Lynden Transit Center.

Each route is coded with several attributes used in transit skimming and assignment. These include headways for the all the periods and the fare for each route. A map of the transit routes is shown in Figure 3.2.

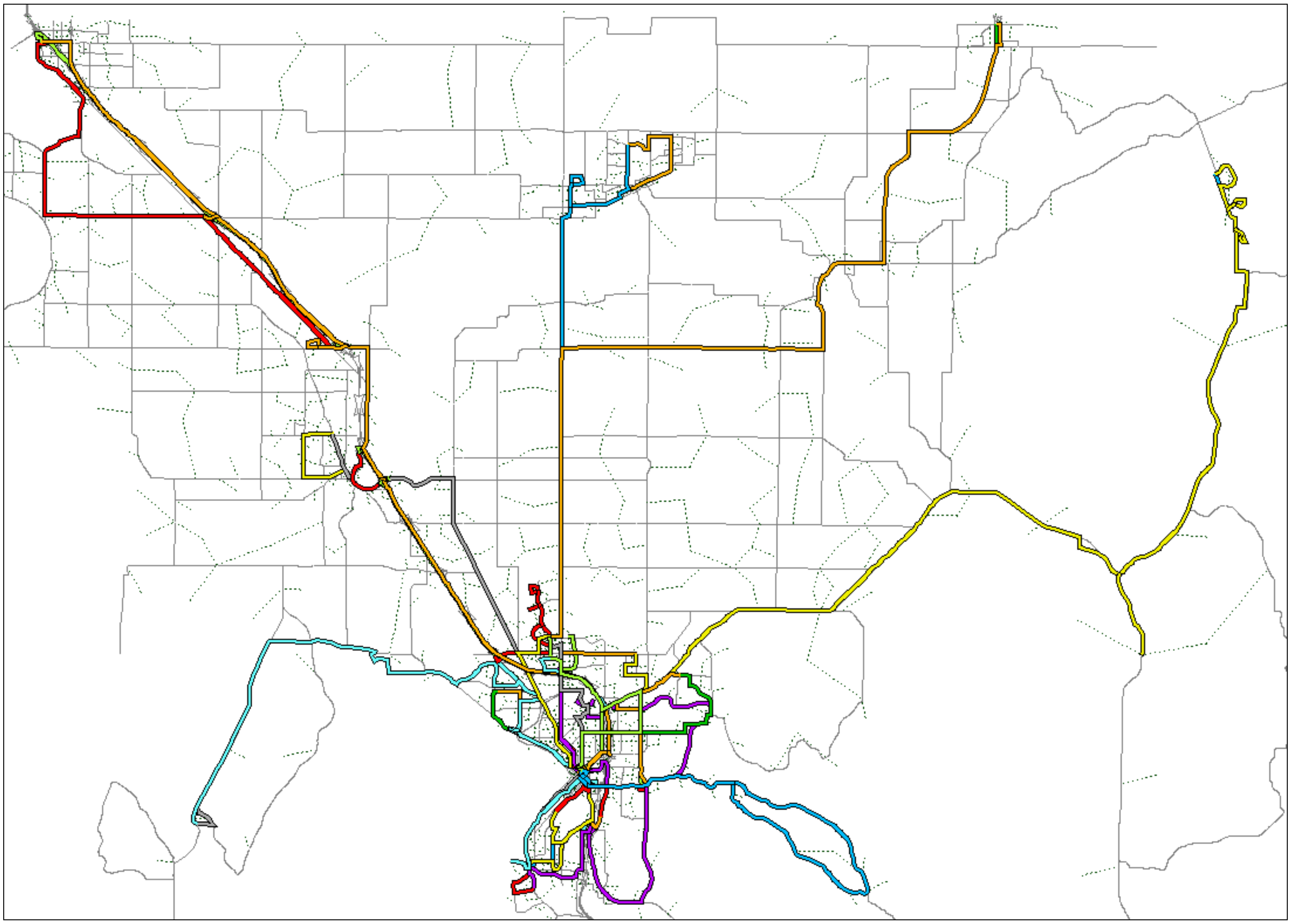

Figure 3.2: Transit Route System

Highway Network Skimming

At several stages in the travel demand modeling process centroid to centroid (zone to zone) measures of travel time or other costs must be computed. The process of computing the shortest path between any origin-destination pair is often referred to as skimming. Skimming is a critical process in any travel demand model and greatly influences the model results. Thus it is imperative to be able to compute skims accurately. The Whatcom model requires highway skims as inputs to the Trip Distribution and the Mode Choice modules.

As described in the model summary, the trip distribution and mode choice models are performed for the Peak (PK) and the OffPeak (OP) periods. The PK periods comprise of the AM and the PM sub-periods and the OP period comprise of the Midday (MD) and Night (NT) sub-periods. The measures of zone to zone skims are necessary for the PK and the OP periods.

Given that the trip distribution generates a Production and Attraction matrix and given the definition of trip ends used in the model, it was determined that the AM period skims be used as a proxy for the PK period skims and that the MD period skims be used as a proxy for the OP period skims.

The initial estimate of the trip distribution is completed using skim values based on free-flow travel times derived from free flow speeds on the links. During the calibration phase of the Whatcom model, a feedback model was performed in which congested times derived for the highway network from the highway assignment are passed back to the skimming process to garner a better estimate of the trip distribution model. Several feedback runs were performed to determine congested link travel times for the AM and the MD period. For the base year model, these congested link travel times are populated in the highway database and are used to start the model, eliminating the need to run additional feedback iterations.

It would be remiss not to mention that skimming is subject to several constraints that must be accounted for in the network settings. These include the representation of prohibited turns in the highway network and the prohibition of paths to utilize centroid connectors except to gain access to or egress from the main network. Finally a measure of the Intra Zonal trip travel times is obtained based on the travel times to the nearest neighbors to each zone.

Transit Network Skimming

Additional inputs to the mode choice procedure are transit skims for the PK and the OP period. The process of computing the transit skims in the Whatcom model is analogous to that of the highway, although it is often the case that in addition to travel time, other attributes such as fare, walk access time, and initial wait time are needed for input into the mode choice model and must be kept track of during the skimming process. For the transit network, skimming is tightly bound to the network settings which greatly influence the paths utilized in the skimming. Further, the path building methodology and the fact that the cost to traverse the transit network is comprised of many weights applied to both the transit and non-transit elements (e.g. walk access and egress), often find more than one viable path between any OD pair.

As in the case of highway skimming, the transit skimming in the Whatcom model is performed for the AM and the MD sub-periods. The Pathfinder transit algorithm developed by Caliper is used to generate zone to zone transit paths. A detailed description of this method is described in the TransCAD Travel Demand Modeling book. The default settings are used along with the fare system by route.

Unlike the highway skims, transit skims are not part of the feedback loop. This is primarily due to the fact that addition of transit skims to the feedback loop is thought to be detrimental towards feedback loop convergence. Typically, transit travel times at a link level are a function of the corresponding highway travel times. During the feedback loop process, the congested highway times are updated after every loop. Hence, the intermediate aggregated transit route travel times can be significantly different from the transit schedule times, which would in turn yield incorrect transit skim estimates. The incorrect skims introduce further variability in the mode share estimates and affect the model convergence.

Chapter 4: Trip Generation

The trip generation module in the Updated Whatcom Planning model predicts daily production and attractions for each of the 8 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 and Truck trips). The trip generation further splits the daily productions and attractions into Peak (PK) and OffPeak (OP) trip productions and attractions, adds special generators and external trips and balances the PK and OP tables.

The Updated Whatcom model trip generation models were determined using the following approach:

- Analyze the various components of the travel survey. Extract a database with all the weekday trip records and attach the person and household characteristics to each record. Attribute a trip purpose to each trip record
- Perform statistical tests to determine the variables that influence trip production and develop all-day trip production rates for each purpose.
- Develop trip attraction models based on employment variables as classified by the employment types.
- Determine special generator zone(s), if any and forecast trip productions or attractions at these zones.
- Split the daily productions and attractions into PK and OP Productions and Attractions.
- Add External trips to the PK and OP tables.
- Balance both the PK and OP Production Attraction tables.

Each of these steps is discussed in detail below.

Survey Processing

The North Sound Travel survey consists of a trip file, a person file and a household file. In the first stage of the analysis, the person and household attributes were integrated into the trip file using the person and household identifiers. A database with the trips made by households in Whatcom County or trips from outside counties into Whatcom County was extracted. There were 6,737 records from the trip file out of 12,711 records that satisfied this condition.

The next stage was to determine the trip purpose for each of the trip. The trip purposes were determined based on the Origin and Destination trip purpose fields. For the initial exploratory analysis, each trip was deemed to be one of the seven purposes; Home Based Work (HBW), Home Based College (HBColl), Home Based School (HBSch), Home Based Shopping (HBShop), Home Based Other (HBO), Non Home Based Work (NHBW) and Non Home Based Other (NHBO). In addition, the Whatcom area has significant truck traffic primarily cross border traffic to and from Canada. However, the survey did not contain adequate or any records regarding the Truck modes and hence the Truck purpose was not considered. However, the truck trip generation models from the previous version of the Whatcom model were retained in this updated version.

The trip classifications are different from the previous version of the model, especially in the treatment of Home Based Other and Non Home Based Trips. This separation will not only affect the trip generation models but will affect other planning model components such as the trip distribution models, the time of day models and will also facilitate more intuitive mode choice models.

Out of 6,717 records, the trip purpose could be determined for 6,649 records. A tabulation of the un-weighted trips and weighted trips (weighted by the WeightFinal_Lu variable) by purpose is shown below:

Trip Purpose	Un-weighted Trips	Weighted Trips
HBW	1,078	85,954
HBColl	65	5,882
HBSch	418	45,208
HBShop	506	49,818
HBO	2,370	237,936
NHB	757	57,519
NHBO	1,455	150,369
Total	**6,649**	**632,684**

Table 4.1: Tabulation of Trip Purposes from the Survey

The other important data from the survey required for the trip generation models and in particular for the trip attraction model are the origin and the destination zones of each of the trip ends and these are contained in the fields O_TAZ and D_TAZ. Further, it is necessary to determine the zone to which each household belongs. This is done using a tagging procedure and the results stored in the field HH_TAZ in the survey database.

Trip Production Models

Typically trip production models, are household-based and rely on variables such as household income, household auto availability and household size. The trip production models are usually determined by the available land use variables and by available forecasts for the future year. As documented in Chapter 3, Whatcom staff provided a land use database of households stratified by household size and income and households stratified by income and number of workers in the household. In addition, the land use database had several employment variables. The trip production models were hence based on these available data.

Trip production rates for the home based purposes are based on the cross-classification of households by income, size and number of workers in the household. Initially, the trip production rates for the Non Home Based purposes (NHBW and NHBO) were also based on household sub-classifications. However, Non-Home based trips do not originate or terminate at the household zone and NHB trips made by members in their households could be in locations far away from the home zones. Thus, the process of computing trip rates for NHB purposes at the TAZ level based on household sub-classification of the zone is not recommended. Trip production rates for the NHBW and NHBO purposes were hence based on regressions using the employment and enrollment variables.

Statistical tests on the survey data revealed that home based work trips are better explained using the number of workers in the household and household income whereas home based non-work trips are better explained by number of household members and household income. Therefore the cross-classification of households by income and number of workers is used for the HBW purpose whereas the classification of households by income and household size is used for the other home based non-work purposes (HBSch, HBColl, HBShop and HBO). Note that for the home based trips, the home end of the trip is deemed to produce trips and the other end is deemed to attract trips. For example, although a person makes a trip from home to work and back to home, we tabulate this as 2 HBW productions at the home zone and 2 HBW attractions at the work zone.

We further decided to examine the effect of the trip production rates with respect to geographical region of the trip maker. Trip production rates vary by geographical location since the distribution of households varies by geographic location. For instance, high income regions have different trip making characteristics than low income regions and they are usually geographically separate. Also, home based trip rates for outlying regions that are not easily accessible from the major CBD zones tend to be lower since household members belonging to these zones tend to perform added trip chaining. The NHB trips for such households seem to be chained with the other trip purposes and occur closer to the employment zone.

Statistical tests were performed to determine the trip making characteristics by geographical region. Trip rates for the city of Bellingham, WA were statistically different from the trip rates for the rest of the region. We decided to use one set of trip rates for Bellingham and another set for the rest of the region. During the model calibration and validation phase, certain trip rate modifications were done for a few additional local regions that warranted special consideration.

Trip Production Rates for Home Based Trips

The trip rates were generated from the survey database using the weights developed. Certain classifications that did not have an adequate sample size were clubbed with other classifications appropriately. In certain instances, the trip rates across various regions also had to be combined due to sample size constraints. The production rates include trips from Whatcom County to external zones.

Tables 4.2 and 4.3 show the trip production rates for the HBW purpose and these are based on household income and number of workers in the household. Out of 696 zones, 219 zones are within the city limits of Bellingham, WA.

Household Income	Number of Workers in the household				
	0	1	2	3	4+
Less than $25,000	-	0.448	2.118	3.359	3.359
$25,000–$49,999	-	1.026	2.009	3.359	3.359
$50,000–$74,999	-	1.143	1.913	3.359	3.359
$75,000 or more	-	0.938	2.465	3.359	3.359

Table 4.2: HBW Trip Production Rates for Bellingham, WA

Household Income	Number of Workers in the household				
	0	1	2	3	4+
Less than $25,000	-	1.036	2.118	3.572	3.572
$25,000–$49,999	-	1.030	2.197	3.572	3.572
$50,000–$74,999	-	0.988	2.080	3.572	3.572
$75,000 or more	-	1.176	2.146	3.572	3.572

Table 4.3: HBW Trip Production Rates for the rest of the region

Tables 4.4 to 4.11 show the trip production rates for the home based non-work purposes (excluding trucks) for Bellingham and the rest of the region. These rates are based on the cross-classification of household income by household size.

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.081	0.000	0.000	0.000
$25,000–$49,999	0.030	0.173	0.038	0.112
$50,000–$74,999	0.000	0.058	0.283	0.303
$75,000 or more	0.000	0.000	0.369	0.565

Table 4.4: HBColl Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.042	0.000	0.000	0.000
$25,000–$49,999	0.016	0.090	0.020	0.058
$50,000–$74,999	0.000	0.030	0.147	0.157
$75,000 or more	0.000	0.000	0.191	0.293

Table 4.5: HBColl Trip Production Rates for the rest of the region

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	-	0.177	0.952	1.777
$25,000–$49,999	-	0.041	0.952	1.777
$50,000–$74,999	-	0.041	0.818	2.957
$75,000 or more	-	0.041	1.208	2.577

Table 4.6: HBSch Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	-	0.177	0.952	1.777
$25,000–$49,999	-	0.041	0.952	1.777
$50,000–$74,999	-	0.041	0.669	3.145
$75,000 or more	-	0.041	0.665	2.675

Table 4.7: HBSch Trip Production Rates for the rest of the region

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.547	0.814	0.543	1.049
$25,000–$49,999	0.288	0.746	0.543	1.049
$50,000–$74,999	0.289	0.854	0.940	0.870
$75,000 or more	0.672	0.748	1.117	0.874

Table 4.8: HBShop Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.266	0.814	0.543	1.049
$25,000–$49,999	0.403	1.291	0.543	1.049
$50,000–$74,999	0.289	0.465	0.689	0.645
$75,000 or more	0.672	0.604	0.490	0.394

Table 4.9: HBShop Trip Production Rates for the rest of the region

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	1.352	1.868	5.240	9.675
$25,000–$49,999	1.982	2.399	5.240	9.675
$50,000–$74,999	1.378	2.622	5.833	8.863
$75,000 or more	1.046	3.262	5.059	8.921

Table 4.10: HBO Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.694	1.401	3.930	7.256
$25,000–$49,999	1.172	2.526	3.930	7.256
$50,000–$74,999	1.033	1.879	2.001	4.864
$75,000 or more	0.785	2.089	2.208	5.859

Table 4.11: HBO Trip Production Rates for the rest of the region

Trip Production Rates for Non-Home Based Trips

The trip production rates for the NHBW and NHBO purposes are based on regression equations developed from the survey data and the land use variables. The NHBW and NHBO trips in the survey were aggregated based on the Origin TAZ. The aggregated dataset was then joined to the land use database and regression equations were developed using the employment and enrollment variables as the independent variables. The models are presented in Table 4.12

Variable	NHBW_P	NHBO_P
Government Employment	0.868	4.923
Finance and Insurance Employment	1.178	
Service Employment	0.648	1.341
Retail Employment	0.822	3.201
Manufacturing Employment	0.968	
Educational Employment		8.448
Telecommunications Employment	1.760	
High School Enrollment	0.234	
College Enrollment	0.139	0.534

Table 4.12: Trip Production Rates for NHBW and NHBO trips

Based on the survey, the NHBO productions for the region outside the Bellingham city limit is multiplied by a reduction factor of 0.8.

Trip Production Adjustments for Special regions

In addition to the rates above, adjustments were made to certain local regions. Fully fledged trip rates could not developed for these local regions for want of sample size.

Sudden Valley Region: The sudden valley region is a set of a few zones in the southeast portion of the Whatcom region. This region is significantly cut-off from the remainder of the Whatcom region. Closer inspection using the survey revealed that the trips produced by households in these zones are starkly different from the rest of the region. This could be attributed to the fact that people in these zones perhaps chain a lot of trip activities and avoid to and fro trips from the household zone. By analyzing the survey, the trip factors for each purpose are developed and shown in Table 4.13.

East Whatcom Region: Likewise, the East Whatcom region is cut off from the main activity centers. Therefore the Home Based Trip rates are much lower for this region.

Birch Bay: This region consists of retirees and produces fewer trips.

Table 4.13 shows the trip rate adjustments by purpose for each of the above areas.

Purpose	Sudden Valley	East Whatcom	Birch Bay
HBW Factor	0.40	0.55	0.80
HBSch Factor	0.30	0.40	0.60
HBColl Factor	0.00	0.00	0.70
HBShop Factor	0.20	0.30	0.80
HBO Factor	0.85	0.25	0.55
NHBW Factor	0.25	0.50	0.50
NHBO Factor	0.95	0.40	0.70

Table 4.13: Trip Production Adjustments for Special Regions

Trip Attraction Models

Trip attraction models developed were based on employment estimates, school and college enrollment, total households and household population. These variables are provided by Whatcom staff in the land use database.

For each record in the survey, we obtained the attraction zone of the trip. For Home Based Trips, the attraction zone is defined as the non-home zone and for the NHB trips, the attraction zone is simply the destination zone. The trips in the survey were aggregated using the attraction zone (weighed by WeightFinal_LU) to yield an estimate of the number of trips by purpose attracted at each zone. Note that though there are 688 zones in the model, we could only obtain trips from the survey for approximately 360 zones. This is perhaps because several trips in the database were not allocated an attraction zone (due to missing geo-coding information) or maybe because the survey did not have any trips to certain zones.

The trip attraction rates were determined using linear regression analysis using separate models for each trip purpose. One such regression models for HBO trips (with results and t-tests) is attached below:

Dependent field HBO_Trips

Outputs

Source	df	SS	Mean SS	F Ratio
Model	7	37273349.92528	5.32476e+006	21.0906
Error	349	88112480.47083	252471.	
Total	356	125385830.39611		

R Squared 0.2973

Adjusted R Squared 0.2832

Estimation Results

Field Name	Estimate	Std. Error	T Test
CONSTANT	199.815982	28.9207	6.90909
FIRE_EMP	0.915692	0.477695	1.91690
SERVICE_EMP	1.270864	0.141182	9.00161
GOVT_EMP	0.871917	0.453857	1.92113

RETAIL_EMP	1.251382	0.285801	4.37851
HHPOP	0.294374	0.0578863	5.08539
grade	0.481403	0.276453	1.74135
middle	0.767891	0.341988	2.24537

Table 4.14: Sample Regression Results for HBO Trips

The other major issue in using regression models for trip attractions is the presence of the constant term. The constant term tries to explain behavior that is not captured by the dependent variables. Since it is obviously not possible to obtain a perfect model with an R-squared value very close to 1, the constant term can be significant. In the above example, the constant is 199.8, which implies there are 71,130 trips for the 359 zones that cannot be explained by the dependent variables.

However, the non-zero constant term implies that certain zones with no employment may have attractions, which is unintuitive. The coefficients of any dependent variable, when multiplied by the sum of the variable across the 359 zones yield the total number of attractions generated by that dependent variable. Thus, we allocated the unexplained trips (71,130 in the example above) based on the attractions generated by the dependent variables and adjusted the co-efficient of each dependent variable. Finally, it is to be noted that since most of the purposes are balanced to productions, we only care about the relative attractions in each zone and thus the adjustment may not be that crucial in the final analysis.

The trip attraction rates are shown in Table 4.15

Variable	HBW	HBShop	HBSch	HBColl	HBO	NHBW	NHBO
Government Employment	1.016	-	-	-	1.530	0.875	1.495
Finance and Insurance Employment	1.016	-	-	-	1.593	0.937	-
Service Employment	1.043	-	-	-	1.940	0.842	0.873
Retail Employment	1.043	3.880	-	-	2.080	0.531	4.536
Wholesale Employment	0.848	-	-	-	-	1.970	-
Manufacturing Employment	0.848	-	-	-	-	1.320	-
Construction Employment	0.429	-	-	-	-	-	-
Educational Employment	-	-	-	-	-	-	-
Agricultural Employment	0.429	-	-	-	-	-	-
Telecommunications Employment	0.429	-	-	-	-	-	-
Mining Employment	-	-	-	-	-	-	-
Other Employment	0.429	-	-	-	-	-	-
Household Population	-	-	-	-	0.495	-	-
Grade School Enrollment	0.100	-	1.840	-	0.792	-	0.590
Middle School Enrollment	0.100	-	1.840	-	1.298	-	0.590
High School Enrollment	0.100	-	1.940	-	-	-	-
College Enrollment	0.208	-	-	0.250	-	0.082	0.075
Total Households	-	-	-	-	-	-	-

Table 4.15: Trip Attraction Rates

We compared the trip coefficients (for example, for the school employment) variable with the ITE trip generation manual and determined that the rates in the above table are reasonable and within the limits specified in the ITE manual.

Truck Productions and Attractions

The North Sound Travel survey did not specifically contain truck trips. The truck trip production and attraction models from the previous version of the Whatcom model were retained. The production and attraction rates are shown in Table 4.16:

Variable	Truck Production Rates	Truck Attraction Rates
Government Employment	0.253	0.114
Finance and Insurance Employment	0.262	0.305
Service Employment	0.262	0.305
Retail Employment	0.623	0.076
Wholesale Employment	0.792	0.190
Manufacturing Employment	0.762	0.433
Construction Employment	0.717	0.375
Educational Employment	0.253	0.114
Agricultural Employment	0.829	0.587
Telecommunications Employment	0.733	0.646
Mining Employment	0.912	67.802
Total Households	0.100	0.319

Table 4.16: Truck Production and Attraction Rates

Special Generators

During the course of model calibration and validation, it was observed that for large retail centers, the trips generated by the attraction model were lower when compared to traffic counts around the region. A similar observation was made in the draft report published by Cambridge Systematics during the development of the previous version of the model. Therefore, special generator rates from the ITE trip manuals were used for these zones. Zones with retail employment of greater than 300 were targeted.

Figure 4.1 shows a map of the special generator zones displayed in orange, most of which are concentrated in and around Bellingham. Table 4.17 identifies the special generator zones. Based on the ITE manual, an attraction rate of 22.96 per retail employee per day was used for these zones. Typically, the trips need to be distributed over the trip purposes. In this version of the model, the daily attractions determined for each special generator zone using the special attraction rates are split to the HBW, HBShop, HBO, NHBW and NHBO trip purposes using the proportions determined by the attraction models (Table 4.15) for that zone.

Special generators for regions such as the Bellingham Airport, Squalicum harbor and St. Josephs' Hospital were not warranted in this update because the trips from the attractions models matched the trips from the survey.

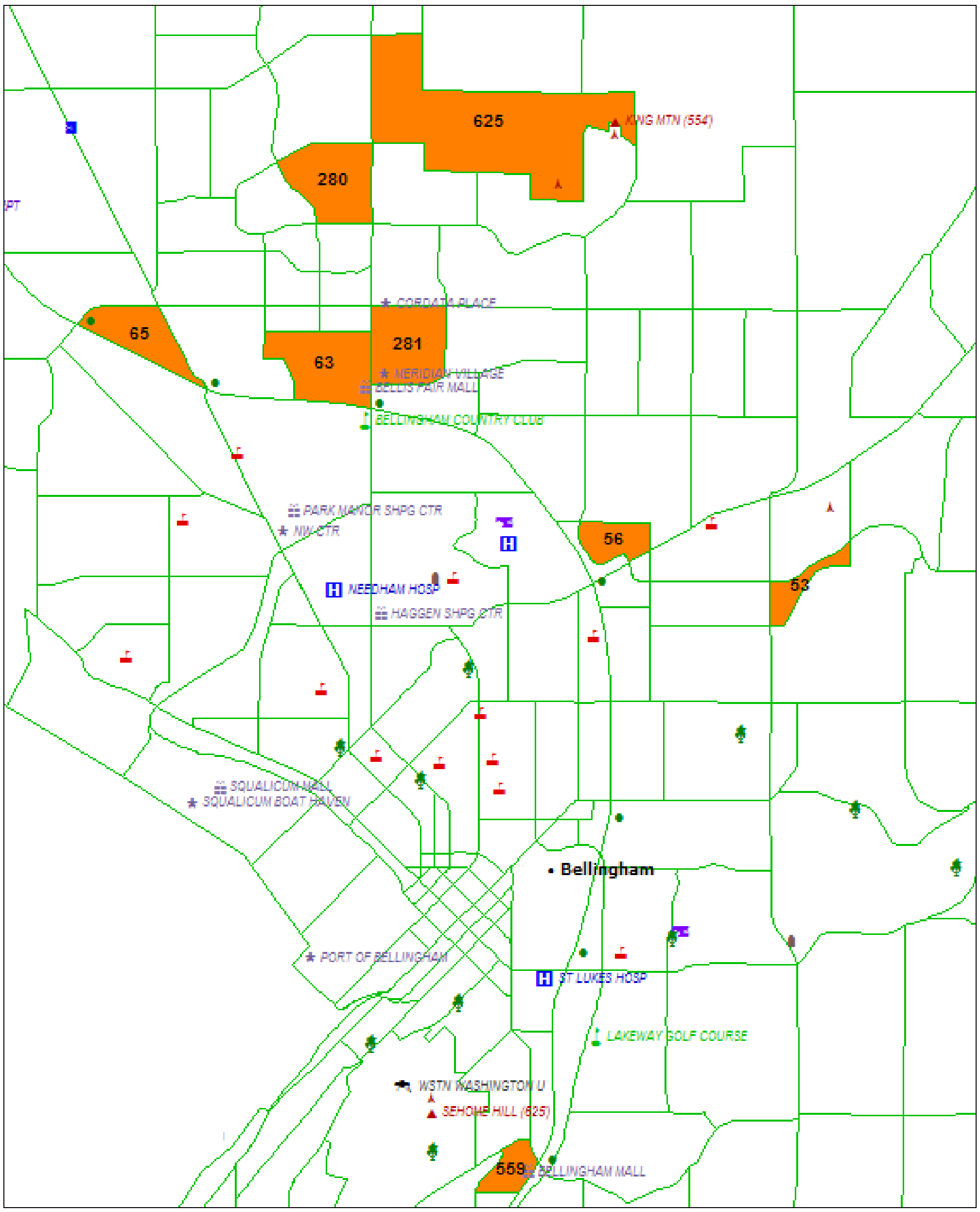

Figure 4.1: Special Generator Zones

Description	TAZ	Retail Employment
Barkley Blvd Mall	53	336
Sunset Square Mall	56	425
Bellis Fair Mall	63	1,323
Bakerview Road Shopping Area	65	399
Cordata Center	280	437
Meridian Village Shopping Center	281	382
Bellingham Mall	559	362
Walmart on Guide Meridian	625	338

Table 4.17 Special Generator Zones

Daily Productions and Attractions

The productions and attractions after applying the above models and adding the special generators are shown in Table 4.18 below.

Purpose	Productions	Attractions
HBW	81,096	90,440
HBShop	46,526	79,201
HBSch	45,878	53,011
HBColl	5,930	4,474
HBO	237,148	232,030
NHBW	64,961	71,868
NHBO	148,315	144,404
Truck	49,126	62,405

Table 4.18: Total Daily Productions and Attractions by Purpose

A few observations of the differences between the total productions and attractions are documented below:

The HBShop purpose shows a discrepancy between the productions and the attractions. This is due to the effect of several special generator zones that were required to match the attractions produced by the survey.

The number of HBColl trips seems lower when compared to the college enrollment. However, the attraction trip rates in Table 4.17 show the effect of the college enrollment on various trip purposes. The sum total of all the attractions produced at the college zone comprise of HBW, HBColl, NHBW and NHBO trips and this total reflects the effect of zones with high college enrollment.

The total trips by purpose match the weighted trips from the survey shown in Table 4.1 with a reasonable degree of accuracy.

Productions and Attractions by Time Period

The Whatcom model is based on two distinct periods Peak (PK) and OffPeak (OP). Further the PK period is sub-divided into the AM peak (trips departing between 7 AM and 9 AM) and the PM Peak (trips departing between 2 PM and 5 PM). Likewise the OP period is sub-divided into the MD period (trips departing between 9 AM and 2 PM) and the night period NT (trips departing after 5PM until 7 AM the following day). The traffic assignment step requires an OD matrix for each of these time periods. The daily trip productions and attractions thus have to be estimated by time period.

During the initial model building efforts, we made the simplifying assumption to treat HBW, HBSch and HBColl trips as occurring during the peak period (AM and PM peak) and the HBShop, HBO and NHB trips as occurring during the off peak period (Mid-day MD and Night NT). However, an analysis of the survey showed that a significant percentage of the trips for each of the purposes take place during both the peak and the off-peak periods. Thus, we decided to separate the daily productions and attractions by PK and OP period. The daily production and attraction estimates are thus split into peak (comprising the AM and the PM) and off-peak (comprising of the MD and the NT trips). For each purpose, these peak and off-peak splits were obtained from the survey. The percentage splits are shown in Table 4.19:

Purpose	Peak Split	Off Peak Split
HBW	42.5%	57.5%
HBCollege	40%	60%
HBSch	75%	25%
HBShop	35%	65%
HBO	40%	60%
NHBW	40%	60%
NHBO	40%	60%
Truck	17.5%	82.5%

Table 4.19: Peak and Off-peak percentages by Purpose

The above factors were used to split the daily productions and attractions into PK and OP productions and attractions.

External Trips

Trips from external zones that use the Whatcom network are obtained as inputs to the model. There are eight external stations in the model shown in Table 4.20. Each of these external stations is assigned a zone number (an external zone) and loaded appropriately onto the network.

TAZ	External Station
1001	I-5 Southern External
1002	I-5 Northern External
1003	SR-543 Northern External
1004	SR-539 Northern External
1005	SR-9 Northern External
1006	SR-11 Southern External
1007	SR-9 Southern External
1008	SR-542 Eastern External

Table 4.20: External Stations

The external trips from each of these locations are available as Origins and Destinations (Entry and Exit) vehicle trips for the AM, MD, PM and the NT time periods as shown in Table 4.21. Entry trips are those trips that enter Whatcom County (EI Trips) and exit trips are those that leave Whatcom County (IE trips).

TAZ	AM Entry	AM Exit	MD Entry	MD Exit	PM Entry	PM Exit	NT Entry	NT Exit	Through Trips Pct	Truck Trips Pct
1001	1,795	2,884	4,060	6,631	3,083	4,513	5,816	8,556	5%	0%
1002	430	215	1,060	939	579	804	1,099	1,603	19%	7%
1003	259	242	1,081	960	672	870	902	1,628	21%	0%
1004	232	154	718	606	407	528	544	650	7%	12%
1005	314	291	994	899	661	723	973	980	7%	6%
1006	36	48	137	167	169	171	260	229	0%	0%
1007	71	198	220	376	216	203	340	542	0%	0%
1008	0	0	0	0	0	0	0	0	0%	0%

Table 4.21: Vehicle Traffic Counts at External Stations

Each station also has the percentage of through trips and truck trips. As a first step to incorporating them into the model, the AM and PM Entries and Exits were added to the PK Productions and Attraction tables respectively and the MD and the NT external Entries and Exits were added to the OP Productions and Attraction tables respectively. The through trip percentage was subtracted from each of the vehicle counts before this process.

Trip Balancing

Trip balancing is generally done by balancing the HBW, HBSch, HBColl, HBO, NHBW, NHBO and Truck trips to productions and by balancing HBShop trips to attractions. However, we had to consider a few special requirements during the trip balancing procedure as listed below:

Balancing was done for the PK Productions and Attractions and the OP Productions and Attractions. Thus there are two balanced output tables.

For all the trip purposes, the external productions and attractions were held constant during the balancing procedure.

For the special generator zones, the attractions for the HBW, HBShop, HBO, NHBW and NHBO purposes are held constant.

The balanced total productions and attractions for the PK and the OP period are listed below:

Purpose	Peak Balanced Trips	Off Peak Balanced Trips
HBW	36,865	51,515
HBColl	29,116	54,389
HBSch	39,759	13,253
HBShop	2,372	3,558
HBO	96,619	145,872
NHBW	27,784	42,641
NHBO	60,845	92,083
Truck	8,780	40,902
Total	**302,140**	**444,213**

Table 4.22: Peak and Off-peak total balanced trips by purpose

In general, the trips during the Off-Peak period are greater than the trips during the Peak period. This is true even for HBW trips, because the PM Peak time from the time of day analysis was 2 PM to 5PM, which is early for returning HBW trips.

Figures 4.2 and 4.3 give a sense of the trip productions and attractions within Whatcom County. In general, the trip productions in Bellingham are higher than the rest of the County.

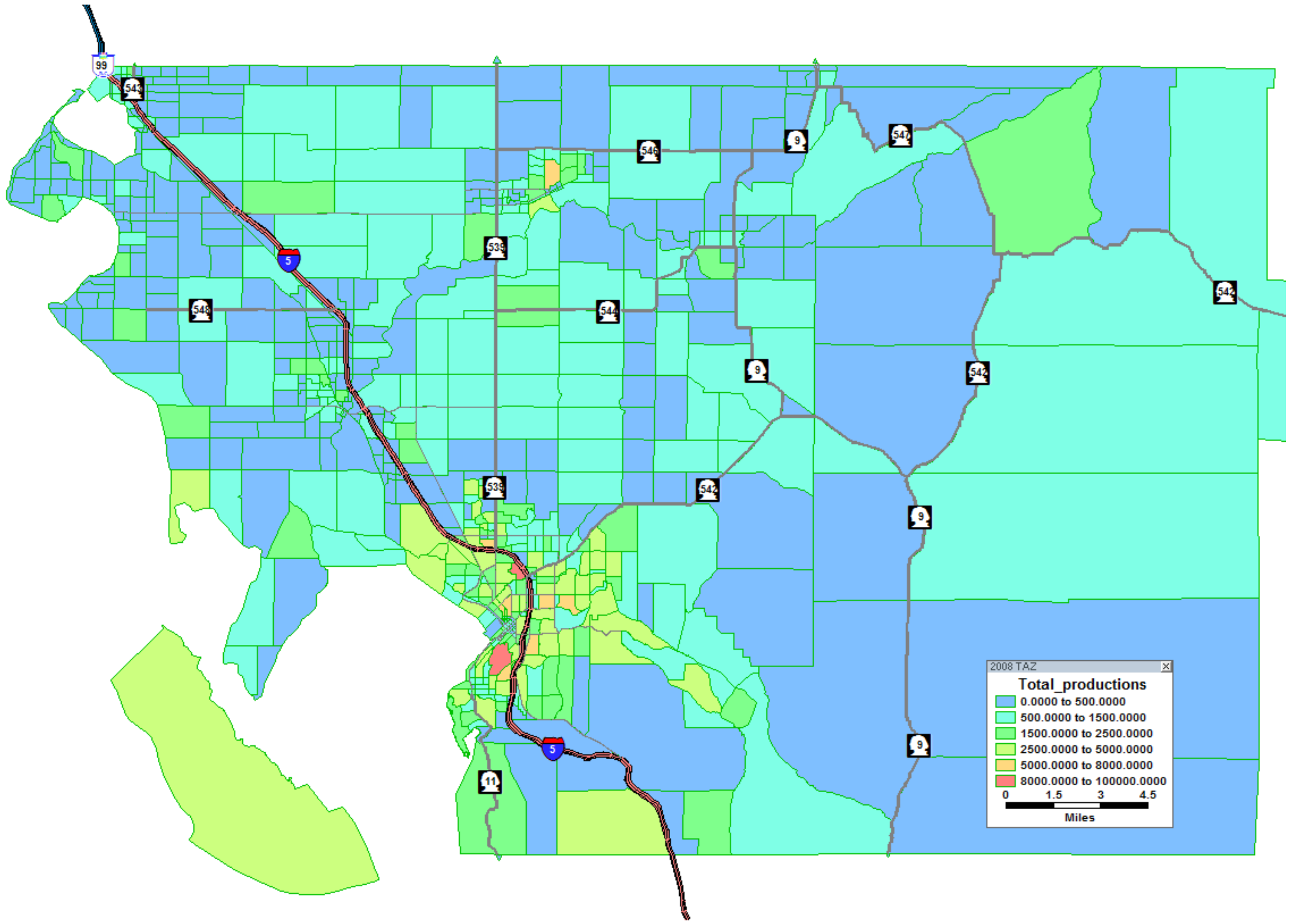

Figure 4.2: Trip Productions for the Whatcom Model

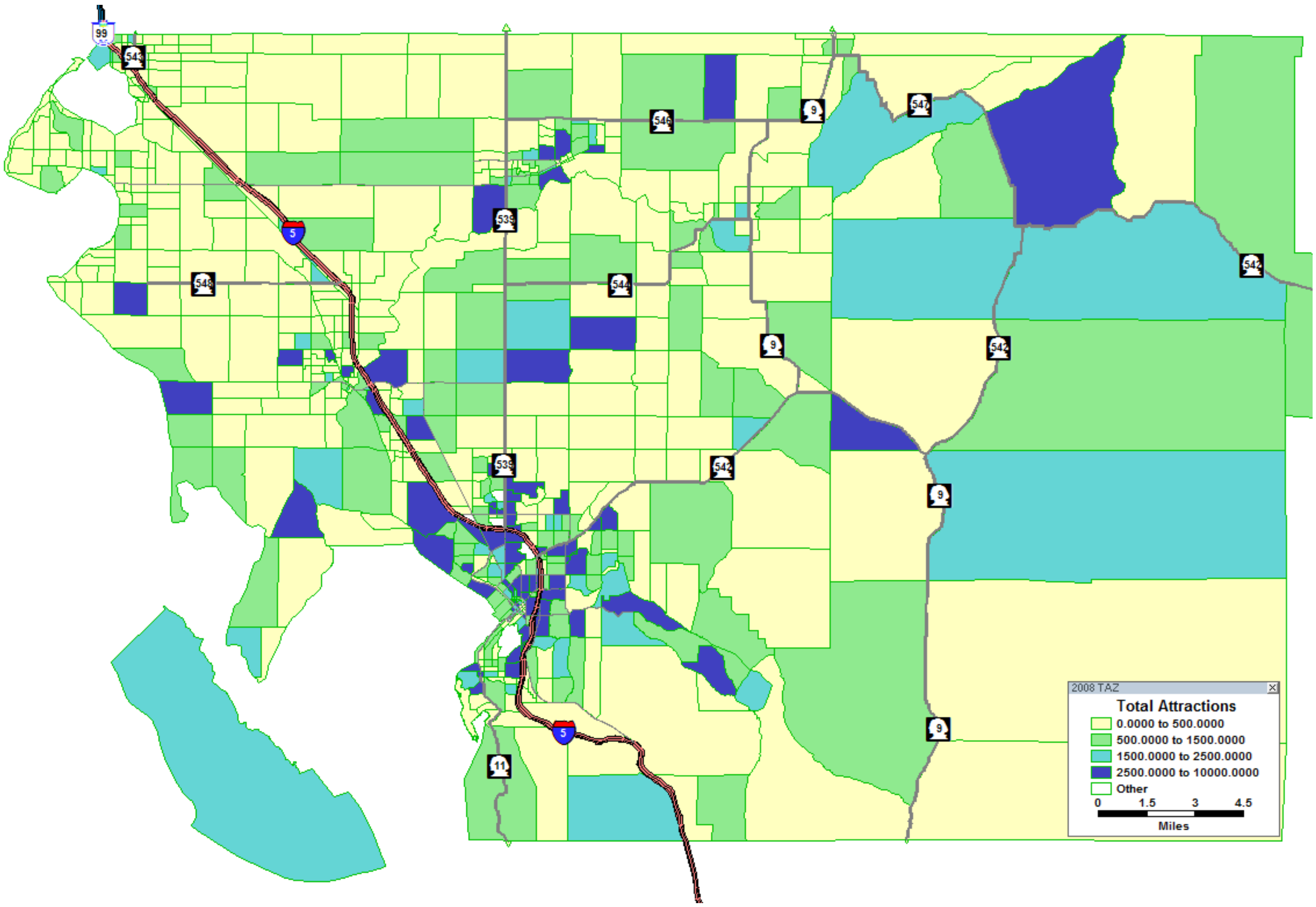

Figure 4.3: Trip Attractions for the Whatcom Model

Chapter 5: Trip Distribution

The trip distribution in the Whatcom Model is a double constrained gravity model using gamma friction factor curves. The trip distribution is applied for the PK period and the OP period. Some salient features of the distribution procedure are:

- The PK Trip Distribution is performed using the PK Balanced Production and Attraction table output from the trip generation, the congested AM Skim times and PK friction factor curves calibrated for each trip purpose.
- Likewise, the OP Trip Distribution is performed using the OP Balanced Production and Attraction table output from the trip generation, the congested MD Skim times and OP friction factor curves calibrated for each trip purpose.
- For each purpose, the tolerance of the gravity procedure was set to 0.001 with a maximum of 1000 iterations.
- While performing the trip distribution, no trips were distributed from external zones to external zones. In other words, external productions were allocated only to internal zones and external attractions were constrained to be produced from internal zones. Note that the through trips were already removed in the trip generation stage.
- A through trip matrix was generated using a FRATAR procedure, one for the PK and another for the OP trips. This matrix is added to the trips prior to the traffic assignment.
- The outputs of the trip distribution procedure are a PK Production Attraction (PA) matrix containing one matrix core for each purpose and an OP Production Attraction (PA) matrix containing one matrix core for each purpose.

The rest of the chapter documents the friction factor calibration exercise and shows a comparison of the model and the survey trip lengths.

Friction Factor Calibration

In order to apply the gravity model, friction factor curves need to be calibrated for each purpose for both the peak (PK) and the off-peak (OP) periods. The calibration is done to ensure that the average trip length frequency for each purpose is similar to the observed trip lengths from the travel survey. Matching the trip length (or time) ensures that the frequency of trips by travel time is as observed in the survey.

Since a travel survey does not typically contain reliable travel time information for each trip, we need to attach the skims from an external skimming calculation based on the best estimate of link travel times. The only estimates of link travel times available at the outset were free flow travel times and hence the first set of friction factor calibration is based on free flow travel times between the zones. It is critical to note that the calibration of the friction factors is an iterative process since the calibration needs to be revisited when better estimates of link travel times become available. Thus this process of calibration had to be repeated a couple of times during the project timeline. The final calibration results are presented here.

Each record of the survey was tagged with the appropriate zone to zone AM and MD congested travel times, depending on whether the trip was made in the PK or the OP period. The frequency of trips by time of travel could be tabulated for each purpose based on 1 minute travel time intervals. During tabulation, we used the trip weights (WeightFinal_LU) to obtain a weighted measure of the number of trips.

We initially experimented with separate friction factor curves for each time period (PK and OP) and purpose. However, the observed trip frequency distributions were choppy for several purposes and in order to obtain a better fit, the PK and OP trip frequencies were combined for each trip purpose and a single curve irrespective of the time period was fitted for each purpose. However, it is to be noted that the travel time used to generate the trip frequency from the survey depended on the time period (PK or OP) of the trip.

The trip frequencies were plotted by purpose and performed a curve fitting exercise, where we tried to fit gamma/exponential curves to match the trip frequencies. During the fitting exercise (which was done using least squares), we experimented with allocating various weights to the observations in order to capture the peak frequencies effectively. The curve fitting was done using Gamma curves. However, we found that having a single curve to fit all the trip frequencies for a particular purpose and period was not desirable. This is because one single fit was unable to capture both the peak and the tail end of the distribution. Typically, we used two gamma curves to fit the observed frequency curves.

It is worthwhile to note that the equation of the gamma curve fitted is:

$$f = a.t^{-b}.e^{-ct}$$

, where f is the trip frequency, t is the travel time and a, b and c are parameters that were calibrated.

The results of the curve fitting exercise along with the gamma parameters are illustrated in Figures 5.1 to 5.7 below. The x-axis displays the travel time and the y-axis depicts the frequency of trips. Both the aggregated values from the survey (in blue) and the fitted curves (in red) are shown in all the graphs. The parameters of the calibrated gamma curves (a, b and c) are also indicated.

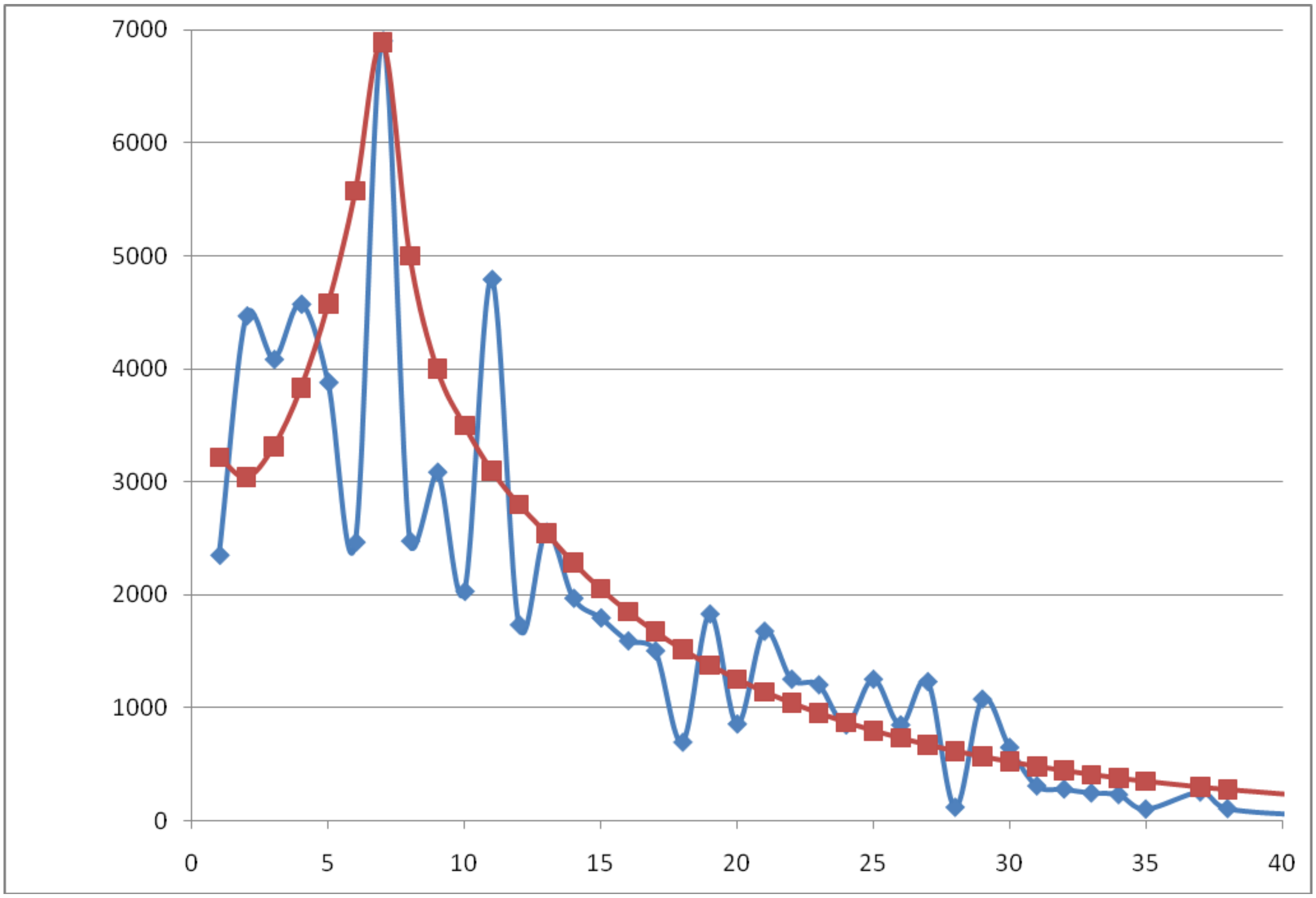

Figure 5.1: HBW Friction Factor Curves

Time	a	b	c
t <= 7	2411.28	0.4992	0.2887
t >= 13	30466.41	0.6584	-0.0610

Table 5.2: HBW Gamma Curve Parameters

Note that for values of time between 8 and 13 minutes, a linear interpolation is assumed.

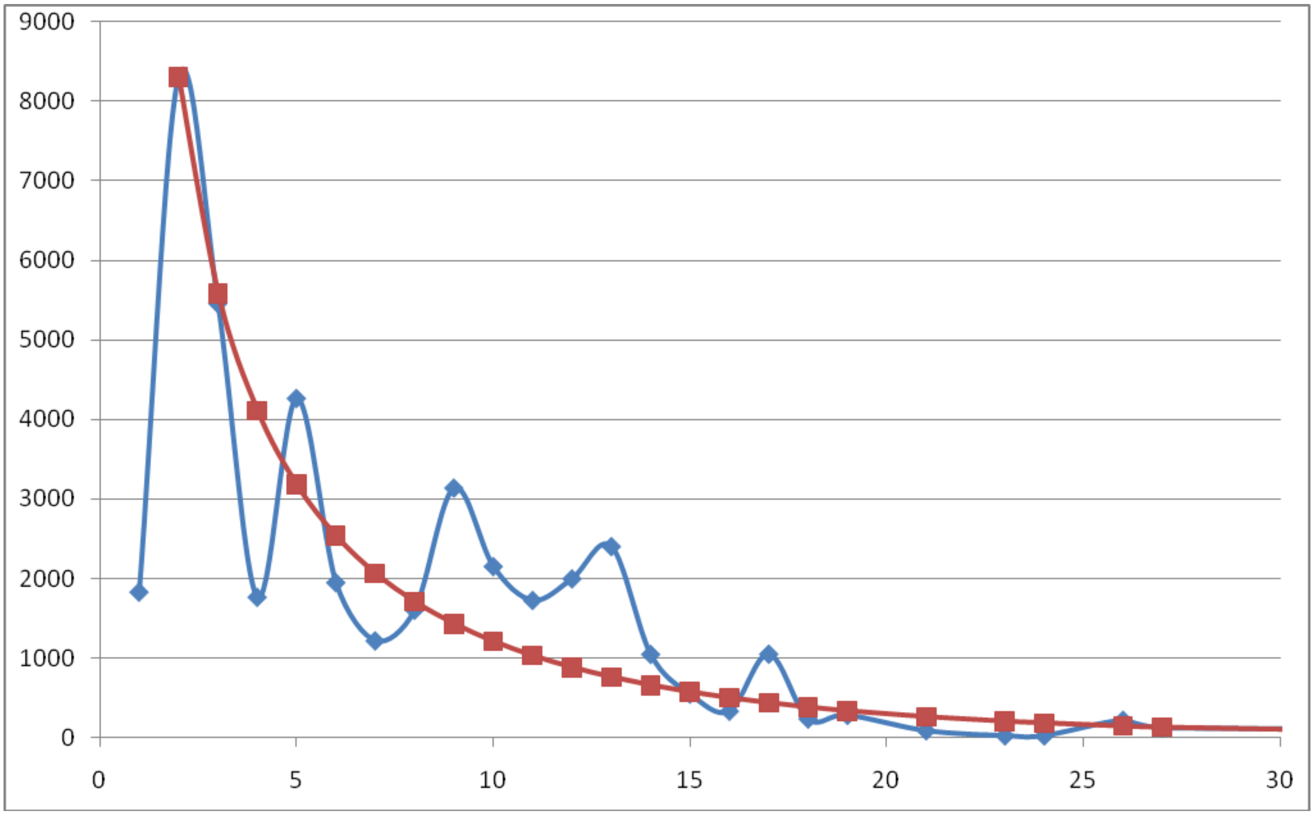

Figure 5.2: HBSch Friction Factor Curves

Time	a	b	c
t >= 2 and t < 21	16763.00	0.7602	-0.0879
t>= 21	19396.3	-0.4687	-0.2906

Table 5.3: HBSch Gamma Curve Parameters

During the calibration phase, the tail region of the above gamma curve was made to drop sharply in order to discourage long school trips.

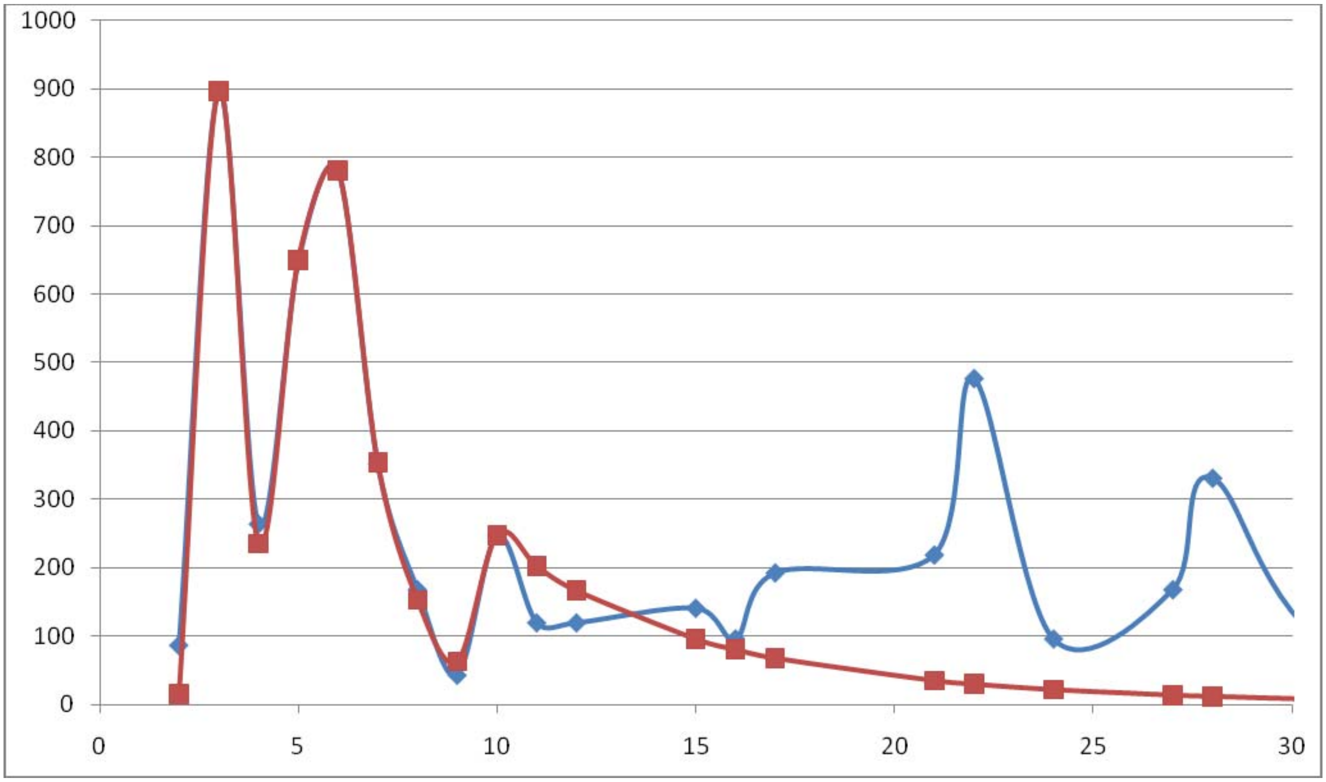

Figure 5.3: HBColl Friction Factor Curves

Time	a	b	c
t <= 5	0.9627	-46.0742	-14.5936
t > 5 and t <= 9	10946.30	-2.4324	-1.1666
t > 9	6139.88	0.8765	-0.1193

Table 5.4: HBColl Gamma Curve Parameters

Note that for values of time between 12 and 14 minutes, a linear interpolation is assumed

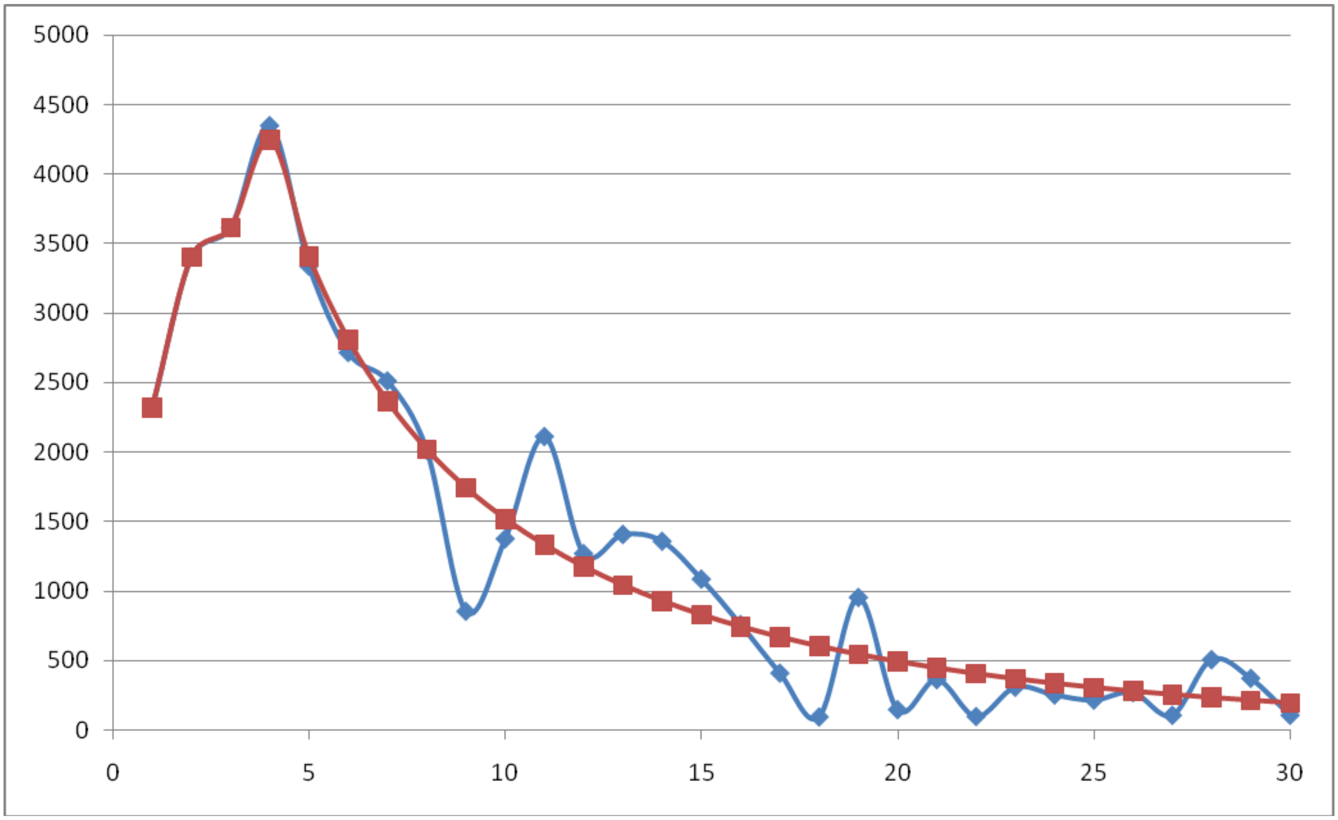

Figure 5.4: HBShop Friction Factor Curves

Time	a	b	c
t <= 3	3450.99	-1.1291	-0.3983
t > 3	14542.63	0.7035	-0.0640

Table 5.5: HBShop Gamma Curve Parameters

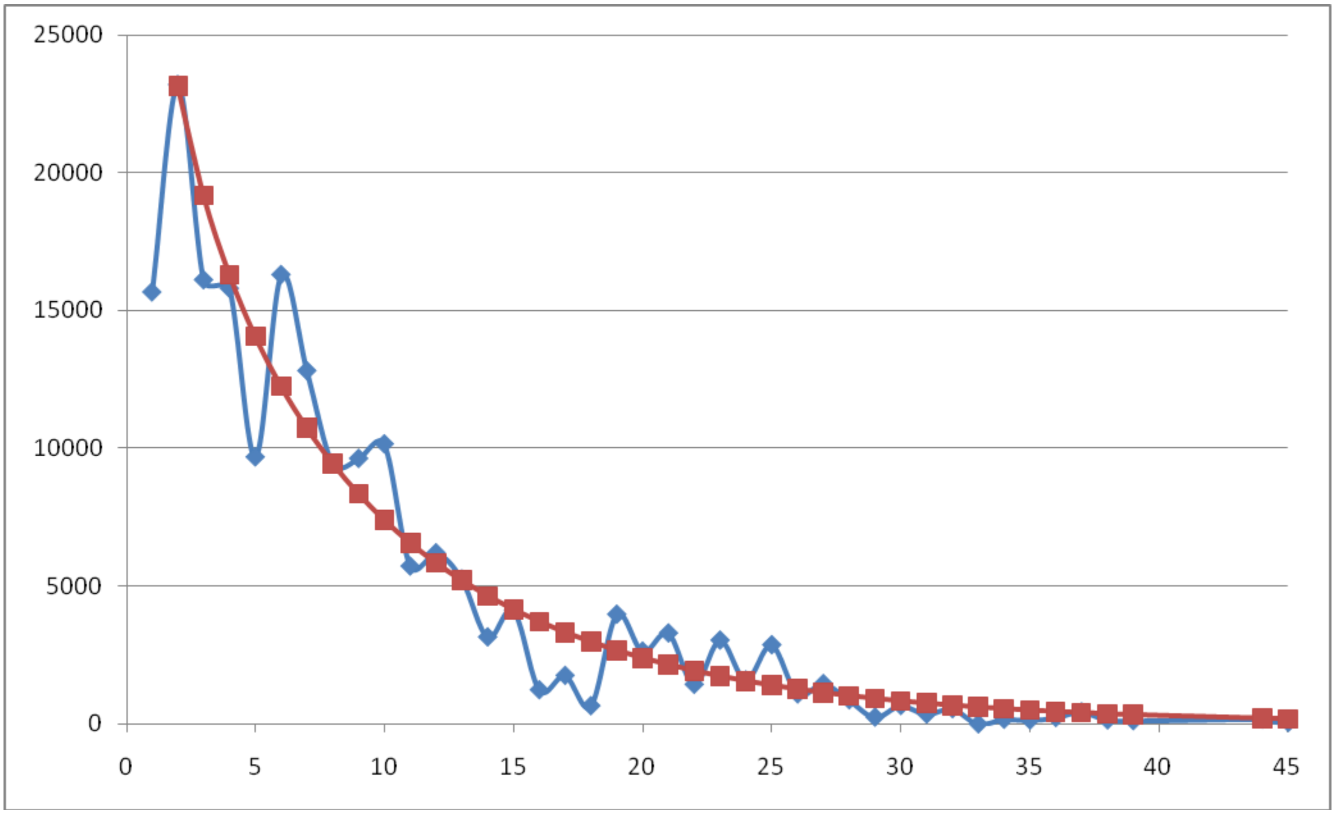

Figure 5.5: HBO Friction Factor Curves

Time	a	b	c
t >= 2	32903.6	0.2256	-0.0974

Table 5.6: HBO Gamma Curve Parameters

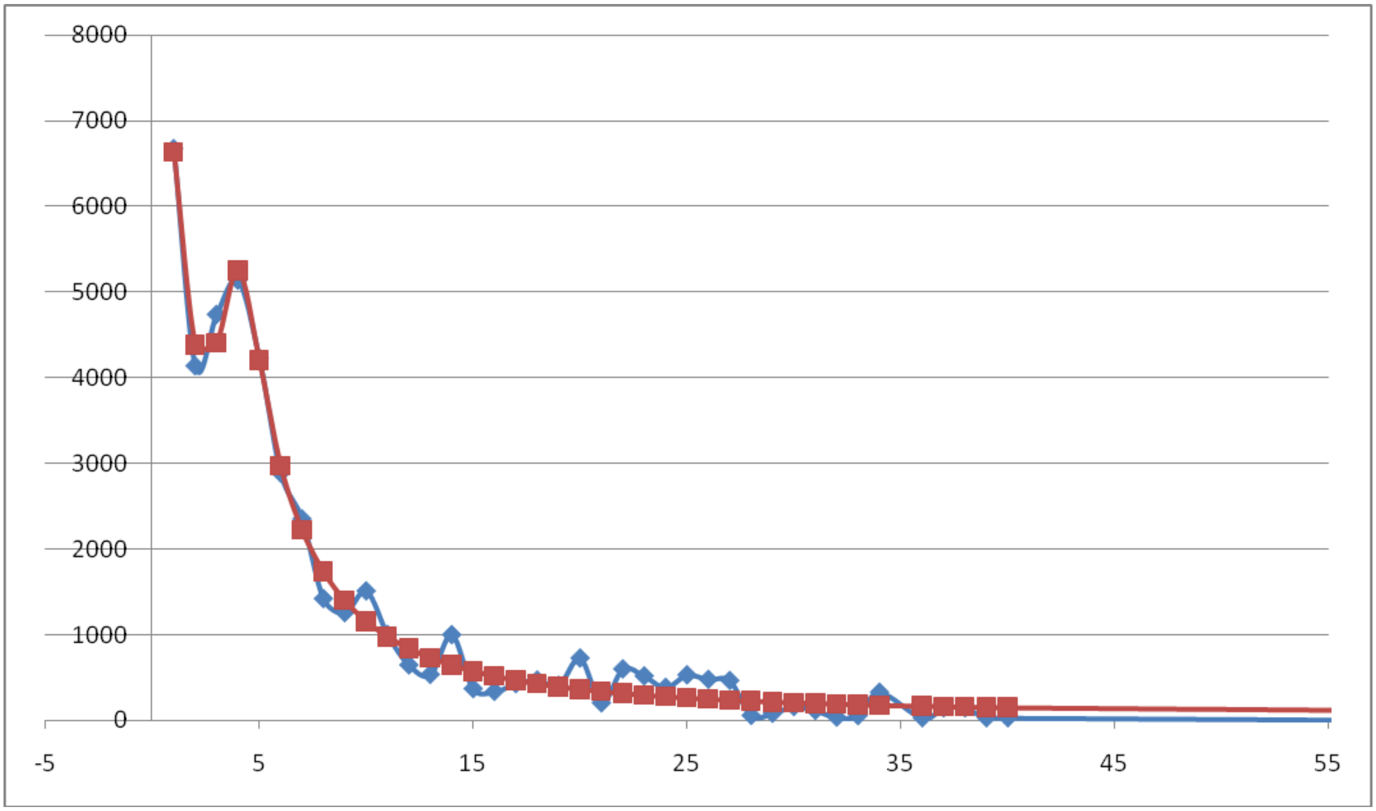

Figure 5.6: NHBW Friction Factor Curves

Time	a	b	c
t <= 4	3665.06	1.4528	0.5934
t > 4	100390.9	2.0551	0.0270

Table 5.7: NHBW Gamma Curve Parameters

Note that for values of time between 6 and 9 minutes, a linear interpolation is assumed

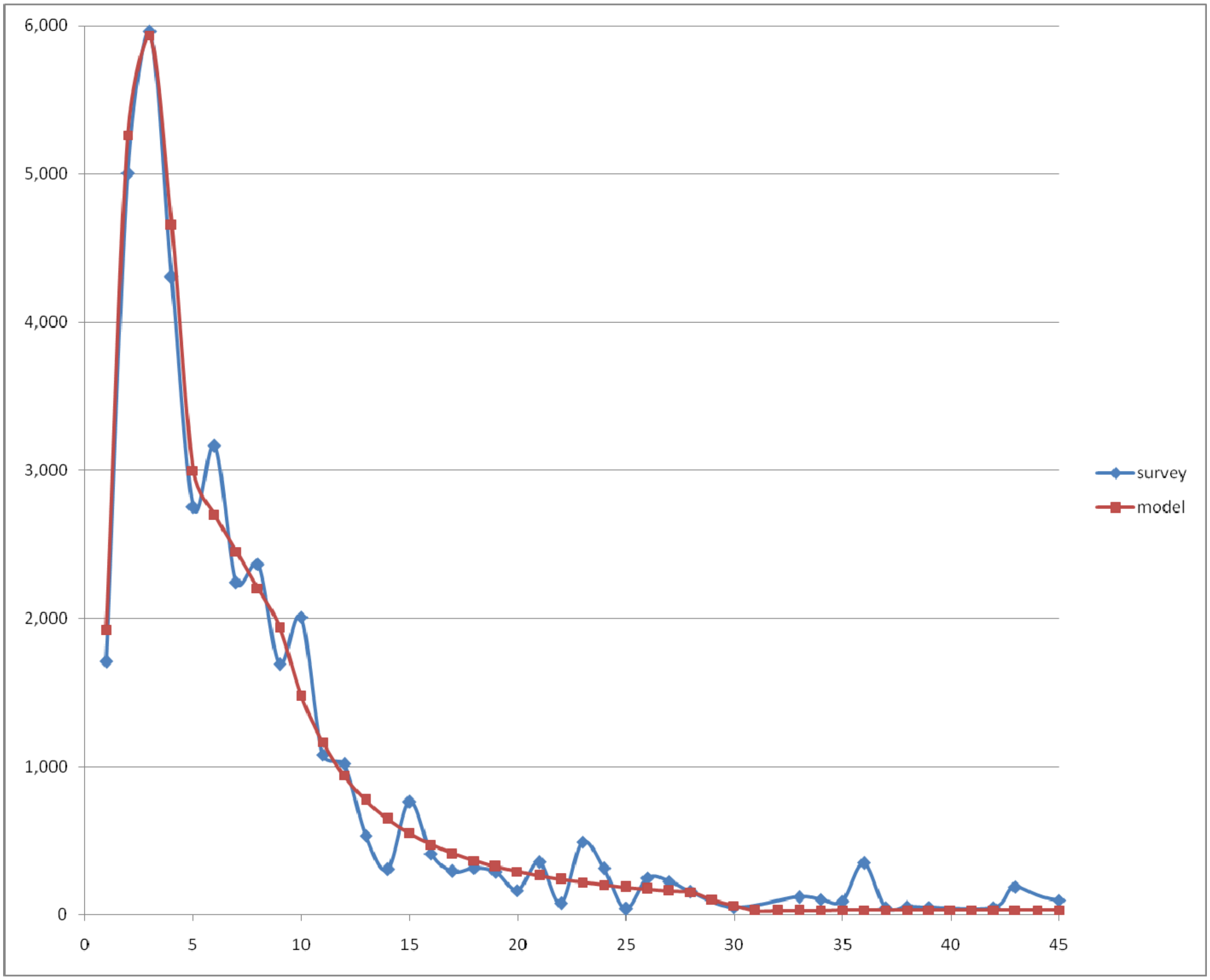

Figure 5.7: NHBO Friction Factor Curves

Time	a	b	c
t > 0	19396.3	-0.4687	-0.2906

Table 5.8: NHBO Gamma Curve Parameters

Note that for values of time between 5 and 9 minutes and between 28 and 31 minutes a linear interpolation is assumed

Truck Friction Factors

A slightly modified form of the truck friction factors from the previous version of the Whatcom model were employed (as shown in Table 5.9). The parameters in the previous version of the truck friction factors for travel times less than 8 minutes seemed unreasonably high and seemed to indicate that a majority of the truck trips are less than 3 minutes. After a few trial model runs, the HBW friction factors were employed for time values less than 8 minutes and the truck factors from the previous version of the model were employed for time values greater than or equal to 8 minutes. It is to be noted that a more accurate calibration of the truck friction factors is warranted and will improve model accuracy.

Time	a	b	c
t < 8	2411.28	0.4992	0.2887
t >= 8	22000	0.6	0.01

Table 5.9: Truck Gamma Curve Parameters

Based on the equations shown, friction factor tables for the PK and the OP trip distribution matrices were filled and used as inputs to the model.

External Trips

In the trip generation stage, the through trip count at each of the external stations was obtained for the PK and the OP period. Using the percentage of trucks at each external station, these counts were further split into auto and truck counts. From a seed through trip matrix (available from the previous version of the Whatcom model), a growth factor (or a FRATAR) method was applied to generate the auto and truck through trip matrix. This is finally added before the traffic assignment step.

Trip Distribution Results

The trip distribution produces a PK and an OP Production Attraction (PA) matrix. Each matrix has eight cores, one for each trip purpose and contains the zone to zone trips. The total number of trips allocated for each purpose and period matches the balanced productions and attractions for that purpose and period.

The model trip times are shown in the table 5.10 below. Note that trips from external to internal zones (XI) and internal to external zones (IX) trips are also included in this estimation. In general, there is no significant difference between the trip lengths in the PK and in the OP period.

Trip Purpose	Average Trip Time PK (min)	Average Trip Time OP (min)
HBW	14.16	14.75
HBSch	10.29	10.38
HBColl	12.63	13.08
HBShop	11.45	11.78
HBO	11.57	11.81
NHBW	10.05	10.72
NHBO	6.65	6.83
Truck	16.46	16.84

Table 5.10: Model Trip Times (including IX and XI trips)

The average trip lengths are shown in Table 5.11

Trip Purpose	Average Trip Length PK (miles)	Average Trip Length OP (miles)
HBW	9.88	10.13
HBSch	6.71	6.54
HBColl	7.85	7.77
HBShop	7.87	7.76
HBO	7.80	7.72
NHBW	7.32	7.68
NHBO	4.39	4.35
Truck	11.44	11.20

Table 5.11: Model Trip Lengths

The output PA matrices from the trip distribution are input to the mode choice procedure.

Chapter 6: Mode Choice

The mode choice module in the Whatcom model is applied for the PK and the OP trip distribution matrices. Nested Logit models were developed with the model structure and co-efficient values dependent on the trip purpose and on the time period (PK or OP). This chapter describes the model choice estimation (and application) process in detail.

Mode Choice Estimation

The process of estimating mode choice models can be grouped below:

- Analyze the various components of the travel survey. Extract a database with all the appropriate trip records and attach the person and household characteristics to each record. Attribute a trip purpose to each trip record.
- Identify survey and demographic variables that can potentially explain mode choice decisions by trip purpose. Develop hypotheses on how each of these variables is expected to affect the different modes.
- Obtain highway and transit skims.
- Define a nested choice tree for each purpose and set up the mode utility equations using TransCAD's Nested Logit Estimation interface.
- Perform comprehensive estimations for each trip purpose to determine the best model that has realistic utility and nesting coefficients consistent with utility maximization theory. Multiple estimations are necessary because the estimated coefficients depend on the starting values of the nesting coefficients.
- Perform goodness of fit tests to ascertain the explaining power of the final model for each purpose. Perform hypothesis tests to ascertain if all variables contribute sufficiently towards explaining choice behavior.

Each of these steps is discussed in detail:

Variable Identification

A wide range of variables are typically available for use in mode choice models. These include mode attributes (e.g. highway and transit skims, tolls, fares, wait times, number of transfers), trip characteristics (e.g. purpose and vehicle occupancy) and trip-maker characteristics (e.g. household size and structure, income, number of licensed drivers, number of workers). In reality however, only some of these variables will contain information pertinent to explaining the mode choice decisions revealed through the survey. We therefore identified the variables that seemed to have the most potential for mode choice models in the Whatcom area.

Skims are perhaps the first variables that must be included in mode choice models. The highway and transit skims are expected to play critical roles in determining whether a person drives or rides a train to work. Further, these skims are likely to change in future scenarios, and therefore must be included in the model.

Other skims can also be very useful in the mode choice context. For example, distance skims can contain valuable information about the attractiveness of non-motorized modes such as bike and walk. If the distance is greater than some value, say 2 miles, such modes are unlikely to be considered by trip-makers. The distance skims can also be used to determine the availability or unavailability of non-motorized modes.

Other variables considered were the household income level and transit fares of 75 cents on the transit system.

We also developed a priori hypotheses on the signs of the coefficients associated with the above variables. A variable with a negative coefficient will reduce the mode's utility (and the chance of this mode being chosen) when the value of the variable increases. Conversely, a positive coefficient increases the attractiveness of the associated mode(s) when the value of the variable rises. Thus skim variables are expected to have negative coefficients: greater the travel time or distance, lower the utility (and lower the probability that the mode is chosen). By the same reasoning, fare is expected to decrease the utility of the transit modes. A higher household income, or a greater number of cars available in the household, is expected to lead to more drive trips, thus resulting in positive coefficients under the Drive Alone and Carpool modes.

During the survey processing, we noticed that transit trips were primarily obtained only for the NHB trips. One likely explanation is that these trips are made by students to get around the university region and are thus NHB trips.

Skimming

Congested highway and transit skims are crucial to mode choice modeling. These skims depend on a realistic OD table and a sufficiently converged assigned. However only highway skims based on free-flow speeds were initially available for the Whatcom network, while measured transit skims were tagged to TransCAD route systems. These skims were used for preliminary mode choice estimation. The parameters were re-estimated after congested highway skims were produced from model feedback runs. This report documents the model parameters from the final round of model estimations.

In addition to highway skims, walk skims and bike skims were created based on speeds of 4mph and 15mph respectively. For this purpose a non-motorized network without highways, ramps were created.

Nested Model Specifications

The following steps must be executed before a mode choice model can be estimated:

Identifying the available modes
Defining the decision tree
Writing the utility equations for each mode

Each trip purpose is likely to have a set of modes that is realistic for that particular choice situation. For example, school trips will include the school bus as an alternative, while this mode will not be available for a good majority of work trips and all shopping trips.

It is very difficult to estimate coefficients for modes that are rarely chosen in the survey. In fact, this task is impossible if a particular mode is never chosen by any of the respondents. The survey was therefore analyzed to determine the modes that dominate each trip purpose. Modes that are chosen infrequently were combined in some instances to yield a single "other" mode. Table 6.1 summarizes the modes deemed available for each purpose. Mode choice estimation is obviously not done for Truck trips.

Mode	HBW	HBSch	HBColl	HBShop	HBO	NHBW	NHBO
Drive Alone (DA)	√	√	√	√	√	√	√
Carpool (CP)	√	√	√	√	√	√	√
Bike	√	√	√	√	√	√	√
Walk	√	√	√	√	√	√	√
Transit						√*	√
School Bus		√				√*	√*

Table 6.1: Availability of Modes by Trip Purpose

It should be noted that the NHBW purpose features the Transit mode only during the peak period and both the NHBO and NHBW purposes feature the School Bus mode only during the peak period.

Table 6.1 lists the modes that are generally available for each trip purpose. However, a specific trip-maker (or origin-destination pair) may not have all these modes available. For example, transit may not be an option if it takes far too long to access the service. Thus the availability of each mode within each trip purpose must be defined in matrix form.

Availability matrices have the same dimension and row/column indices as the OD or PA matrix used by the planning model. Each cell in the matrix is a binary value indicating the availability of a specific mode (1 if the mode is available for that OD pair, 0 otherwise). Transit availability is usually determined through a transit slimming procedure. If an OD pair has no feasible transit skim, then transit is deemed unavailable for that OD pair. The availability of non-motorized modes such as walk and bike may be determined more directly based on a distance skim cut-off. The walk mode was deemed unavailable if the distance was greater than 2 miles and bike mode was deemed unavailable if the distance was greater than 5 miles. TransCAD's mode choice model estimation and application engines explicitly allow the modeler to specify mode-specific availability matrices. For the Whatcom model, Transit, Walk and Bike availability matrices were used. The drive modes (DA and CP) were assumed to be available for all OD pairs.

Once the available modes have been identified, they must be arranged into a decision tree for each purpose. When all modes are assumed to be independent, a multinomial logit (MNL) model is obtained. MNL has a mathematical form that is easy to apply, though it suffers from the Independence from Irrelevant Alternatives (IIA) property. Essentially, if two or more modes share unobserved effects, the MNL probabilities and elasticities could be unrealistic. Nested logit (NL) models are recommended as an upgrade to MNL in such situations. NL assumes that the mode choice decision happens in two or more levels. For example, trip-makers selecting from the modes in Table 6.1 may first choose between Auto 'mode' nest, Walk or Bike. If auto modes are preferred, then a further choice between Drive Alone and Carpool may be made.

For the Whatcom area, NL trees were defined for each of the seven trip purposes. The tree for HBW trips, both Peak and Off-Peak, is shown in Figure 6.1.

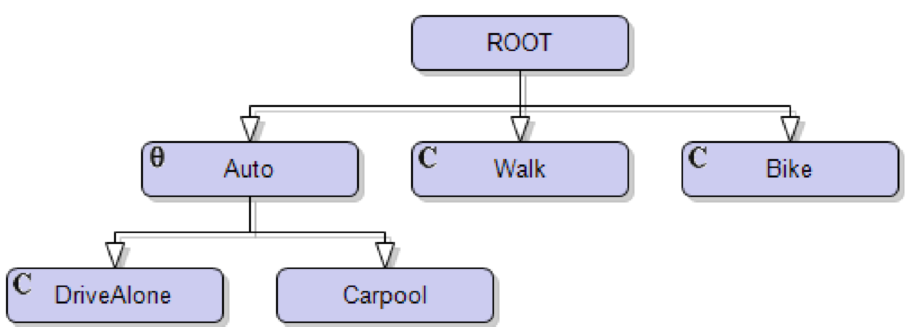

Figure 6.1: Nested Logit Tree for HBW Trips (Peak and Off-Peak)

In the NL model for work trips, Drive Alone (DA) and Carpool (CP) have been bunched together under the Auto nest. This implies that trip-makers perceive these two modes are somehow being similar. For example, they might share such attributes as safety, comfort and privacy. Bike and Walk are separate modes.

Note that the nests have structural parameters (denoted by **θ**) that must also be estimated along with the utility coefficients. Each **θ** is required to be within 0 and 1 to satisfy theoretical assumptions. For instance Bike and Walk trips in Figure 6.1 were initially grouped under a Non-Motorized nest but the structural parameter for the nest (**θ**) did not satisfy the theoretical assumptions. Hence this nest was abandoned. The **C** symbols indicate the modes that have alternative-specific constants (ASC). In Figure 6.1, the carpool mode is designated as the base and therefore has no ASC.

The Nested Logit tree structures for Peak and Off-Peak HBColl, HBShop, HBO trips and for Off-Peak NHBW trips are identical to the HBW trip purpose shown in Figure 6.1.

Figure 6.2 illustrates the NL decision trees for the HBSch purpose.

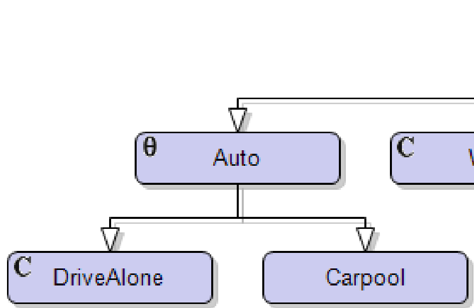

Figure 6.2: Nested Logit Tree for HB School Trips (Peak and Off-peak)

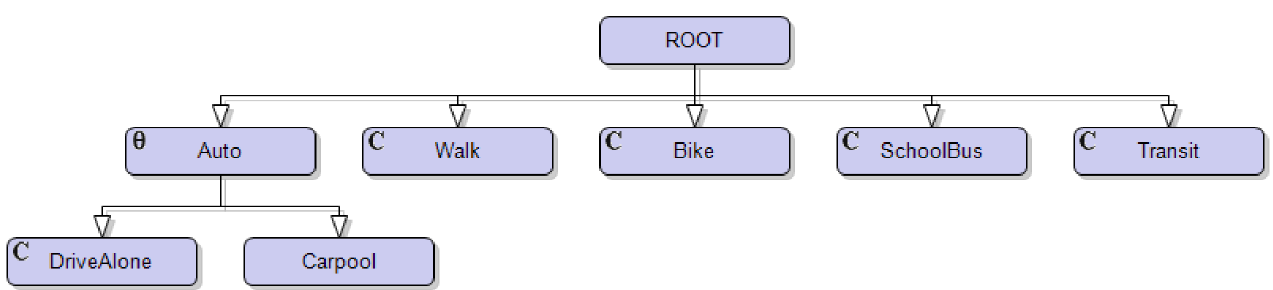

Figure 6.3: Nested Logit Tree for the Peak NHBO and Peak NHBW Trips

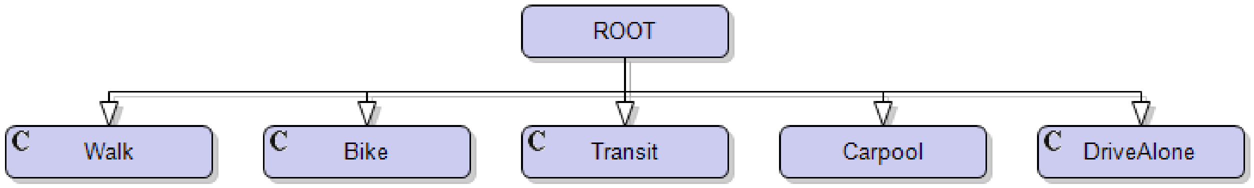

Figure 6.4: Nested Logit Tree for the Off-Peak NHBO Trips

During the model estimation, the main variables that we could use were the skims for each mode and the In-Vehicle time for transit. Due to the lack of a parking cost variable, we did not use any cost variables. The income variable was tried but yielded incorrect signs on the co-efficients. Various nest combinations were also examined. The utilities structure for the HBW, HBColl, HBShop, HBO and NHBW are identical and are shown in Table 6.2. For the Peak trips, the Auto_Time is the AM_Time and for Off-Peak trips, the Auto_Time is the MD_Time.

Coefficient	DA	CP	Bike	Walk
ASC_DA	1			
ASC_CP		Base		
ASC_Bike			1	
ASC_Walk				1
B_IVTT	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.2: General Utility Equations Structure for most trip purposes

Table 6.3 shows the utility equations for HBSch trips.

Coefficient	DA	CP	Bike	Walk	School Bus
ASC_DA	1				
ASC_CP		1			
ASC_Bike			Base		
ASC_Walk				1	
ASC_SchoolBus					1
B_IVTT	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	

Table 6.3: Utility Equations for HBSch trips (Peak and Off-Peak)

Tables 6.4 and 6.5 show the utility equations for NHBO Peak and Off-Peak trips

Coefficient	DA	CP	Bike	Walk	Transit	School Bus
ASC_DA	1					
ASC_CP		Base				
ASC_Bike			1			
ASC_Walk				1		
ASC_Transit					1	
ASC_SchoolBus						1
B_IVTT	Auto_Time	Auto_Time	Bike_Time	Walk_Time	Bus_IVTT	

Table 6.4: Utility Equations for NHBW Peak and NHBO Peak Trips

Coefficient	DA	CP	Bike	Walk	Transit
ASC_DA	1				
ASC_CP		Base			
ASC_Bike			1		
ASC_Walk				1	
ASC_Transit					1
B_IVTT	Auto_Time	Auto_Time	Bike_Time	Walk_Time	Bus_IVTT

Table 6.5: Utility Equations for NHBO Off-Peak Trips

Model Estimation

A model was estimated for each combination of trip purpose and time period (peak and off-peak) using TransCAD 5.0's new Nested Logit model estimation functionality. All estimated coefficients have the expected signs, and all structural parameters (**θ**) are between 0 and 1. The estimated models are thus consistent with discrete choice theory. The parameter estimates for each model are summarized below in Tables 6.6 to 6.17:

A nested logit model could not be estimated for HBColl trips after several experiments. HBColl trips were clubbed with HBW trips and a model was estimated for the combination (one model for PK and another for OP).

Parameter	Estimate	t statistic
B_IVTT	-0.0548	-1.50
ASC(DA)	0.2276	17.94
ASC(Bike)	-1.3026	-5.01
ASC(Walk)	-0.7044	-1.26
Theta(Auto)	0.1166 (starting = 0.1)	-80.14
Log-Likelihood at Zero		-463.4862
Log-Likelihood at End		-298.6193
Rho^2		0.3557
Adjusted Rho^2		0.3449

Table 6.6: Estimation Results for HBW and HBColl Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.0704	-3.66
ASC(SchoolBus)	-0.5342	-2.90
ASC(DA)	-0.9788	-8.28
ASC(Bike)	-1.6360	-5.60
ASC(Walk)	0.8973	3.61
Theta(Auto)	0.4858 (starting = 0.4)	-5.55
Log-Likelihood at Zero		-459.0589
Log-Likelihood at End		-363.5906
Rho^2		0.2080
Adjusted Rho^2		0.1949

Table 6.7: Estimation Results for HB School Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.2170	-2.45
ASC(DA)	0.1837	-0.07
ASC(Bike)	-3.0751	0.25
ASC(Walk)	1.7589	-1.08
Theta(Auto)	0.8133 (starting = 0.1)	-0.07
Log-Likelihood at Zero		-188.9571
Log-Likelihood at End		-142.1351
Rho^2		0.2478
Adjusted Rho^2		0.2213

Table 6.8: Estimation Results for HB Shop Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.1583	-7.90
ASC(DA)	-0.0437	-4.97
ASC(Bike)	-2.1248	-10.01
ASC(Walk)	1.0668	4.72
Theta(Auto)	0.1153 (starting = 0.1)	-26.85
Log-Likelihood at Zero		-905.1408
Log-Likelihood at End		-742.9100
Rho^2		0.1792
Adjusted Rho^2		0.1737

Table 6.9: Estimation Results for HBO Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.0824	-3.01
ASC(DA)	1.3909	2.59
ASC(Bike)	-1.1845	-1.83
ASC(Walk)	0.9220	1.25
ASC(Transit)	-2.4874	-4.52
ASC(School Bus)	-3.4659	-6.20
Theta(Auto)	0.8642 (starting = -3.0)	-0.41
Log-Likelihood at Zero		-371.9805
Log-Likelihood at End		-193.3328
Rho^2		0.4803
Adjusted Rho^2		0.4614

Table 6.10: Estimation Results for NHBW Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.0697	-5.11
ASC (DA)	-0.3521	-4.35
ASC (Transit)	-1.4149	-8.99
ASC(School Bus)	-2.8754	-11.77
ASC(Walk)	-0.0035	-0.02
ASC(Bike)	-3.9365	-7.01
Theta(Auto)	0.8922 (starting = -2.0)	-1.28
Log-Likelihood at Zero		-849.3956
Log-Likelihood at End		-643.1592
Rho^2		0.2428
Adjusted Rho^2		0.2346

Table 6.11: Estimation Results for NHBO Trips (Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.1328	-3.99
ASC(DA)	0.2400	20.59
ASC(Bike)	-1.1129	-4.88
ASC(Walk)	0.2068	0.54
Theta(Auto)	0.1179 (starting = 0.1)	-89.81
Log-Likelihood at Zero		-584.4742
Log-Likelihood at End		-645.8709
Rho^2		0.3882
Adjusted Rho^2		0.3797

Table 6.12: Estimation Results for HBW and HBColl Trips (Off-Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.0142	-0.37
ASC(SchoolBus)	-1.4791	-3.58
ASC(DA)	-0.2419	-7.54
ASC(Bike)	-2.3983	-3.96
ASC(Walk)	-0.6683	-1.27
Theta(Auto)	0.1293 (starting = 0.1)	-28.57
Log-Likelihood at Zero		-117.4438
Log-Likelihood at End		-90.1724
Rho^2		0.2322
Adjusted Rho^2		0.1811

Table 6.13: Estimation Results for HB School Trips (Off-Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.2120	-4.54
ASC(DA)	0.0488	2.43
ASC(Bike)	-1.4319	-4.35
ASC(Walk)	0.9751	2.24
Theta(Auto)	0.1234 (starting = 0.1)	-12.26
Log-Likelihood at Zero		-320.3424
Log-Likelihood at End		-267.9367
Rho^2		0.1636
Adjusted Rho^2		0.1480

Table 6.14: Estimation Results for HB Shop Trips (Off-Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.1838	-9.36
ASC(DA)	-0.1881	-1.53
ASC(Bike)	-2.2647	-4.67
ASC(Walk)	1.4673	3.68
Theta(Auto)	0.8880 (starting = 0.29)	-0.19
Log-Likelihood at Zero		-1527.5453
Log-Likelihood at End		-1205.6663
Rho^2		0.2107
Adjusted Rho^2		0.2074

Table 6.15: Estimation Results for HBO Trips (Off-Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.2098	-6.35
ASC(DA)	0.7780	5.07
ASC(Bike)	-1.8279	-3.58
ASC(Walk)	1.8495	5.45
Theta(Auto)	0.6022 (starting = 0.4)	-3.00
Log-Likelihood at Zero		-474.0647
Log-Likelihood at End		-309.1784
Rho^2		0.3478
Adjusted Rho^2		0.3373

Table 6.16: Estimation Results for NHBW Trips (Off-Peak)

Parameter	Estimate	t statistic
B_IVTT	-0.0779	-5.92
ASC (Walk)	-0.1952	-1.12
ASC (Bike)	-3.1827	-10.07
ASC(Transit)	-2.0764	-12.89
ASC(DA)	-0.2663	-3.45
Log-Likelihood at Zero		-1148.4032
Log-Likelihood at End		-858.4551
Rho^2		0.2525
Adjusted Rho^2		0.2481

Table 6.17: Estimation Results for NHBO Trips (Off-Peak)

Statistical Tests

The final log-likelihood and $\overline{\rho}^2$ (adjusted rho squared) statistics were inspected to ensure that the models possess a reasonable ability to predict the mode choice behavior observed in the survey. The *t* ratios for all estimated coefficients and parameters were further checked to verify that all selected variables contributed to explaining choice behavior for the respective trip purposes. These values may be seen in Tables 6.6 to 6.17 above. It should be noted that the utility coefficients and ASCs are tested against zero, while the **θ** values are tested against one (the null hypothesis of **θ** = 1 corresponds to the MNL model).

In a small number of instances, the estimated parameters possess relatively low *t* ratios. These parameters were nevertheless retained because of their known *a priori* importance to the task of explaining mode choice. For example, IVTT is an important driver of mode choice and must be included so that future scenarios may be sensitive to changes in skims.

Re-calibration of Constants (ASCs)

It should be noted that the estimation of mode choice models is performed on the un-weighted survey records. This is based on the assumption that the sampling method inherently yields survey records that are representative of the population. For various reasons, the weights cannot be directly used to replicate records in the estimation dataset. First, weights are generally not integers. Second, trip-makers with identical mode attributes and socio-economic characteristics can still make different choices, and this behavior is not captured through the weights alone.

For the above reasons, the performance of the estimated mode choice models may seem to be sub-optimal when the predicted shares are compared against the weighted survey shares. The ASCs of the choice models may therefore have to be re-calibrated to better reflect these weighted trips.

For the Whatcom model, the ASC's of the drive, walk, bike, school bus and transit modes were adjusted to match weighted shares in the survey by purpose and time period. The final model set with the adjusted ASC values is shown in the next section. Note that the values of the time co-efficient and the value of the nest structural parameter (**θ**) are not altered.

Final Model Set

The following tables (6.18-6.31) summarize the final set of models (by trip purpose and time period) proposed for the Whatcom region.

Peak Mode Choice Models

θ_Auto = 0.1166

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.2384	1			
ASC_CP			Base		
ASC_Bike	0.0915			1	
ASC_Walk	2.6858				1
B_IVTT	-0.0548	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.18: Utility Equations for HB Work Trips (Peak)

θ_Auto = 0.1166

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.0711	1			
ASC_CP			Base		
ASC_Bike	1.0960			1	
ASC_Walk	2.7268				1
B_IVTT	-0.0548	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.19: Utility Equations for HB CollegeTrips (Peak)

θ_Auto = 0.4858

Coefficient	Value	DA	CP	Bike	Walk	School Bus
ASC_DA	-1.3027	1				
ASC_CP			Base			
ASC_Bike	-0.2002			1		
ASC_Walk	4.9952				1	
ASC_SchoolBus	-1.6785					1
B_IVTT	-0.0704	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	

Table 6.20: Utility Equations for HB School Trips (Peak)

θ_Auto = 0.8133

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.1485	1			
ASC_CP			Base		
ASC_Bike	-1.3140			1	
ASC_Walk	4.8237				1
B_IVTT	-0.2170	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.21: Utility Equations for HB Shop Trips (Peak)

θ_Auto = 0.1153

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	-0.0836	1			
ASC_CP			Base		
ASC_Bike	-0.4212			1	
ASC_Walk	4.9934				1
B_IVTT	-0.1583	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.22: Utility Equations for HBO Trips (Peak)

θ_Auto = 0.8642

Coefficient	Value	DA	CP	Bike	Walk	Transit	School Bus
ASC_DA	1.6618	1					
ASC_CP			Base				
ASC_Bike	0.4827			1			
ASC_Walk	3.4220				1		
ASC_Transit	-2.487					1	
ASC_SchoolBus	-3.466						1
B_IVTT	-0.070	Auto_Time	Auto_Time	Bike_Time	Walk_Time	Bus_IVTT	

Table 6.23: Utility Equations for NHBW Trips (Peak)

θ_Auto = 0.8922

Coefficient	Value	DA	CP	Bike	Walk	Transit	School Bus
ASC_DA	-0.302	1					
ASC_CP			Base				
ASC_Bike	-4.037			1			
ASC_Walk	3.437				1		
ASC_Transit	-0.748					1	
ASC_SchoolBus	-3.008						1
B_IVTT	-0.070	Auto_Time	Auto_Time	Bike_Time	Walk_Time	Bus_IVTT	

Table 6.24: Utility Equations for NHBO Trips (Peak)

Off-Peak Mode Choice Models

θ_Auto = 0.1166

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.2905	1			
ASC_CP			Base		
ASC_Bike	-2.3361			1	
ASC_Walk	1.8285				1
B_IVTT	-0.1328	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.25: Utility Equations for HB Work Trips (Off-Peak)

θ_Auto = 0.1166

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.2209	1			
ASC_CP			Base		
ASC_Bike	-0.1255			1	
ASC_Walk	4.4558				1
B_IVTT	-0.1328	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.26: Utility Equations for HB College Trips (Off-Peak)

θ_Auto = 0.1293

Coefficient	Value	DA	CP	Bike	Walk	School Bus
ASC_DA	-0.2615	1				
ASC_CP			Base			
ASC_Bike	-2.1359			1		
ASC_Walk	0.6106				1	
ASC_SchoolBus	-1.6354					1
B_IVTT	-0.0142	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	

Table 6.27: Utility Equations for HB School Trips (Off-Peak)

θ_Auto = 0.1234

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.3580	1			
ASC_CP			Base		
ASC_Bike	-3.7514			1	
ASC_Walk	1.2403				1
B_IVTT	-0.2120	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.28: Utility Equations for HB Shop Trips (Off-Peak)

θ_Auto = 0.8880

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	-0.2916	1			
ASC_CP			Base		
ASC_Bike	-3.7510			1	
ASC_Walk	2.1214				1
B_IVTT	-0.1838	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.29: Utility Equations for HBO Trips (Off-Peak)

θ_Auto = 0.6022

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	1.2533	1			
ASC_CP			Base		
ASC_Bike	-3.5670			1	
ASC_Walk	0.0282				1
B_IVTT	-0.2098	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 6.30: Utility Equations for NHBW Trips (Off-Peak)

Coefficient	Value	DA	CP	Bike	Walk	Transit
ASC_DA	-0.2063	1				
ASC_CP			Base			
ASC_Bike	-3.5046			1		
ASC_Walk	-0.0377				1	
ASC_Transit	-1.3415					1
B_IVTT	-0.0779	Auto_Time	Auto_Time	Bike_Time	Walk_Time	Bus_IVTT

Table 6.31: Utility Equations for NHBO Trips (Off-Peak)

Application of the Mode Choice Models

The mode choice models are applied to the outputs of the trip distribution stage. Specifically, the PK mode choice model is applied to the PK PA matrix in conjunction with the PK highway and transit skims and using appropriate variables from the TAZ layer. The Drive Alone and Carpool trips components are output to the Auto matrix, the Walk and Bike components are output to the Non-Motorized matrix, the transit components are output in the transit matrix and all other modes (school bus) are output to the *Other* matrix.

The above process was likewise applied to the OP period (using OP skims and TAZ attributes).

Comparison of Survey and Model Mode Shares

The following four tables show the comparison of the model mode choice shares with those aggregated from the survey. Tables 6.32 and 6.33 compare model and survey shares by purpose, for the PK and the OP periods respectively. The tables indicate a reasonably close match to the survey shares. In general, it was difficult to match walk shares for the PK period and due to the availability variable, increasing the walk ASC beyond any value had no effect.

Purpose	DA Share	CP Share	Walk Share	Bike Share	Transit Share	School Bus Share
HBW Survey	79.0%	8.7%	4.6%	7.7%	-	-
HBW Model	79.3%	10.3%	3.8%	6.6%	-	-
HBColl Survey	51.6%	24.9%	5.0%	18.6%	-	-
HBColl Model	50.2%	27.3%	4.0%	18.5%	-	-
HBSch Survey	4.5%	34.6%	17.2%	3.9%	-	39.9%
HBSch Model	3.3%	47.5%	5.7%	3.6%	-	40.0%
HBShop Survey	50.7%	39.9%	8.7%	0.8%	-	-
HBShop Model	52.2%	43.4%	3.7%	0.7%	-	-
HBO Survey	28.0%	46.6%	23.1%	2.4%	-	-
HBO Model	29.5%	60.8%	6.7%	3.0%	-	-
NHBW Model	65.3%	15.0%	9.6%	4.1%	4.3%	1.7%
NHBW Survey	70.0%	10.2%	7.2%	3.6%	6.5%	2.4%
NHBO Survey	21.4%	31.0%	14.5%	0.4%	24.6%	8.2%
NHBO Model	28.8%	40.4%	10.7%	0.1%	11.7%	8.3%

Table 6.32: Comparison of PK Mode Choice Shares by purpose

The OP comparisons are shown in the table below. Note that the OP contains the bulk of the trips and the shares are replicated closely.

Purpose	DA Share	CP Share	Walk Share	Bike Share	Transit Share	School Bus Share
HBW Survey	81.4%	8.9%	5.3%	4.4%	-	-
HBW Model	83.8%	7.1%	4.2%	4.9%	-	-
HBColl Survey	68.3%	10.8%	11.1%	9.8%	-	-
HBColl Model	68.1%	10.5%	6.2%	15.3%	-	-
HBSch Survey	7.5%	61.2%	11.4%	3.4%	-	16.4%
HBSch Model	7.8%	58.9%	12.6%	3.6%	-	17.1%
HBShop Survey	82.2%	9.0%	5.3%	4.4%	-	-
HBShop Model	83.6%	4.6%	6.2%	5.6%	-	-
HBO Survey	35.1%	51.2%	12.2%	1.1%	-	-
HBO Model	36.1%	50.2%	10.8%	2.9%	-	-
NHBW Model	81.8%	9.0%	5.3%	4.4%	-	-
NHBW Survey	79.4%	9.8%	6.5%	4.4%	-	-
NHBO Survey	30.8%	41.3%	9.6%	1.0%	16.8%	-
NHBO Model	35.9%	44.1%	11.0%	2.0%	7.1%	-

Table 6.33: Comparison of OP Mode Choice Shares by purpose

The percentage of transit trips for the NHBO purpose for both the Peak and Off-Peak period is lower than the survey share. Initially the ASC for transit was adjusted to exactly replicate the transit survey shares. However, this resulted in an unreasonable number of transit trips and the total boardings from the transit assignment were significantly greater than the observed boardings provided by the Whatcom Transit Agency (WTA).

It is also to be noted that a slightly different weighing scheme for the survey database (Chapter 2) may have resulted in slightly different transit survey shares. Further, the sample size of survey records for modes that are not frequently used are small and hence the mode shares of these modes can vary depending on the weighing procedure. Therefore, we decided to adjust the transit shares to match the boardings data rather than the weighted survey shares. This resulted in lower transit shares as seen in Tables 6.32 and 6.33.

The Mode Choice module is not applied to the IX (Internal External) and XI (External Internal) trips because these matrices were created using auto and truck counts at the external stations.

Chapter 7: Time of Day Procedure

The Whatcom model update has a time of day component that splits the PK PA and the OP PA matrices obtained after the mode choice procedure into sub-period (AM, PM) and (MD and NT) OD matrices respectively. These are then input to the traffic and transit assignment. The onset and duration of each time period were obtained by plotting the various trips from the survey by departure hour. A plot of trips (all purposes) by departure hour is shown in Figure 7.1 below:

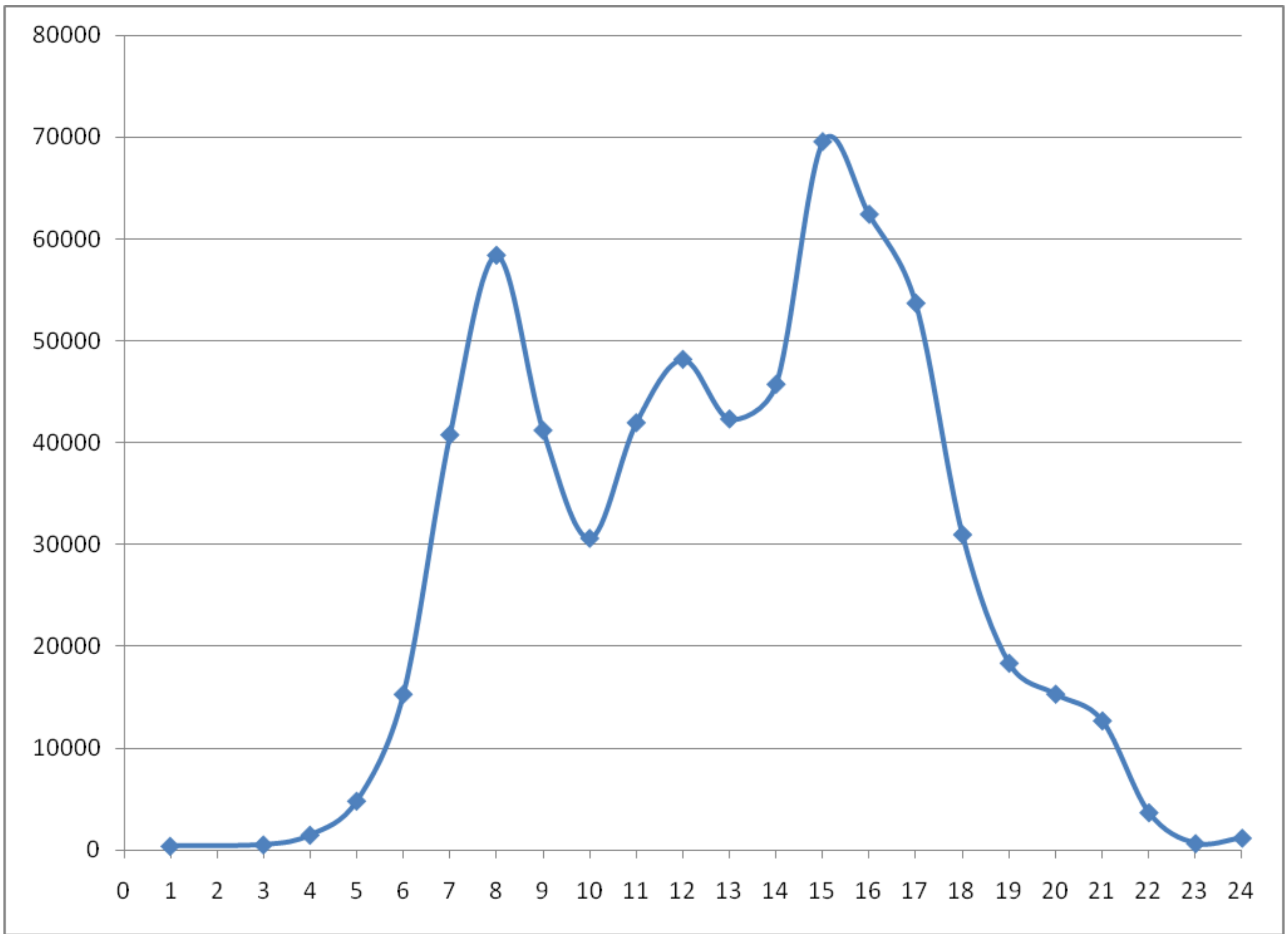

Figure 7.1: Trips by Departure Hour

Based on the figure, we designated the four time periods; AM Peak, Mid-day (MD), PM Peak and Night (NT) as follows:

AM – 7 AM to 9 AM

MD – 9 AM to 2 PM

PM – 2 PM to 5 PM, with the NT containing the rest of the hours

The time of day departure and return rates were constructed from the survey, using the above time period definitions. It is worthwhile to note that for any hour (or period), the appropriate OD matrix can be obtained by multiplying the departure rate with the PA matrix and adding to this the product of the return rate multiplied by the transpose of the PA matrix. In the case of converting carpool trips, this result is further multiplied by the appropriate carpool occupancy rate in order to obtain vehicle trips. The salient features of the time of day procedure are:

- The time of day departure and return rates are developed separately for the auto and transit modes. For each case, PK and OP departure and return rates were obtained.
- The **Auto** time of day procedure is applied on the PK and OP mode choice auto matrices by purpose. The PK Auto time of day procedure operates on the PK Auto matrix (that contains PK drive alone and carpool trips by purpose) and the OP Auto time of day procedure operates on the OP Auto Matrix (that contains OP drive alone and carpool trips by purpose).
- Likewise, the **Transit** time of day procedure is applied on the PK and OP mode choice transit matrices by purpose.
- The PK time of day procedure (both auto and transit) split the trips into the AM and the PM sub-periods and creates AM and PM OD matrices (auto and transit).
- The OP time of day procedure (both auto and transit) split the trips into the MD and NT sub-periods and creates MD and NT OD matrices (auto and transit).
- During the process, vehicle carpool occupancy rates are used to convert person trips of the carpool auto mode to vehicle trips. The carpool occupancy rates (2+ carpool) for the HBW, HBSch, HBColl, HBShop, HBO, NHBW and NHBO purposes are 2.254, 2.520, 2.000, 2.186, 2.576, 2.341 and 2.371 respectively. These occupancy factors were obtained from the carpool trips reported in the survey. Note that transit OD trips are left as person trips for transit assignment. There is no occupancy factor for Truck Trips.
- The time of day procedure (above) is not applicable to the Internal External (IX) and the External Internal Trips (XI) trips, since the original data was already in OD format. (As mentioned earlier in the mode choice chapter, this is why the mode choice output matrices were zeroed out for IX and XI trips).
- Once the time of day procedure is complete, the IX and XI trips are added directly from the PK and OP trip distribution results into the OD matrices for the appropriate sub-period. (Note that during this procedure, the PK trips had to split into AM and PM trips and the OP trips had to be split into MD and NT trips. These splits were done using the ratios in the External Trips input file).

Time of Day Tables

In order to develop departure and return rates, trips had to be classified as departure trips or return trips. For the home based trip purposes, the departure trip occurs from the home end and the return trips is one that is destined to the home end of the trip. For the NHB purposes however, there is no such clear demarcation and hence the total rate was equally split to obtain departure and return rates.

The Auto PK departure and return rates are obtained by looking at all the Auto trips from the survey that departed during the PK period (7 AM to 9 AM and 2 PM to 5 PM). The Auto OP departure and return rates are obtained by looking at all the Auto trips from the survey that departed during the OP period (9 AM to 2 PM and 5 PM to 7 AM). Likewise, transit departure and return rates were determined using the transit trips in the survey.

The departure and return rates were developed for hourly intervals but have been aggregated to the respective time periods. Table 7.1 shows the Auto departure and return rates for the PK period.

Purpose	AM_Dep	AM_Ret	PM_Dep	PM_Ret
HBW	44.0%	1.0%	6.0%	49.0%
HBColl	50.0%	0.0%	0.0%	50.0%
HBSch	49.1%	0.0%	0.9%	50.0%
HBShop	14.2%	2.5%	35.8%	47.5%
HBO	22.9%	5.5%	27.1%	44.5%
NHBW	12.8%	12.8%	37.2%	37.2%
NHBO	7.9%	7.9%	42.1%	42.1%
Truck	15.5%	15.5%	34.5%	34.5%

Table 7.1: Peak Auto Hourly Table

Some features of the above table are:

The above departure and return percentages by purpose pertain only to the Peak Period (7 AM to 9 AM and 2PM to 5PM). Note that this lookup table operates only on the PK Auto and Carpool trips from the mode choice.

The departure percentages sum to 50% and the return percentages sum to 50%, thus constituting 100% of the trips.

For example, in order to compute the HBW Drive Alone OD matrix and the HBW Carpool OD Matrix for the AM period, the formulation is:

- HBW Drive Alone AM OD = 44.0 % of (HBW Drive Alone PA) + 1.0 % of (HBW Drive Alone PA transpose)
- HBW Carpool AM OD = (44.0 % of (HBW Carpool PA) + 1.0 % of (HBW Carpool PA transpose)/2.254, where 2.081 is the carpool 2+ occupancy rate for the HBW purpose.

Table 7.2 shows the Auto departure and return rates for the Off-Peak period (9 AM to 2PM and 5PM to 7 AM of the following day). This lookup table operates only on the OP Auto and Carpool trips from the mode choice model.

Purpose	MD_Dep	MD_Ret	NT_Dep	NT_Ret
HBW	18.8%	12.7%	32.2%	37.3%
HBColl	19.9%	6.8%	30.1%	43.2%
HBSch	26.4%	19.4%	23.6%	30.6%
HBShop	37.2%	27.9%	12.8%	22.1%
HBO	26.1%	18.3%	23.9%	31.7%
NHBW	35.9%	35.9%	14.1%	14.1%
NHBO	36.4%	36.4%	13.6%	13.6%
Truck	25.0%	25.0%	25.0%	25.0%

Table 7.2: Off-Peak Auto Hourly Table

After the PA to OD conversion, the IE (Internal-External) and EI (External-Internal) Auto and Truck trip matrices are added to the respective periods. Previously, the IE and EI trips for the PK and OP periods were generated during the trip distribution and these already contained auto and truck vehicle trips. The AM peak and PM Peak counts at the external stations are used to split the Peak Auto and Truck IE and EI trips into AM and PM matrices, which are then added to the respective OD matrices. Likewise, the Off-Peak Auto and Truck IE and EI trips are split into MD and NT IE and EI trips and added to the respective OD matrices. Finally, the through trip auto and truck matrices are added to the auto and truck OD matrices for each period.

Tables 7.3 and 7.4 show the departure and return rates for the PK and OP transit matrices. Note that the transit hourly tables only apply to the NHBW and NHBO purposes, since these are the only purposes that have transit trips. These purposes are combined to obtain the transit time of day factors.

Purpose	AM_Dep	AM_Ret	PM_Dep	PM_Ret
NHBW and NHBO	13.4%	13.4%	36.6%	36.6%

Table 7.3: Peak Transit Hourly Table

Purpose	MD_Dep	MD_Ret	NT_Dep	NT_Ret
NHBW and NHBO	38.2%	38.2%	11.8%	11.8%

Table 7.4: Off-Peak Transit Hourly Table

Time of Day Results

The following four tables show the auto and transit OD totals by time period and purpose after the Time of Day procedure and before the traffic assignment.

Trip Purpose	AM Auto/Truck OD Trips
HBW	12,159
HBSch	4,575
HBColl	757
HBShop	3,272
HBO	13,856
NHBW	4,542
NHBO	4,157
Trucks	2,730
Total	**46,046**

Table 7.5: AM OD Auto and Transit Trips

Trip Purpose	MD Auto/Truck OD Trips
HBW	11,459
HBSch	1,890
HBColl	696
HBShop	28,089
HBO	33,580
NHBW	20,722
NHBO	36,635
Trucks	20,473
Total	**153,543**

Table 7.6: MD OD Auto and Transit Trips

Trip Purpose	PM Auto/Truck OD Trips
HBW	14,861
HBSch	4,206
HBColl	757
HBShop	16,319
HBO	34,934
NHBW	13,199
NHBO	22,152
Trucks	6,074

Total	**112,502**

Table 7.7: PM OD Auto and Transit Trips

Trip Purpose	NT Auto/Truck OD Trips
HBW	24,970
HBSch	2,238
HBColl	1,914
HBShop	15,084
HBO	42,131
NHBW	8,101
NHBO	13,621
Trucks	20,479
Total	**128,538**

Table 7.8: NT OD Auto and Transit Trips

Period	Transit OD Trips
AM	2,205
MD	4,555
PM	6,023
NT	1,407
Total	**14,190**

Table 7.9: Transit OD Trips by period

Chapter 8: Traffic Assignment

The traffic assignment procedure is run for each of the four time periods (AM, PM, MD and NT). If a feedback procedure is employed, then only the AM and MD assignments are run during the intermediate loops. The assignments for all the time periods are executed during the final loop of the feedback process. The feedback process is discussed in detail in the following chapter.

The features of the traffic assignment during each loop are as follows:

The assignment method is Origin User Equilibrium run to a relative gap of 1e-6
The assignment consists of two classes, cars and trucks
Trucks have a Passenger Car Equivalence (PCE) of 2.0
The assignment employs the BPR delay function

Assignment Parameters

The volume delay function (VDF) used in the previous version of the Whatcom model was essentially retained. The VDF is a BPR formulation as shown, where v/c represents the volume to the capacity ratio, α and β are delay parameters that vary depending on the type of the link as shown in Table 8.1, t_f is the free flow time and t is the congested time.

$$t = t_f\left[1 + \alpha\left(\frac{v}{c}\right)^{\beta}\right]$$

Type	Class	Alpha	Beta
1	Freeway	0.25	9.0
2	Major Arterial	1.25	6.0
4	Minor Arterial	1.00	5.0
5	Major Collector	1.00	6.0
6	Minor Collector	1.00	6.0
7	Ramp	1.00	6.0
9	Centroid Connector	0.15	4.0

Table 8.1: VDF Parameters

The plot of the VDF equations is shown in Figure 8.1. The horizontal axis shows the volume to capacity ratio and the vertical axis represents the ratio of congested time to free flow times. The values of the delay parameters are from HCM recommendations.

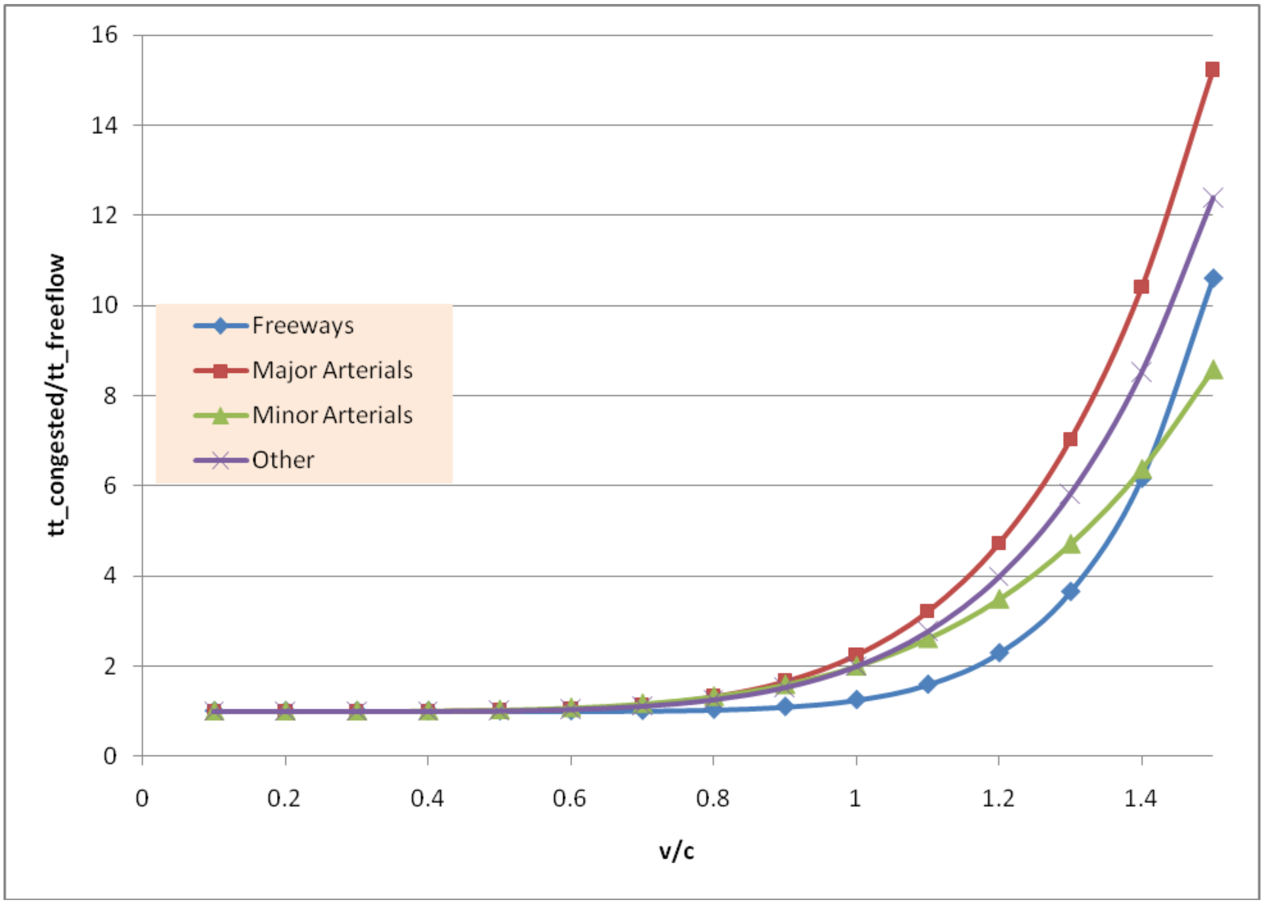

Figure 8.1: Volume Delay Functions by Functional Class

Assignment Results

The traffic assignment results are presented for the four time periods. The congestion plots for each of the time periods are shown in figures 7.2 to 7.5. The assignment results for each period were compared with traffic count data by period and the results are then discussed:

Figure 7.2 shows a scaled symbol and color theme plot where the thickness of each line feature is proportional to the flow on the link and the color theme shows the congestion of each feature (measured using the Volume to Capacity VOC ratio on the link). A red color indicates a high VOC and a green color indicates a low VOC value.

Figure 7.3 shows a close-up of the assignment results in the city of Bellingham.

Figures 7.4 and 7.5 show the plots for the PM period.

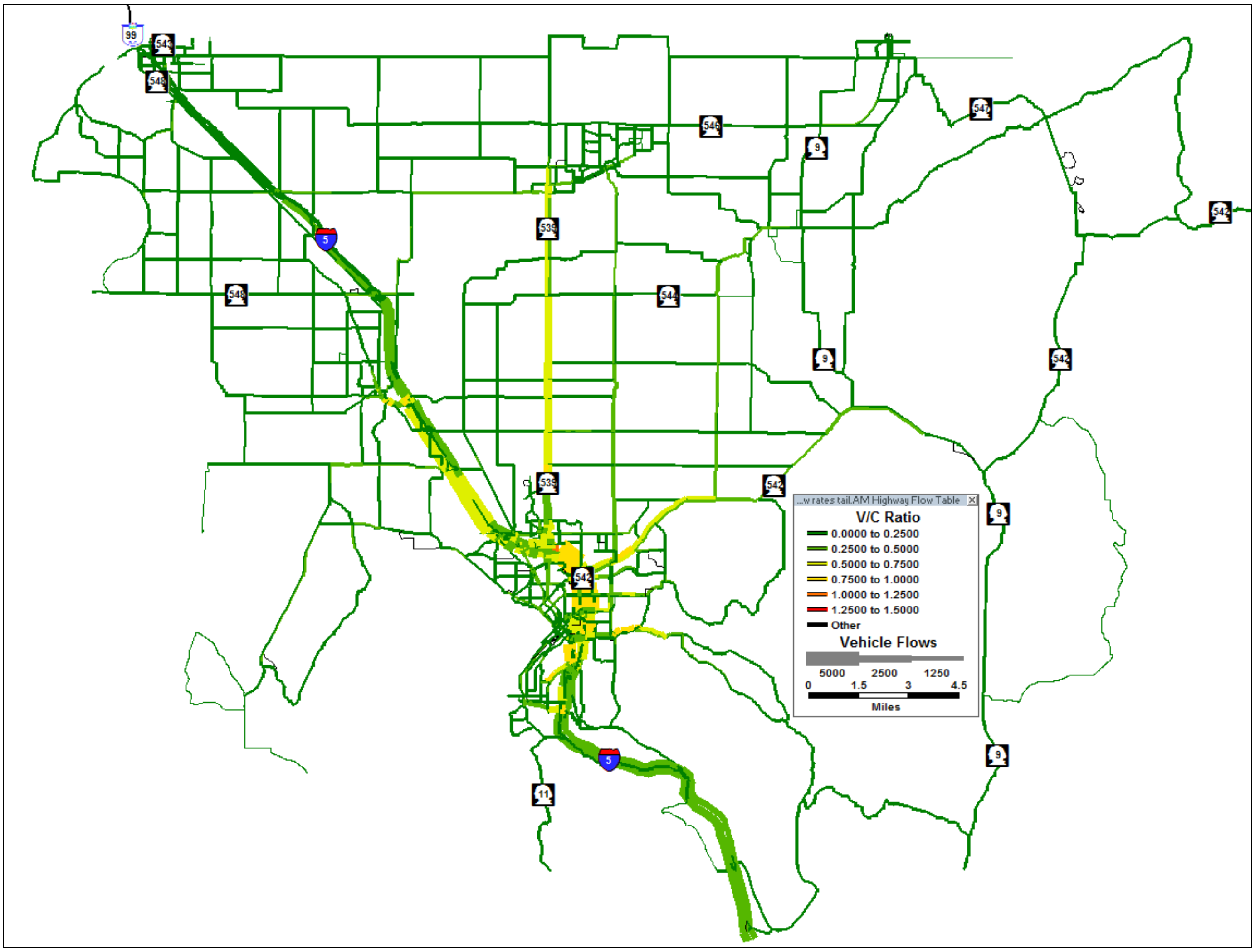

Figure 8.2: AM Period Congestion Pattern

The AM period congestion pattern shows significant congestion along the I-5 corridor in the vicinity of Bellingham and along route 539 (Guide Meridian road). Most of the other locations are not congested. Figure 8.3 shows a close up of the AM assignment in Bellingham.

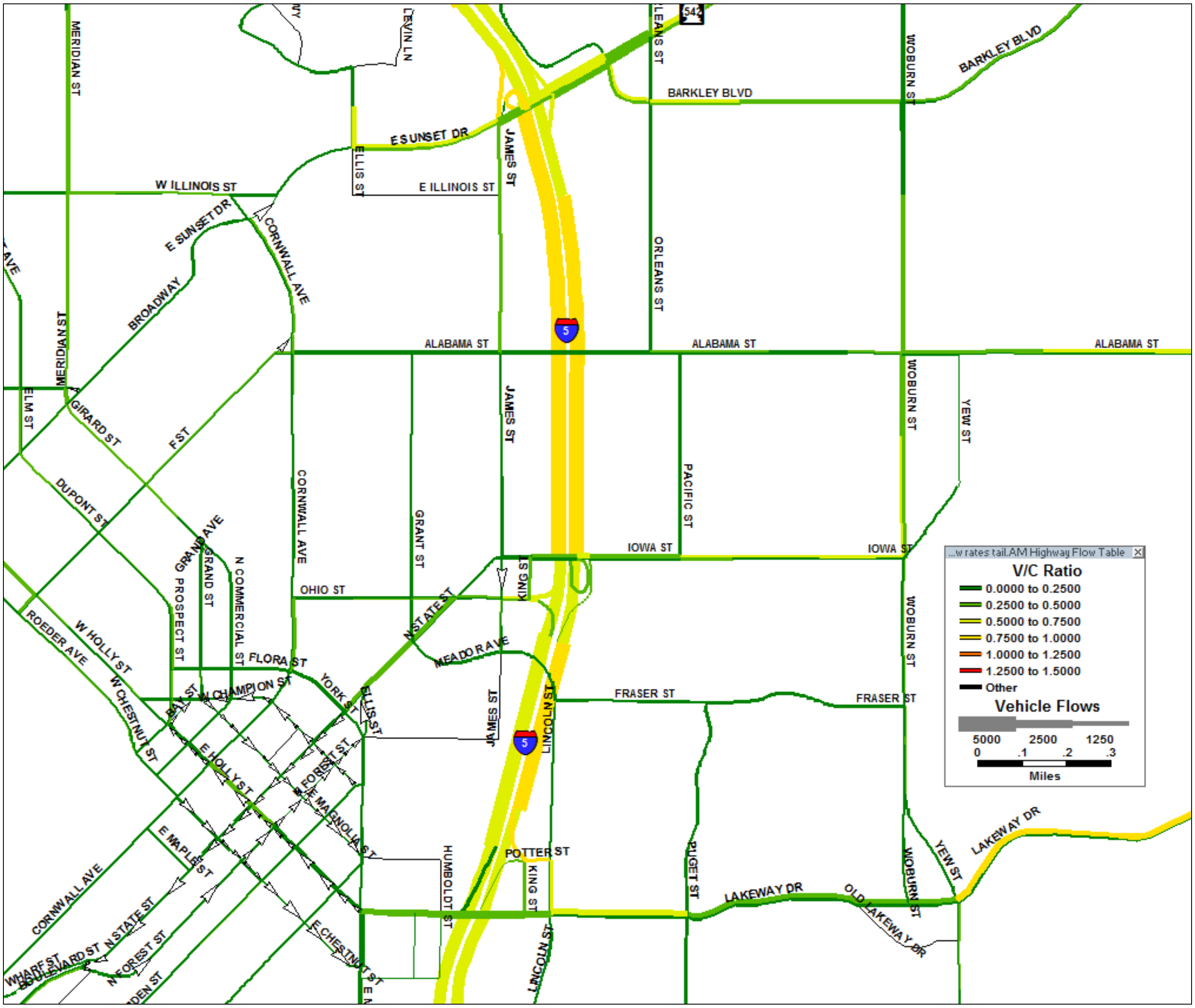

Figure 8.3: Close-up of the AM Assignment around Bellingham

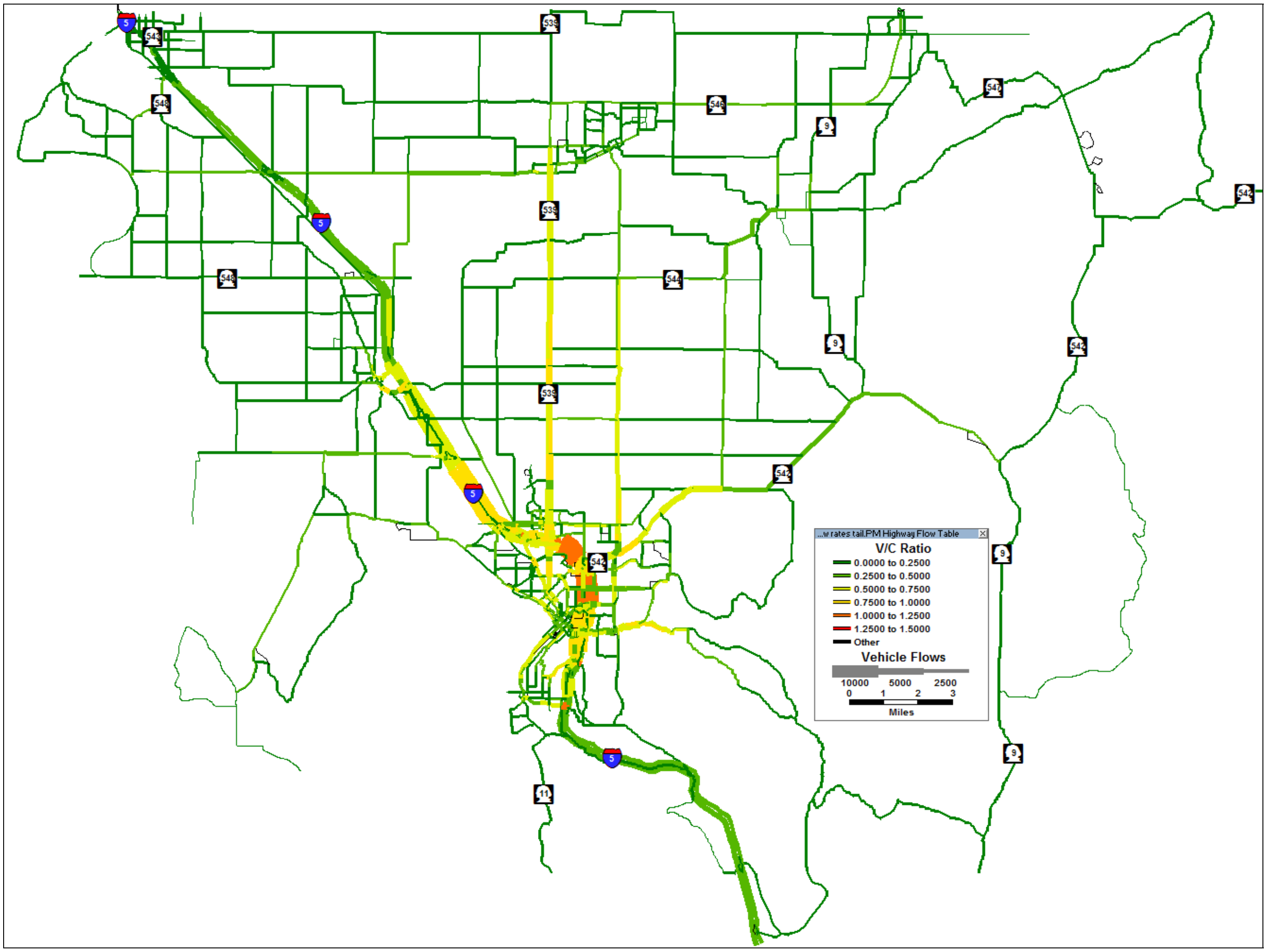

Figure 8.4: PM Period Congestion Pattern

The congestion during the PM period is higher than during the AM period, as seen in Figures 8.4 and 8.5.

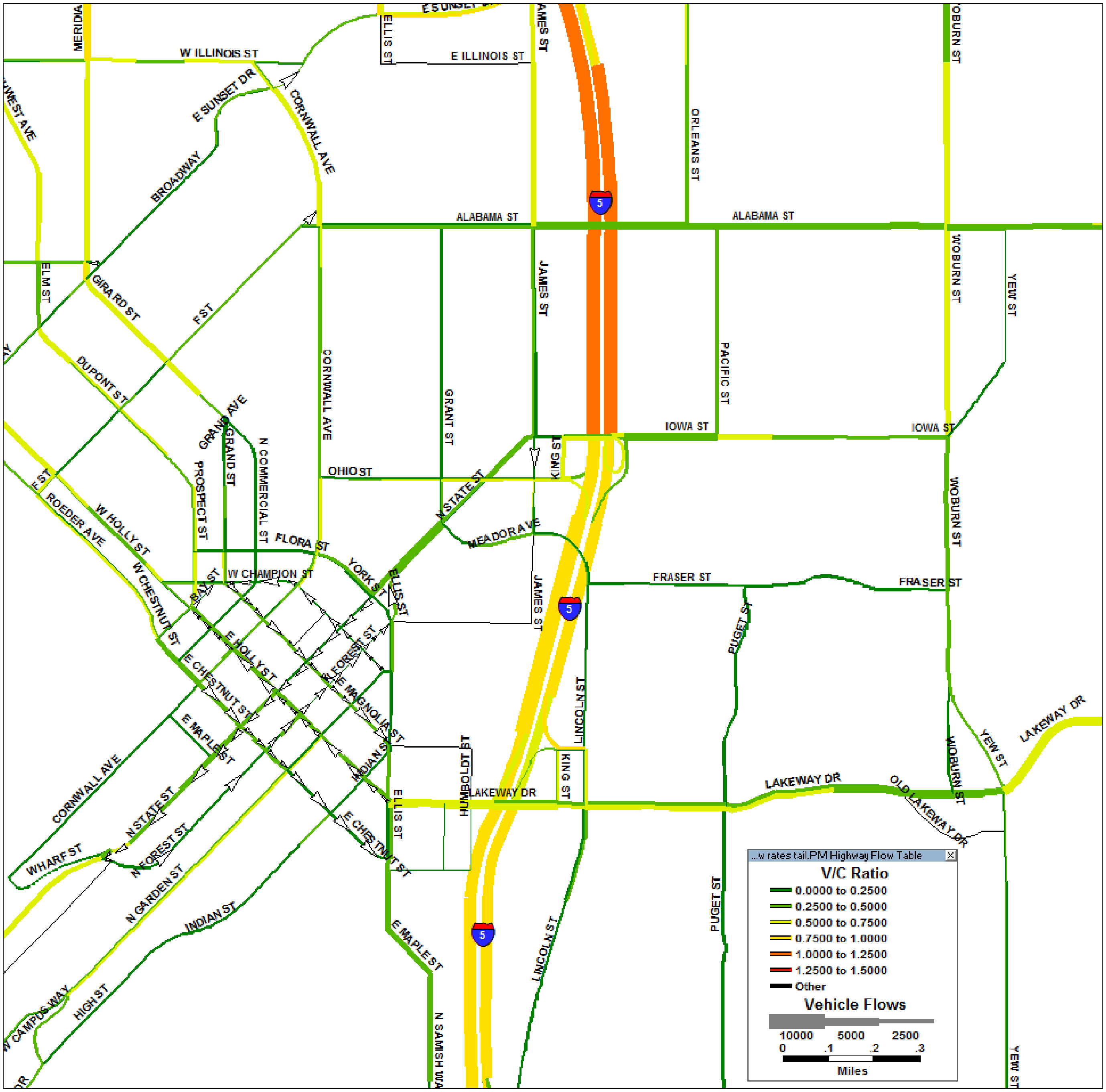

Figure 8.5: Close up of PM Period Flows

Comparison of Assignment Volumes to Traffic Counts

The validity of the model was determined by comparing against ground counts on a time period basis. The counts were pooled together from various sources by Whatcom County staff and provided for one hour intervals. The counts were aggregated to the respective time periods and used to compare against the assignment flows. The assignment flows from all the four periods were added to obtain the daily flows.

Tables 8.2 to 8.6 show the comparison of the flows versus the counts for the daily period and for each of the time periods. The RMSE%, a statistic most helpful in determining how the counts match up with the flows, is shown for all the links and specifically for highway links, ramps, major and minor arterials for each of the time periods.

The Percent RMSE formula is given by:

$$\%RMSE = 100 * \sqrt{(\sum_i (Model_i - Count_i)^2 / (Numberofcounts)} / (\sum_i (Count_i / NumberofCounts)$$

A RMSE% of 40% or below is recommended for all the links. For freeway links, it is generally recommended that the RMSE% be below 20%.

It can be seen from that tables that the RMSE% between the flows and the counts clearly satisfies this criteria. Further the RMSE% for highway is well below 20%, indicating an excellent match of the flows to highway counts for all the four periods and for the daily model.

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	889	3,138,475	3,234,129	-2.96	**27.98**
Highway	16	377,285	364,829	3.41	**9.96**
Major Arterials	320	1,708,527	1,741,314	-1.88	**22.14**
Minor Arterials	283	692,606	760,290	-8.90	**36.22**
Major Collectors	226	235,550	248,316	-5.14	**53.35**
Ramps	14	107,173	99,283	7.95	**19.41**

Table 8.2: Flows vs Count for the Daily period

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	889	340,761	371,826	-8.35	**40.07**
Highway	16	44,374	43,900	1.08	**8.78**
Major Arterials	320	183,222	196,642	-6.82	**35.38**
Minor Arterials	283	73,567	88,231	-16.62	**48.95**
Major Collectors	226	24,909	28,239	-11.79	**71.17**
Ramps	14	12,784	12,482	2.42	**19.33**

Table 8.3: Flows vs Count for the AM period

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	889	1,039,138	996,646	4.26	**34.40**
Highway	16	115,285	107,477	7.27	**12.17**
Major Arterials	320	571,177	549,519	3.94	**27.44**
Minor Arterials	283	235,076	234,879	0.08	**43.19**
Major Collectors	226	78,983	69,820	13.12	**67.38**
Ramps	14	33,088	29,342	12.77	**26.14**

Table 8.4: Flows vs Count for the MD period

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	889	753,754	753,021	0.10	**30.66**
Highway	16	83,000	80,775	2.76	**11.21**
Major Arterials	320	408,621	404,961	0.90	**24.48**
Minor Arterials	283	175,128	182,275	-3.92	**38.41**
Major Collectors	226	59,637	58,197	2.48	**54.78**
Ramps	14	23,308	22,273	4.65	**24.86**

Table 8.5: Flows vs Count for the PM period

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	889	1,004,819	1,114,860	-9.87	**35.78**
Highway	16	134,624	132,677	1.47	**10.85**
Major Arterials	320	545,505	590,267	-7.58	**30.66**
Minor Arterials	283	208,833	257,012	-18.75	**43.93**
Major Collectors	226	72,020	92,102	-21.80	**63.69**
Ramps	14	37,991	35,186	7.97	**18.31**

Table 8.6: Flows vs Count for the NT period

In general, both the period assignments and the daily assignments are well calibrated. Figure 8.6 shows a scatter plot of flow versus count for the daily period. As can be seen, a majority of the points lie on the 45 degree line indicating a very good match for the base year.

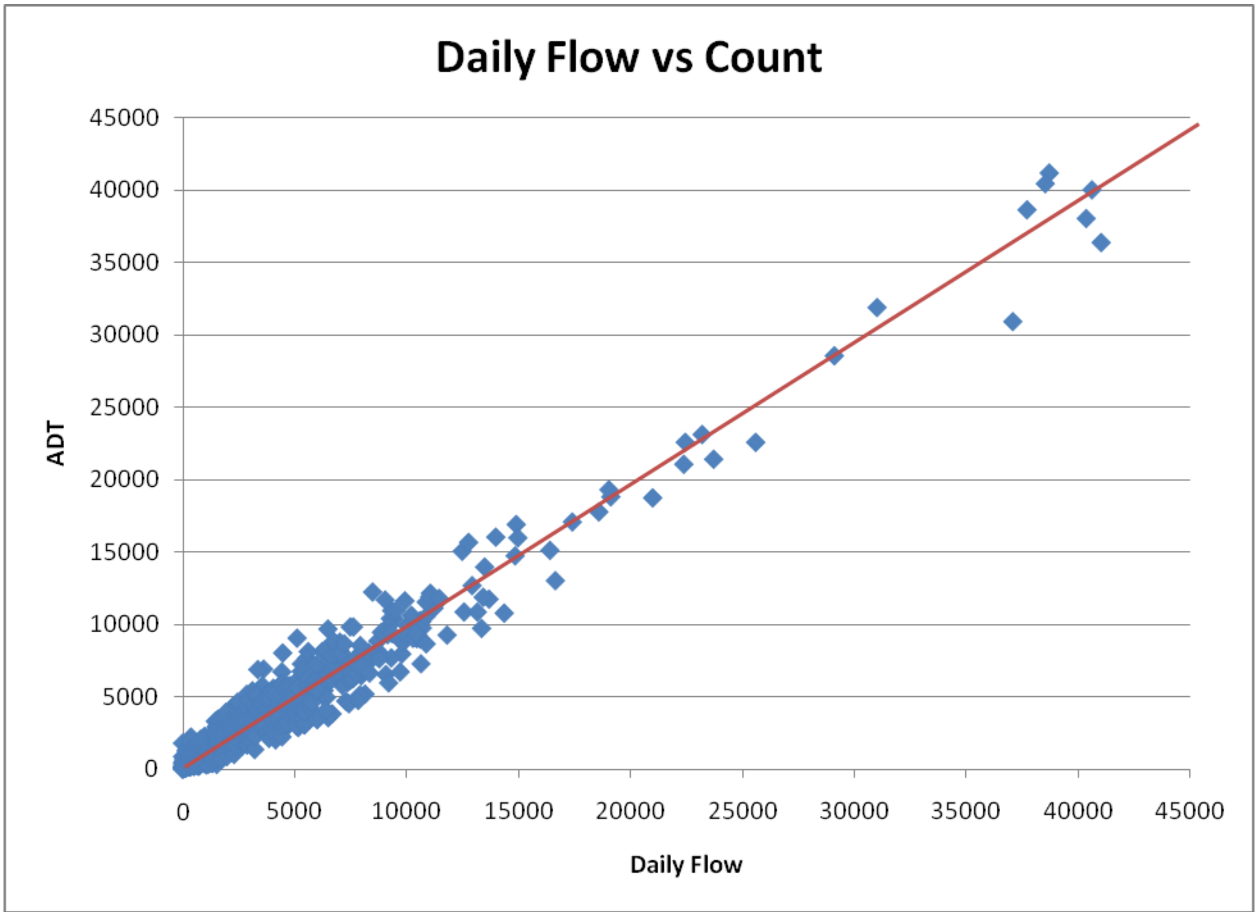

Figure 8.6: Daily Flow versus ADT

Vehicle Hours of Travel and Vehicle Miles of Travel

The total Vehicle Miles Traveled (VMT) and the total Vehicle Hours of Travel (VHT) for each of the time periods is shown in Table 8.6

Time Period	Total VMT	Total VHT
AM	463,651	11,064
MD	1,390,455	34,808
PM	994,557	25,066
NT	1,413,137	33,434
24-hour	**4,261,800**	**104,372**

Table 8.7: VMT and VHT by time period

Transit Assignment

The transit assignment is performed for the 4 time periods AM, PM, MD and NT and the results are added to give the total boardings for the daily period. Figure 8.7 shows the transit flows aggregated to the line layer. A thicker line indicates greater transit flow. As can be seen from the map, the transit flows are greater around Bellingham, in particular around the university (in the south west corner of the map).

The sum of all the boardings on all the stops was 20,530 which is close to the 21,600 boarding counts provided by WTA.

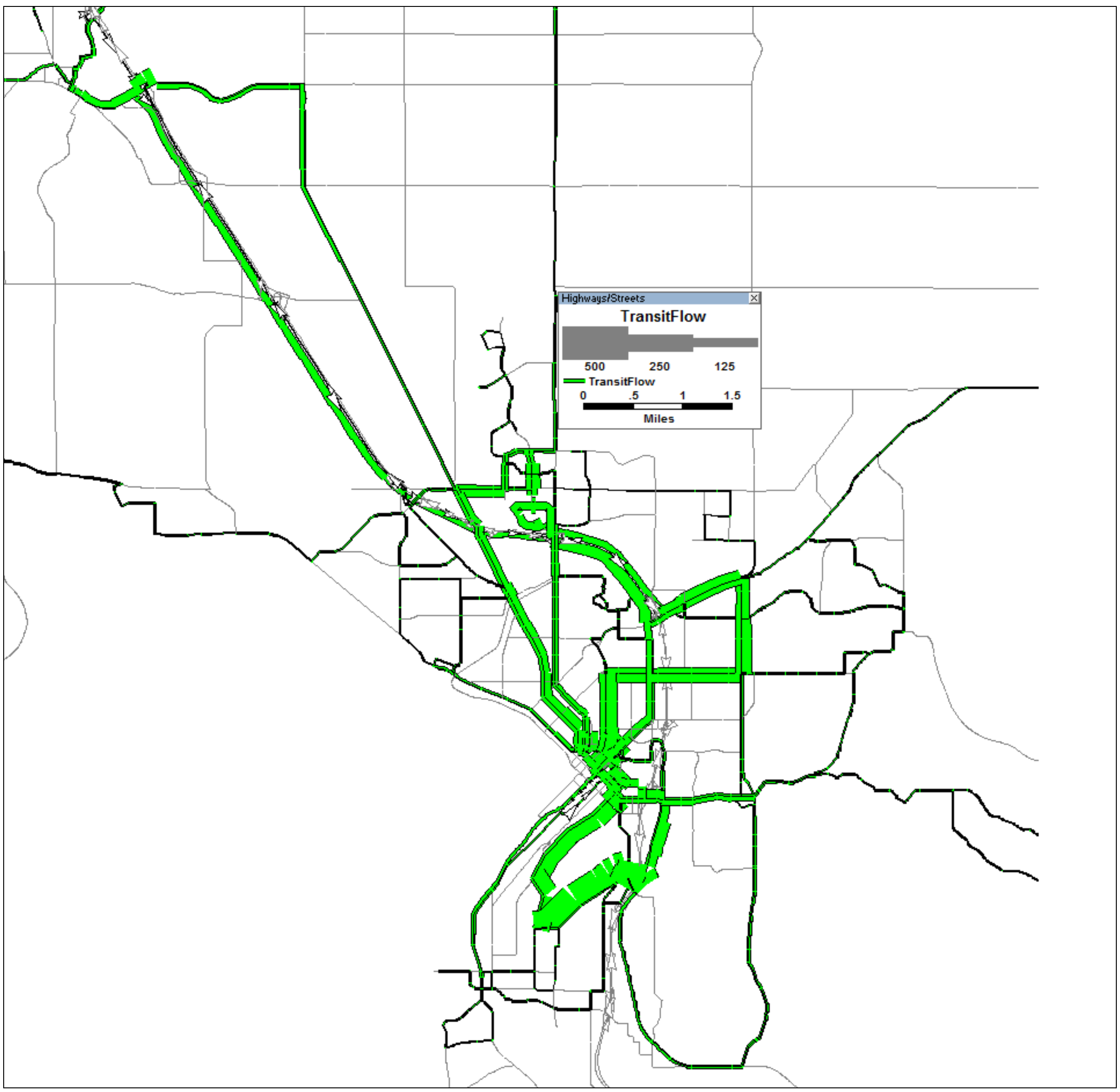

Figure 8.7 Transit Flow Map

Chapter 9: Feedback Algorithm

The Updated Whatcom Planning model utilizes a feedback model option. It is necessary for planning models to incorporate a feedback model to ensure the congested link travel times that result from the assignment algorithm are identical to the link travel times that was used to generate the skims. The feedback is hence a fixed point problem.

The updated Whatcom model generates PK and OP trip ends, performs trip distribution and mode spilt to generate PK and OP trips by purpose and mode. The Time of Day further produces OD matrices by AM, PM, MD and NT periods. Since the trip distribution primarily works on Production and Attraction data, the AM skims is representative of the PK skims. Likewise the MD skims is representative for the OP skims. The feedback loop hence is designed to achieve consistency in the AM and MD congested link travel times.

The skimming procedure is run for the AM and the MD period and these skims are used for the trip distribution for the PK and OP periods respectively. The mode spilt is then executed, (using the AM skims for the PK skim utility terms and the MD skims for the OP skim utility terms). The time of day procedure then produces AM, MD, PM and NT OD matrices, out of which the AM and the MD assignment are executed within the feedback loop. The flows from AM assignments in successive feedback loops are smoothed using the Method of Successive Averages (MSA). Likewise an MSA flow vector is generated for the MD trips. These flows are then used to construct MSA link travel times for the AM and the MD periods using the VDF functions. These times are fed back into the AM and MD highway skimming procedure.

Note that transit skimming is not part of loop. The primary reason being that transit skimming within the feedback loop is thought to undermine feedback loop convergence. Note finally that the PM and the NT assignment and transit assignment are executed only in the final feedback loop.

During the process of calibration, several runs were performed and the base year highway network was eventually populated with the congested link travel times for the AM and the MD periods. A flag in the model allows the user to start the model using these congested times. It is recommended that for the base year scenario, the user utilizes this option and runs through the model steps just once. It is not necessary to run the feedback procedure.

It is to be noted that for a new model scenario (such as a future year run) that has different demographics, land use patterns etc, the user start with free flow travel times and runs sufficient feedback loops first to generate the congested times. In the case of a short term scenario run (such as closing of a couple of lanes), it may not be necessary to run the feedback. Rather, in this case, it may be useful to code in the network change and simply re-run the traffic assignment. It is left to the judgment of the user to decide when a feedback run is warranted. Typically, for any given scenario, the answer depends on whether OD patterns change and whether travelers will adjust their travel patterns in response to the scenario.

Given a particular scenario that requires feedback loops, it is recommended to perform at least five loops of the feedback process starting with free flow times, followed by one loop of feedback starting with congested times. There is no harm in running additional feedback loops, such as 10 loops starting with free flow times, followed by one loop with congested times, especially if the demand for the scenario is high.