The Updated Whatcom Model 2014

Project Final Report

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The Whatcom Council of Governments

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Chapter 1: Introduction and Motivation for Model Update

This section briefly describes the travel demand prior to the current modeling update effort and the motivation for an update.

2008 Base Year Model

The Whatcom Regional Travel Demand Model for Whatcom County was developed for the Whatcom Council of Governments (WCOG) in Washington State in the year 2010 by Caliper Corporation for the 2008 base model year in order to help WCOG with their regional transportation planning needs. This work was a significant improvement and a complete overhaul to the original travel demand model developed by Cambridge Systematics Inc. for the 2000 base year that used a countywide network and county-level analysis zones. During the model update for the 2008 base year, the software platform was switched from EMME/2 to TransCAD 5.0, based on recommendations by the Whatcom County staff after a thorough software evaluation. More details can be obtained from the previous model update document provided to WCOG by Caliper Corporation in March 2010[1].

The 2008 model was based on a fresh approach in terms of the modeling process and procedures and was entirely estimated based on the 2008 North Sound Travel Survey (put together by NuStats) for the three county regions of Whatcom, Skagit and Island. 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 had 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.

The calibration of the 2008 model and its integrity with respect to replicating the survey was at the highest level and the model provided traffic flows by period which highly matched observed traffic counts. This effort coupled with a new interface to handle various model scenarios and provide excellent visualization, resulted in a highly successful model.

Motivation for the Model Update

The motivations for a model update are manifold and listed below:

- The key motivation for updating the model is due to the availability of updated census data in 2010. As part of their decennial update, the Census Bureau provided updated block, block group and tract geography and demographics. Further, a more recent ACS (American Community Survey) data was available. Since the census demographics are integral to the inputs for the travel demand model, it necessitated the update of the current regional model. Consequently, the model base year was now determined to be 2010 and the model components needed to be updated to reflect the new base year.

- The original 2008 travel survey was initially un-weighted and a comprehensive weighting mechanism was developed in the previous model update round based on the then available census 2000 demographics. It was therefore imperative that the weighting be repeated with the latest census demographics, which in turn would require the individual model components to be updated.

- In lieu of the new census geography, WCOG updated their base year zone and network files. Particularly, WCOG staff redefined the TAZ so that roads and natural barriers are used as boundaries using the 2010 census blocks layer. Further, in order to better explain the model behavior in certain city limits, TAZ's were split in several of the urban areas. The previous model 2008 TAZ structure had 719 internal zones and 8 external zones. The new 2010 TAZ structure has 961 internal zones and 8 external zones.

  Further, WCOG staff adjusted the new 2010 base year network. The network was adjusted to reflect the additional zones in the landuse. The network was also updated based on comments from the local jurisdictions. The Functional Class, Number of Lanes, additional roads not previously modeled and area type were updated. WCOG staff also collected traffic counts from local jurisdictions. These traffic counts form the basis for calibrating and validating the updated base year 2010 model.

- Another motivation was to improve upon the transit methodology in the 2008 model in order to address some of its minor shortcomings. Particularly, the availability of updated transit procedures in the TransCAD software required a closer look at the transit methodology.

- In keeping with the latest software, the WCOG model was designed to be upgraded to the TransCAD 6.0 platform. It is expected that access to the latest procedures and algorithms in TransCAD 6.0 particularly in highway and transit path building, highway and transit assignments will greatly enhance the model. This coupled with the advances in the software related to multithreading that yield better running times will enable WCOG to obtain results in a timely and rapid fashion.

This document describes many of the modeling improvements that resulted in a very well calibrated base year 2010 model. Caliper Corporation is pleased to deliver this model to Whatcom and to continually support them in its application to ensure success. We would like to provide a special mention to Andres Gomez at WCOG for his continual dedicated resolve and his relentless excitement and hard work towards developing this quality product. We have full confidence in the updated model and believe it will be a great tool to help WCOG staff plan the future transportation needs for the region.

Chapter 2: Model Framework

The main modeling framework is shown in Figure 2.1 below

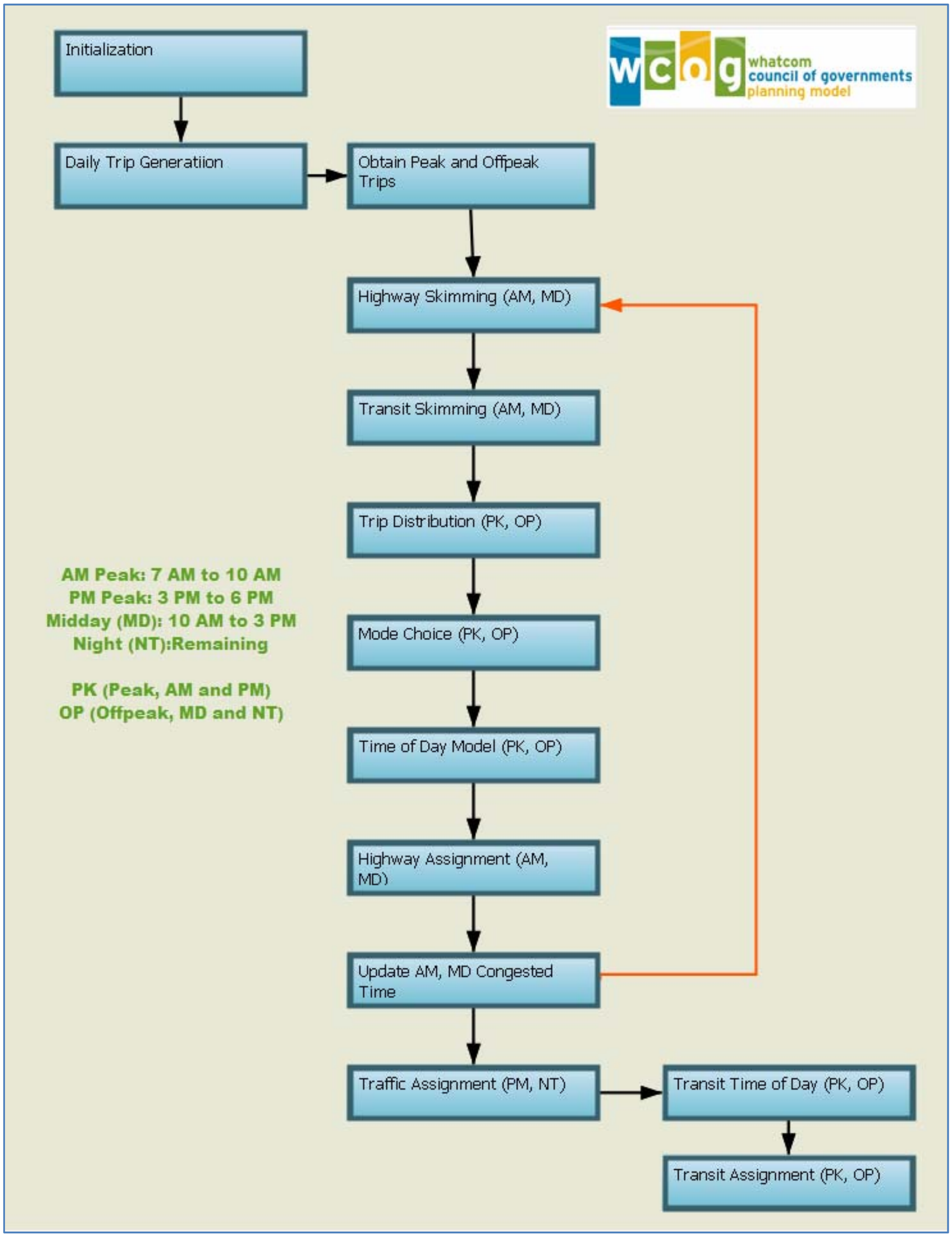

Figure 2.1: Whatcom Planning Model 2010 Flowchart

The model framework is similar to the 2008 model, albeit with a couple of key differences; the transit skimming module is now within the feedback loop as opposed to outside the loop and the time period definitions for the AM and PM peak have changed. These issues are discussed in the appropriate sections.

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.

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. There are no special generators in this model unlike the 2008 base year model.

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 **Transit Skimming** is then run using the pathfinder skims to generate skims for the AM and MD time period. One of the key inputs to the skim is the origin to parking node input matrix that contain drive times from each of the centroids to the appropriate parking nodes. The drive times used for calculating the skims come from the latest estimate of the AM or MD congested times.

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 transit skims, 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.

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

Key Changes to the 2010 Model

This section summarizes the key differences of the Whatcom 2008 planning model versus the updated planning model and then illustrates all of the models that were recalibrated:

- The 2010 model uses updated demographics derived from the 2010 Census files. The distribution of households by size and income and the distribution of households by income and workers is determined using an innovative population synthesis approach (Chapter 3).
- The 2008 tri-county survey was reweighted based on the approach adopted during the 2008 model cycle, except that the control totals were obtained from the 2010 census data.
- As a result of the survey weighting, many of the individual model components were re-estimated. Models that were re-estimated include trip production and attraction models, mode choice models and time of day models. The trip distribution friction

factors were not modified because the model and observed trips lengths were still in agreement.

- The time period definitions in the 2010 model have changed. The AM peak period has been changed from 7AM-9AM to 7AM-10AM. The PM peak period has been shifted by an hour and has been changed from 2PM-5PM to 3PM-6PM. The MD period sandwiches the two peaks and the NT period constitutes the remaining hours.
- Owing to the way Transit Park and ride is implemented, the transit skimming procedure is now within the feedback loop.
- The 2010 updated model does not use any special generators, since the updated trip attraction models sufficiently explain the attractions and there was no need to have special rates for retail heavy zones.
- The transit functionality in the model has been upgraded. The park and ride capacity has been enforced by choosing buffer zones around the parking nodes and allocating park and ride access to selective zones. This feasible set of origin zone to parking nodes is an input into the transit skimming procedure. The transit assignment procedure has been updated to use an equilibrium pathfinder assignment.
- Several key parameters such as the network speeds and capacities by functional class were modified.
- The model was validated using the latest counts (Year 2010 and earlier) assembled by WCOG staff from various agencies.

Model Update Methodology

The update methodology consisted of several stages, given the updated TAZ and network files:

- The first stage consisted of assimilating the census 2010 data and developing a comprehensive routine to generate the household cross tabulations.
- The second stage consisted of fixing some input files such as external counts, performing some basic calibration of the mode choice constants to match observed shares, removing components such as the special generators and moving the model to the TransCAD 6 platform. A comparison of the trial model run with the updated counts indicated that further detailed calibration was warranted.
- The third stage consisted of reweighing the survey data and re-estimating many of the key model components.

- The fourth stage consisted of the heavy duty calibration effort to match observed trip patterns and observed counts. This was a highly iterative process with several adjustments to the various models, model re-runs and discussion with WCOG staff.
- The final stage of the calibration focused on the transit modeling with an aim to match overall boardings by period, boarding at key stations and park and ride observed usage.

Chapter 3: Data Preparation

This chapter details the development of the land use data for 2010, specifically the household cross tabulations and describes briefly the work performed by Caliper and WCOG staff towards developing the updated TAZ and network files.

Land Use Data Generation

The key land use inputs are the household and the employment variables. The household classification in the 2008 models required for the trip generation were the tabulation of households by household size and household income and the tabulation by household income and number of workers in the household. The table below shows the various fields that need to be populated:

Household Income	Household Size			
	1	2	3	4+
Low : [0, $24,999]	1HHLINC	2HHLINC	3HHLINC	4HHLINC
Medium Low: [$25,000, $49,999]	1HHLMINC	2HHLMINC	3HHLMINC	4HHLMINC
Medium High: [$50,000, $74,999]	1HHMHINC	2HHMHINC	3HHMHINC	4HHMHINC
High: [$75,000,]	1HHHINC	2HHHINC	3HHHINC	4HHHINC

Table 3.1: Household Income by Size Variables

Household Income	Number of Workers in the Household			
	0	1	2	3+
Low : [0, $24,999]	0WLINC	1WLINC	2WLINC	3WLINC
Medium Low: [$25,000, $49,999]	0WLMINC	1WLMINC	2WLMINC	3WLMINC
Medium High: [$50,000, $74,999]	0WMHINC	1WMHINC	2WMHINC	3WMHINC
High: [$75,000,]	0WHINC	1WHINC	2WHINC	3WHINC

Table 3.2: Household Income by Household Workers Variables

The 2008 model had additional income by 4+ worker category variables but these were not generated in the 2010 update. The earlier 2008 numbers were populated by the forecasting department of the Whatcom county staff, based on projections of Census 2000 data. A brief analysis of the latest census data showed that the income distribution in the Whatcom region was significantly different than in the previous Census. Consequently, any projection methodology based on earlier 2008 data was bound to be erroneous.

Therefore, during this phase, Caliper Corporation and WCOG decided to approach the problem using an innovative population synthesis procedure. The details of this procedure are discussed in the next section.

Generation of Household Cross Tabulations

Figure 3.1 below shows the methodology for the 2010 model using a population synthesis approach.

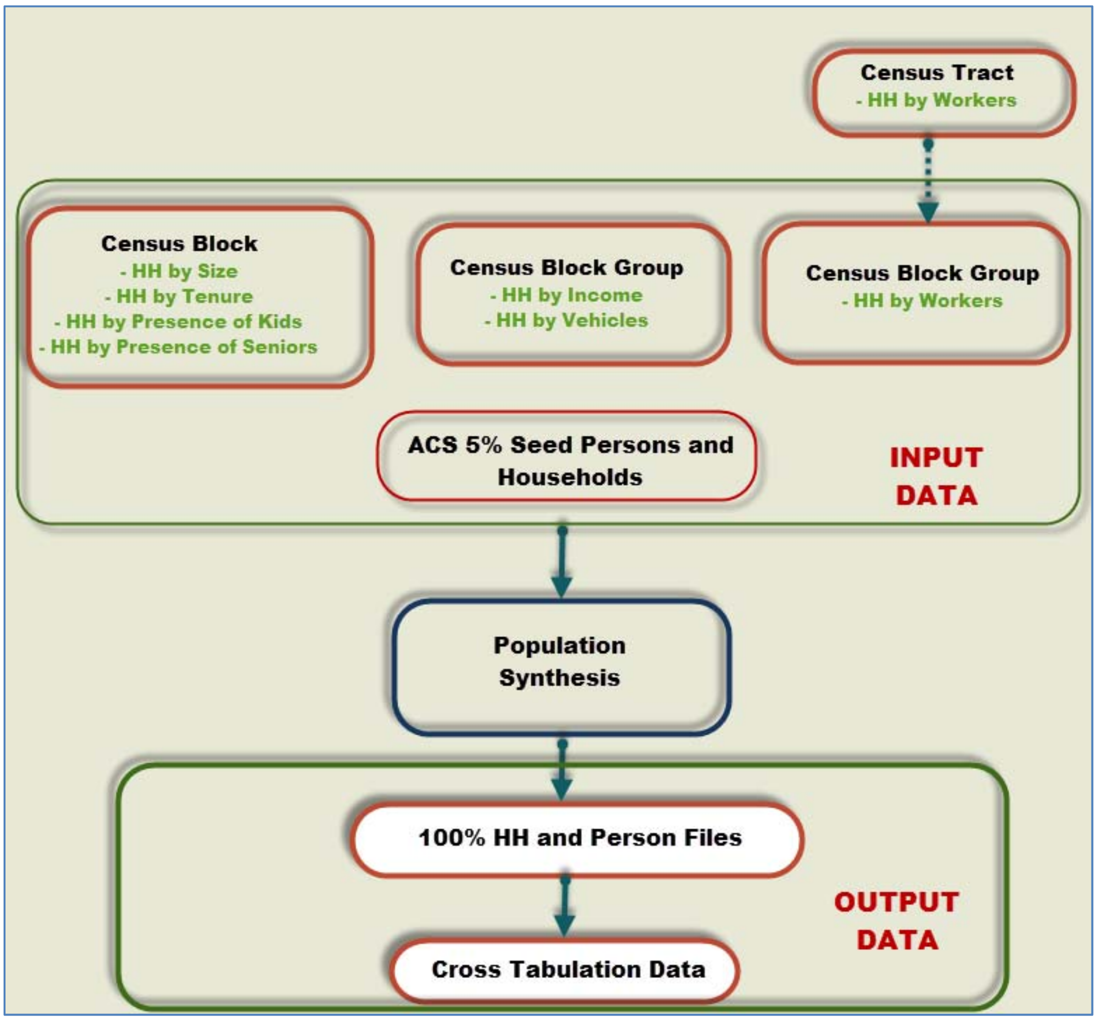

Figure 3.1: Generation of Land Use Cross Tabulation

The methodology involved the use of the TAZ geography, the census 2010 block, block group and tract data and data from the ACS 5% (2006-2010) household and person sample. The technique used was a nested population synthesis approach using the ACS 5% Household and Person data as the seed. Control totals from various levels of geography used in the synthesis are shown in Figure 3.1 (highlighted in green). Particularly, control totals of Households by Household size were supplied from the Census 2010 block data, control totals of Households by Income were supplied from the Census 2010 block group data and control totals of Households by Household Workers were supplied using the Census 2010 tract data. The tract data was first disaggregated to block group data before being used in the population synthesis algorithm.

After running the synthesis procedure, a 100% population and household database sample was generated for the Whatcom region that has a similar distribution as the ACS 5% seed but also matches the appropriate marginal totals at the various census geography levels. The following output fields are generated.

- Household Output Fields:
    - Household ID
    - Census Block ID,
    - Census Block Group ID,
    - HH Size,
    - Number of Vehicles in the Household
    - Number of workers in the Household
    - Income category
    - Tenure,
    - Presence/Absence of kids in the household.
    - Presence of one or more seniors in the household.
- Population Output Fields:
    - Household ID
    - Age
    - Class of Worker
    - Employment Status
    - Sex
    - Education
    - Is Student?
    - Race

The output of the population synthesis resulted in 80,067 HH records and 191,785 person records. Particularly, the household attributes after being aggregated to the TAZ level will be fairly accurate and can be confidently used for the planning model. After the aggregate, the key land use cross tabulations for the Whatcom County region are shown below (i.e. All TAZ's):

Household Income	**Household Size**				
	1	**2**	**3**	**4+**	**All**
Low : [0, $24,999]	14.1%	6.2%	2.4%	2.3%	**25.0%**
Medium Low: [$25,000, $49,999]	8.2%	10.1%	3.5%	4.1%	**25.9%**
Medium High: [$50,000, $74,999]	3.2%	8.3%	3.3%	4.7%	**19.5%**
High: [$75,000,]	2.4%	12.1%	5.6%	9.5%	**29.6%**
All Income	**27.9%**	**36.7%**	**14.8%**	**20.6%**	**100.0%**

Table 3.3: Household Income by Size Distribution

Household Income	**Number of Workers in the Household**				
	0	**1**	**2**	**3+**	**All**
Low : [0, $24,999]	13.1%	8.9%	2.8%	0.3%	**25.0%**
Medium Low: [$25,000, $49,999]	7.2%	12.4%	5.7%	0.7%	**25.9%**
Medium High: [$50,000, $74,999]	3.9%	7.2%	6.9%	1.4%	**19.5%**
High: [$75,000,]	3.8%	9.2%	13.5%	3.1%	**29.6%**
All Income	**27.9%**	**37.7%**	**29.0%**	**5.4%**	**100.0%**

Table 3.4: Household Income by Household Workers Distribution

For the future year forecasts, the synthesis can be re-run using available Household marginals at any available levels of geography.

Traffic Analysis Zones (TAZ) Update

WCOG staff redefined the TAZ so that roads and natural barriers are used as boundaries using the 2010 census blocks layer. TAZ have a smaller geographical area in city limits and urban growth areas and larger in rural areas. The current TAZ structure has 719 internal zones and 8 external zones. The new TAZ structure has 961 internal zones and 8 external zones. Primarily, the zones in the urban centers have been disaggregated into smaller zones. This helps in the prediction of productions and attractions and also facilitates better centroid connector placement and consequently a more accurate traffic assignment.

After review of the external zones, Caliper and WCOG staff decided to use the same external zone configuration as in the 2008 model. A figure of the TAZ layer along with the classification by jurisdiction is shown in Figure 3.2

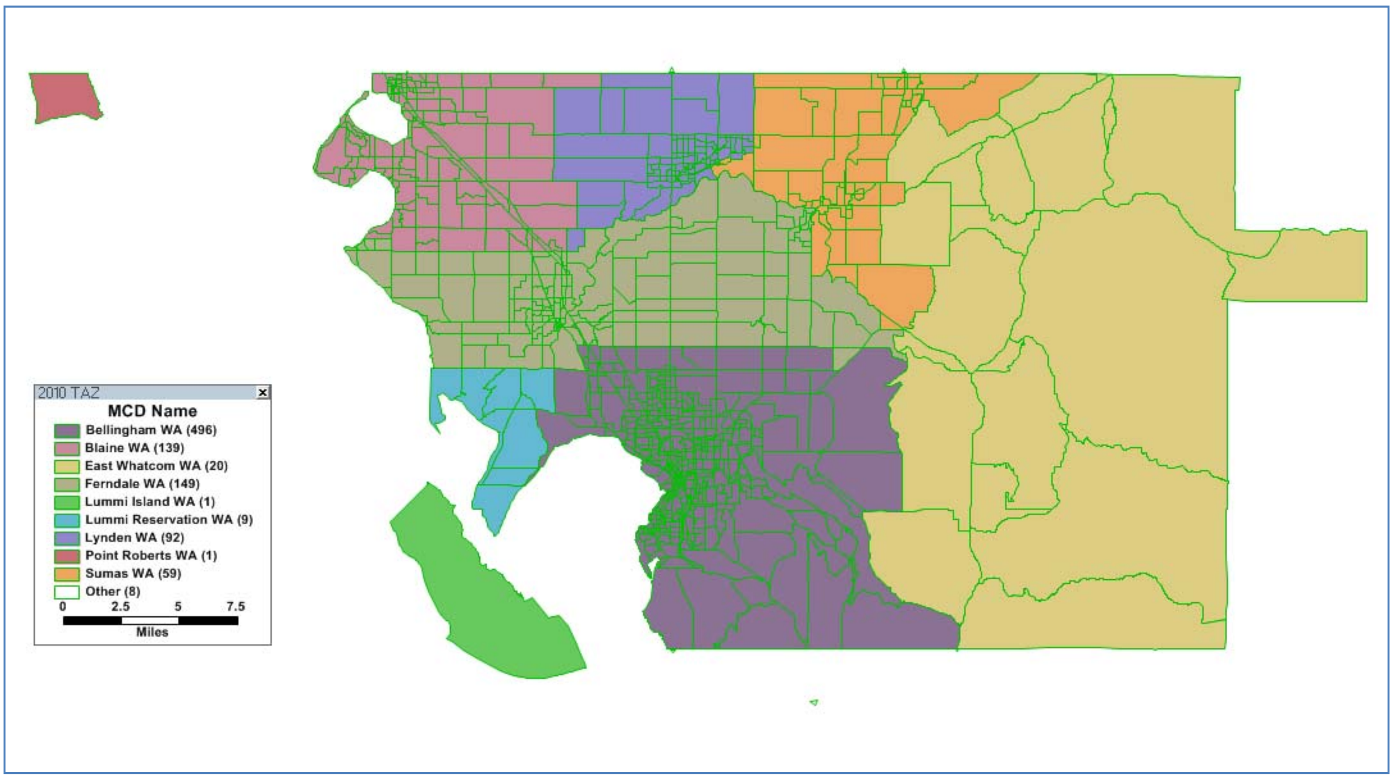

Figure 3.2: Base Year 2010 TAZ

Roadway Network Update

A geographically accurate highway network was developed in 2008 from existing GIS data sources, including centerlines and aerial photographs. Further, WCOG staff deliberated on the placement of centroids and connectors and established very good databases for planning applications.

During this round of the update process, WCOG staff adjusted the new 2010 base year network to reflect the additional zones in the landuse, including the placement of the connectors etc. The network was also updated based on comments from the local jurisdictions (Functional Class, Number of Lanes, additional roads not previously modeled and area type). WCOG staff also collected traffic counts from local jurisdictions. WCOG staff later identified some gaps where future traffics counts will be beneficial when validating the model.

As before, 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 3.5. These values have been updated during the current calibration effort, especially with regard to the hourly capacity for road classifications of collectors and lower. The updated values are shown in the table 3.5. 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 the table. 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	60	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	700
5	Major Collector	2 - Suburban	31	750
5	Major Collector	3 - Rural	37	800
6	Minor Collector	1 - Urban	25	700
6	Minor Collector	2 - Suburban	30	750
6	Minor Collector	3 - Rural	35	800
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 3.5 Speed and Capacities by Functional Class

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. A map of the network is shown in Figure 3.3.

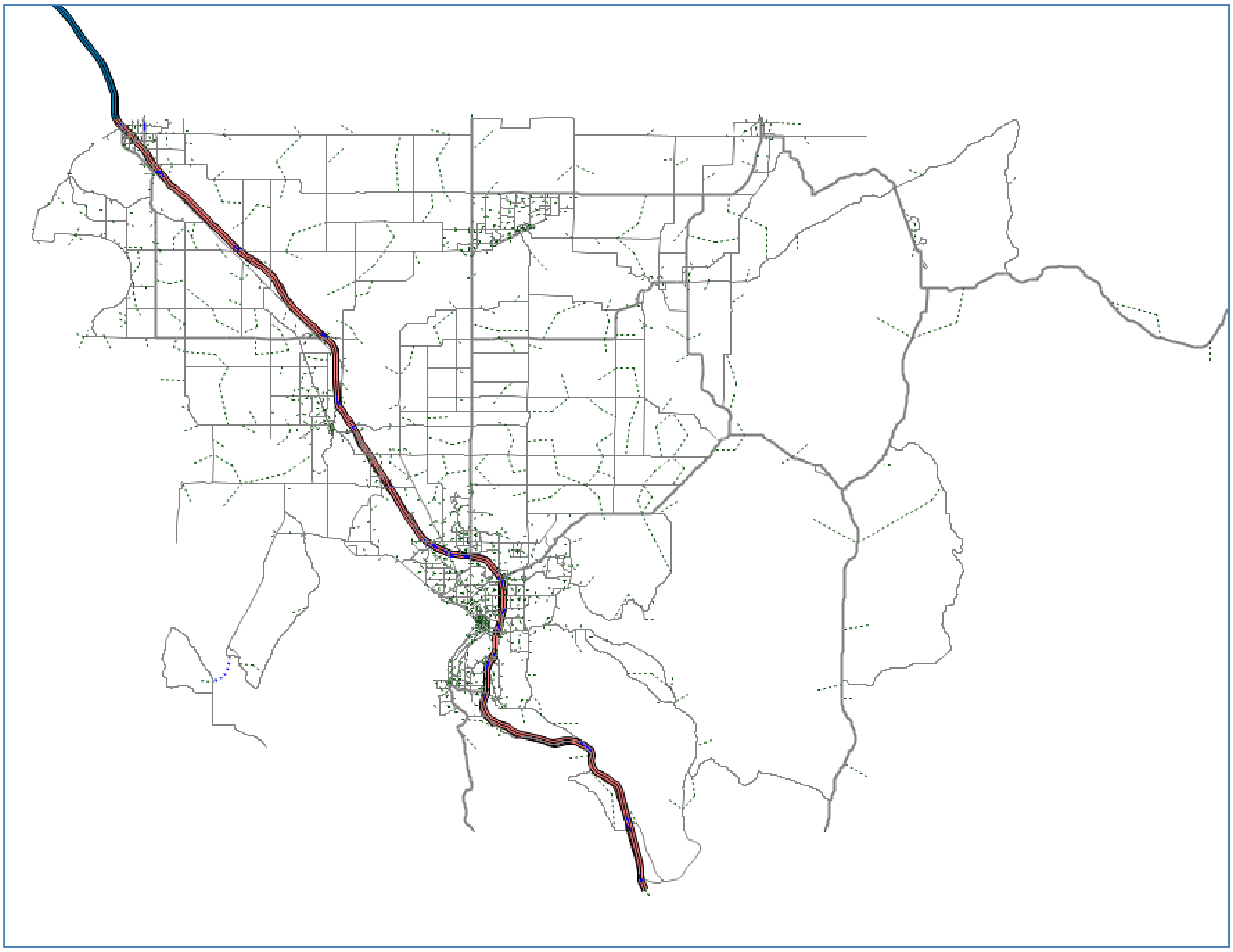

Figure 3.3: Base Year 2010 Highway Network

Transit Network Update

Utilizing the Whatcom roadway network as the underlying geography, Whatcom staff and Caliper Corporation developed a geographically accurate Transit Network during the previous model update. This transit network provides an inventory of available routes and stops. Since the highway network changed during this round of the update, the transit network was appropriately modified to fit the line geography.

As in the previous update, 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.

The current park and ride stations in the Whatcom area were re-examined and based on the usage of the parking lots, three parking stations were employed in the model, namely: Lincoln Creek, Ferndale Transit Center and 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 3.4.

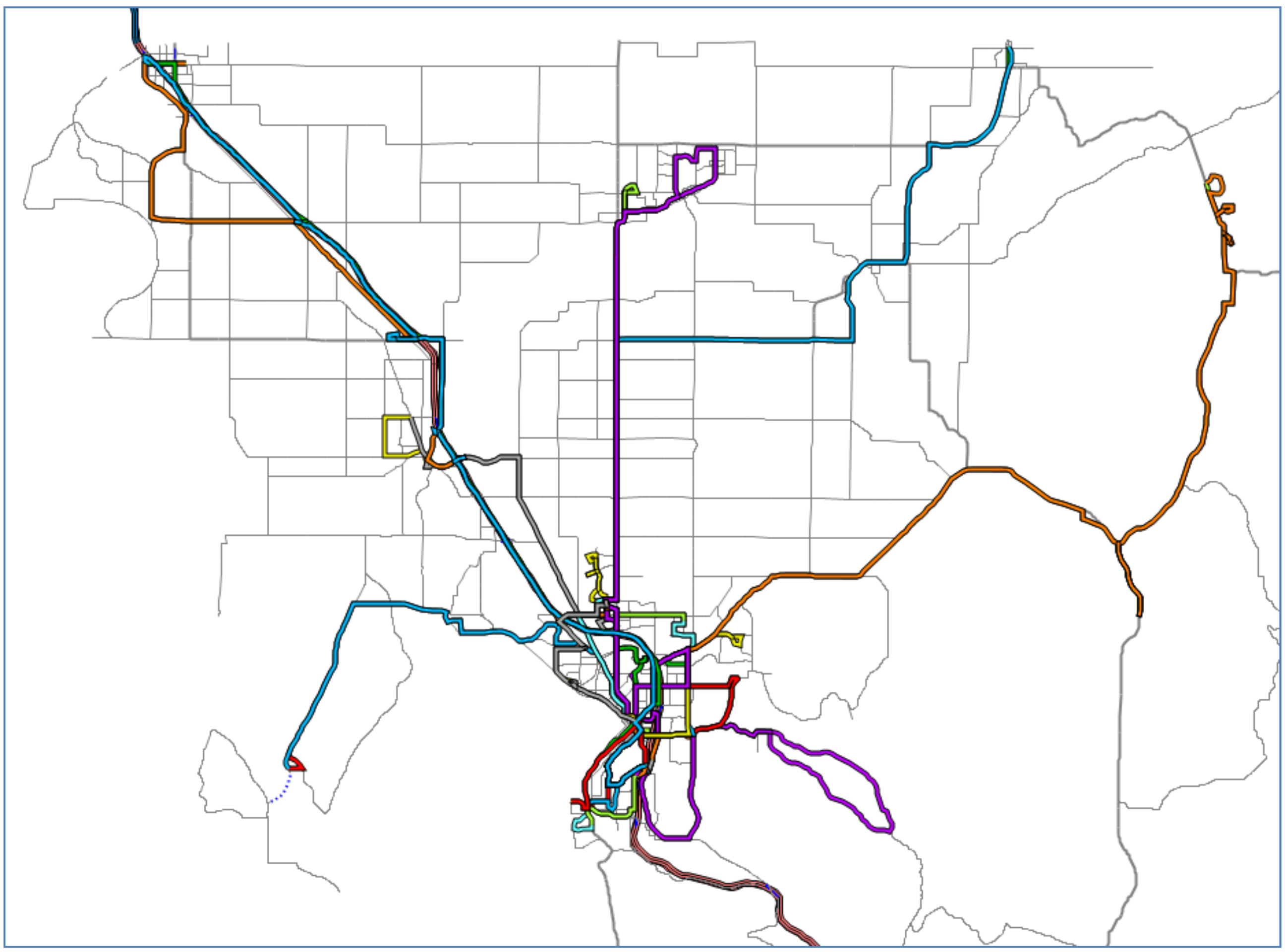

Figure 3.4 Whatcom 2010 Transit Route System

Highway Network Skimming

The highway skimming process has been unaltered since the previous update. Below is a description of the procedure, as in the previous model document.

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. All the network turn penalties were examined and modified as necessary. Finally a measure of the Intra Zonal trip travel times is obtained based on the travel times to the nearest neighbor 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. During this update, the transit parameters were examined and modified as warranted.

For the parking nodes, given the capacity of the nodes and the transit usage, it became clear that the park and ride mode was only being utilized by the population in the vicinity of the parking node. Therefore, for each parking node, a series of network bands were used to identify potential zones within a mile of the transit parking node. Only these zones were allowed access to the parking and the appropriate centroids corresponding to these zones were assigned the parking node information. Various other criteria were experimented with during the calibration process but the chosen 1 mile radius condition yielded the most logical result in terms of the observed park and ride utilization.

An Origin to Parking Node time matrix is developed based on the latest congested travel times to the eligible centroids and this is used as an input in the transit network settings. 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.

Unlike the previous update of the model, the transit skims are also now part of the feedback loop. This is mainly motivated because of the fact that the origin to parking node skims are determined from the latest estimate of the congested times. Therefore, it makes sense to include this procedure and also the transit skims as part of the feedback loop. During the calibration phase, it was determined that including the transit skims in the feedback loop yielded better results in terms of transit ridership and usage. Further, this did not affect the convergence of the model feedback.

Chapter 4: Re-estimation of Survey Weights for the North Sound 2008 Travel Survey

The updated Whatcom model for the previous 2008 year model was calibrated based on the 2008 North Sound Travel Survey. The North Sound Travel Survey 2008 was 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. 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.

To offset this, a comprehensive weighing scheme was developed for the survey during the previous 2008 year model update (Method 2)[1]. The chosen method used the 2008 landuse database cross classification of households by income and size and cross classification based on household income and number of workers in the household to weigh the survey. The method also ensured the correct expanded household totals for nine key sub-regions. The resulting weighing scheme was highly successful and the survey with the weights was representative of all the households in the three-county region and especially in Whatcom County.

Whatcom County Weights

At the outset of the 2010 model update, we decided to use the same weights during the first phase of the calibration (i.e after updating the land use data and all the 2010 inputs). However, inspection of the 2000 versus the 2010 census income distributions revealed that the two were quite different, especially the high income category. The differences are shown in Table 4.1

Household Income	Percentage Distribution of Households	
	2000 Census	2010 Census
Low : [0, $24,999]	32.2%	25.0%
Medium Low: [$25,000, $49,999]	31.8%	25.9%
Medium High: [$50,000, $74,999]	19.4%	19.5%
High: [$75,000,]	16.6%	29.6%

Table 4.1: Comparison of 2000 vs 2010 Census Whatcom County Income Distribution

Since the land use demographics are based on the census, which are in turn used to weigh the survey, it was necessary to repeat the weighing and then re-estimate the various travel demand models.

The same method that was adopted during the 2008 model update was used to reweigh the survey, albeit with the 2010 lands use numbers. As before, 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 Tables 4.2 to 4.6.

Sub Region	Number TAZs	Number HH Landuse 2010	Number HH from survey (using Weights)
Bellingham	496	46,573	46,573
Ferndale	149	11,102	11,102
Blaine	139	7,979	7,979
Lynden	92	5,892	5,892
East Whatcom	28	3,247	3,247
Sumas	59	2,751	2,751
Lummi Reservation	9	1,628	1,628
Lummi Island	1	479	479
Point Roberts	1	678	678

Table 4.2: Households by Sub-Region (matches exactly with census data)

HHSize	Annual HH Income	Percent HH Landuse 2010	Percent HH using Survey with Weights
1	< 25K	14.1	14.3
1	25K-50K	8.2	9.2
1	50K-75K	3.2	2.6
1	>75K	2.4	3.1
2	< 25K	6.2	6.8
2	25K-50K	10.1	10.7
2	50K-75K	8.3	9.0
2	>75K	12.1	12.6
3	< 25K	2.4	1.7
3	25K-50K	3.5	2.9
3	50K-75K	3.3	3.2
3	>75K	5.6	5.2
4+	< 25K	2.3	1.4
4+	25K-50K	4.1	4.2
4+	50K-75K	4.7	4.6
4+	>75K	9.5	8.3

Table 4.3: Weights Comparison - HH Size by HH Income

Num Workers In HH	Annual HH Income	Percent HH Landuse 2010	Percent HH using Survey with Weights
0	< 25K	13.1	13.2
0	25K-50K	7.2	6.6
0	50K-75K	3.9	3.6
0	>75K	3.8	2.6
1	< 25K	8.9	8.6
1	25K-50K	12.4	12.5
1	50K-75K	7.2	6.6
1	>75K	9.2	9.6
2	< 25K	2.8	2.3
2	25K-50K	5.7	7.0
2	50K-75K	6.9	7.4
2	>75K	13.5	13.9
3+	< 25K	0.3	0.1
3+	25K-50K	0.7	0.9
3+	50K-75K	1.4	1.8
3+	>75K	3.1	3.2

Table 4.4: Weights Comparison - HH Income by HH Workers

Note that the 2010 updated model does not have a separate tabulation for 4+ worker households unlike the previous model. The 3 and 4+ worker categories are now aggregated to the 3+ worker category.

Tables 4.5 and 4.6 show that the cross classification totals match for large sub-regions, e.g. Bellingham. Only classifications with more than 1000 households are shown below.

Sub Region	HHSize	Income	Num HH Land Use 2010	Num HH using Survey Weights
Bellingham	**1**	**< 25K**	7,792	7,590
Bellingham	**1**	**25K-50K**	4,202	4,213
Bellingham	**1**	**50K-75K**	1,530	1,527
Bellingham	**1**	**>75K**	1,231	1,233
Bellingham	**2**	**< 25K**	3,275	3,410
Bellingham	**2**	**25K-50K**	4,635	4,483
Bellingham	**2**	**50K-75K**	3,494	3,554
Bellingham	**2**	**>75K**	5,708	5,923
Bellingham	**3**	**< 25K**	1,257	1,256
Bellingham	**3**	**25K-50K**	1,602	1,606
Bellingham	**3**	**50K-75K**	1,419	1,398
Bellingham	**3**	**>75K**	2,481	2,482
Bellingham	**4+**	**< 25K**	998	1,001
Bellingham	**4+**	**25K-50K**	1,625	1,641
Bellingham	**4+**	**50K-75K**	1,661	1,634
Bellingham	**4+**	**>75K**	3,662	3,621
Blaine	**2**	**>75K**	1,239	1,439
Ferndale	**2**	**25K-50K**	1,028	1,278
Ferndale	**2**	**>75K**	1,362	1,389
Ferndale	**4**	**>75K**	1,561	1,575

Table 4.5: Comparison for Large Sub-regions - HH Size by Income

Sub Region	Num Workers	Income	Num HH Land Use 2008	Num HH using Survey Weights
Bellingham	0	< 25K	6,856	6,714
Bellingham	0	25K-50K	3,100	3,037
Bellingham	0	50K-75K	1,597	1,557
Bellingham	0	>75K	1,765	1,758
Bellingham	1	< 25K	4,743	4,952
Bellingham	1	25K-50K	5,897	5,891
Bellingham	1	50K-75K	3,004	2,929
Bellingham	1	>75K	4,027	3,979
Bellingham	2	< 25K	1,593	1,591
Bellingham	2	25K-50K	2,792	2,889
Bellingham	2	50K-75K	2,890	3,012
Bellingham	2	>75K	6,081	6,301
Bellingham	3+	>75K	1,210	1,221
Blaine	1	25K-50K	1,074	1,135
Blaine	1	>75K	1,071	1,142
Blaine	2	>75K	1,109	1,230
Ferndale	0	< 25K	1,032	1,091
Ferndale	1	25K-50K	1,230	1,298
Ferndale	1	>75K	1,208	1,284
Ferndale	2	>75K	1,856	1,968

Table 4.6: Comparison for Large Sub-regions - HH Workers by Income

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. Further, since these are not effectively used for the re-estimation of the models, the same weights used in the older survey were simply rescaled to match the new household totals.

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 5: 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 external trips and balances the PK and OP tables.

The main difference to the previous model update is that all the models have been re-estimated following the update to the survey weights and that the special generators were removed. The various model components are discussed below:

Trip Production Models

After a brief analysis using the updated survey, the current cross classifications for the trip productions were retained and explained the trip production behavior adequately. As in the 2008 model, all purposes other than NHBW and NHBO used cross-classification trip rates, whereas the NHBW and NHBO trip productions were determined using regression models. Trip production rates are also varied by the geographic region. One set of rates were developed for the city of Bellingham, WA and another set for the rest of the region. Finally, 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 5.1 and 5.2 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 966 internal zones, 427 zones are within the city limits of Bellingham, WA.

Household Income	Number of Workers in the household			
	0	1	2	3+
Less than $25,000	-	0.366	2.007	3.912
$25,000–$49,999	-	0.975	2.062	3.912
$50,000–$74,999	-	1.136	1.977	3.191
$75,000 or more	-	0.918	2.470	3.282

Table 5.1: HBW Trip Production Rates for Bellingham, WA

Household Income	Number of Workers in the household			
	0	1	2	3+
Less than $25,000	-	1.015	2.007	3.912
$25,000–$49,999	-	1.002	2.238	3.912
$50,000–$74,999	-	0.921	2.088	3.191
$75,000 or more	-	1.147	2.188	3.282

Table 5.2: HBW Trip Production Rates for rest of region

Tables 5.3 to 5.10 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.

HBCollege Trip Rates

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.065	0.000	0.000	0.000
$25,000–$49,999	0.043	0.179	0.049	0.000
$50,000–$74,999	0.000	0.073	0.121	0.245
$75,000 or more	0.000	0.000	0.293	0.472

Table 5.3: HBCollege Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.041	0.000	0.000	0.000
$25,000–$49,999	0.000	0.036	0.000	0.142
$50,000–$74,999	0.000	0.000	0.273	0.130
$75,000 or more	0.000	0.000	0.182	0.252

Table 5.4: HBCollege Trip Production Rates for rest of region

HBSchool Trip Rates

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.000	0.158	1.000	0.000
$25,000–$49,999	0.000	0.000	1.226	2.017
$50,000–$74,999	0.000	0.070	0.793	3.023
$75,000 or more	0.000	0.025	1.222	2.578

Table 5.5: HBSchool Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.000	0.438	2.000	0.000
$25,000–$49,999	0.000	0.000	0.713	3.091
$50,000–$74,999	0.000	0.000	0.658	3.433
$75,000 or more	0.000	0.000	0.799	2.793

Table 5.6: HBSchool Trip Production Rates for rest of region

HBShop Trip Rates

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.711	1.260	0.000	3.000
$25,000–$49,999	0.310	0.864	0.566	0.259
$50,000–$74,999	0.316	0.938	1.008	0.899
$75,000 or more	0.547	0.787	1.114	0.793

Table 5.7: HBShop Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	0.444	0.851	0.000	0.000
$25,000–$49,999	0.426	1.689	0.916	0.417
$50,000–$74,999	0.367	0.406	0.717	0.599
$75,000 or more	1.056	0.545	0.494	0.399

Table 5.8: HBShop Trip Production Rates for rest of region

HBO Trip Rates

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	1.426	2.253	4.000	9.000
$25,000–$49,999	1.854	2.366	5.107	9.069
$50,000–$74,999	1.526	2.519	5.056	7.613
$75,000 or more	1.453	3.093	4.298	7.748

Table 5.9: HBO Trip Production Rates for Bellingham, WA

Household Income	Household Size			
	1	2	3	4+
Less than $25,000	1.309	1.851	0.000	5.000
$25,000–$49,999	1.574	3.543	3.182	8.429
$50,000–$74,999	1.121	2.372	1.820	6.369
$75,000 or more	0.588	2.370	3.233	7.186

Table 5.10: HBO Trip Production Rates for the rest of the region

In all of the trip rates above, it must be noted that the number of low income households in the county with size greater than 3 is negligible.

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. Based on the new survey weights, several regression models were experimented. The models are presented in Table 5.11

Variable	NHBW_P	NHBO_P
Government Employment	3.386	
Finance and Insurance Employment	0.874	6.468
Service Employment	0.643	1.832
Retail Employment	1.010	6.270
Manufacturing Employment	0.707	
College Enrollment	0.282	0.413

Table 5.11: NHBW and NHBO Production Rates

Trip Production Adjustments for Special regions

In addition to the rates above, adjustments were made to certain local regions, as before. An explanation of these adjustments was provided in the previous model documentation. The adjusted factors were developed for each sub-region. These adjustment rates were recomputed using the updated weighted survey.

Purpose	Bellingham	Birch Bay	East Whatcom	Sudden Valley	Other
HBW Factor	1.00	1.20	1.05	0.35	1.15
HBSch Factor	1.20	0.80	0.80	0.25	0.80
HBColl Factor	1.25	1.50	0.00	0.00	0.75
HBShop Factor	1.00	0.85	0.85	0.40	0.95
HBO Factor	1.00	0.75	0.67	0.80	0.90
NHBW Factor	1.00	0.50	0.50	0.25	1.00
NHBO Factor	1.00	0.25	0.40	0.45	0.80

Table 5.12 Trip Production Rate Geographical Adjustments

All production rates for the Point Roberts region are set to 0.

Trip Attraction Models

Trip attraction models are typically developed based on employment estimates, school and college enrollment, total households and household population. The same methodology as in the 2008 model update was used. The trips in the survey were aggregated using the attraction zone to yield an estimate of the number of trips by purpose attracted at each zone. This is the dependent variable for the regression equation.

There are two main issues with estimating such attraction models. First is the fact that not all the zones are represented or covered well enough by the survey respondents. Thus there could be two identical zones with similar employment but for some reason the chosen survey sample yields very few attractions for one of the zones. Including both these zones in the regression could skew the model results. Secondly, the eventual model applied should have no constant, since the presence of one will imply attractions for zones where there is no employment/enrollment. These limitations require several iterations and experiments. However, 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 regression equations are shown in Table 5.13

Variable	HBW	HBShop	HBSch	HBColl	HBO	NHBW	NHBO
Government Employment	2.162				1.350	5.926	
Finance and Insurance Employment	1.279				0.756	0.950	
Service Employment	1.357				1.747	0.373	1.458
Retail Employment	0.701	3.100			1.309	0.985	6.947
Wholesale Employment	3.946						1.906
Manufacturing Employment	0.463					1.087	
Construction Employment	2.162						
Educational Employment	2.162						0.420
Agricultural Employment	2.162						
Telecommunications Employment	2.162						
Other Employment	2.162						
Household Population					0.682		
Grade School Enrollment			2.152		1.017		0.624
Middle School Enrollment			1.855		1.017		
High School Enrollment			1.618		1.017		
College Enrollment				0.300	1.707		0.304

Table 5.13: Trip Attraction Rates

After applying the attraction models for NHBW and NBHO, it was clear that the attractions in areas outside Bellingham had to be severely reduced. Table 5.14 shows the attraction geographic adjustment factors developed from the survey.

Purpose	Bellingham	Birch Bay	East Whatcom	Sudden Valley	Other
NHBW Factor	1.0	0.50	0.50	0.50	1.0
NHBO Factor	1.0	0.25	0.40	0.30	0.8

Table 5.14: Trip Attraction Rate Geographical Adjustments

Truck Productions and Attractions

The North Sound Travel survey did not contain truck trips. The truck trip production and attraction models from the previous version of the Whatcom model were retained (Table 5.15).

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 5.15: Truck Production and Attraction Rates

Special Generators

There are no special generators in the updated 2010 model. During the previous update, the number of trips attracted around primary retail centers such as malls and shopping complexes could not be adequately explained by the attraction models. However, the attraction models from the updated survey explain the trips around major retail zones very well so as to not warrant any special treatment.

Daily Productions and Attractions

The applied productions and attractions are shown in Table 5.16 below:

Purpose	Model Productions	Model Attractions	Survey Trips
HBW	97,274	114,523	**99,905**
HBShop	53,108	57,232	**53,626**
HBSch	50,476	52,239	**50,168**
HBColl	6,812	9,051	**6,730**
HBO	252,041	286,105	**259,790**
NHBW	61,769	56,913	**67,812**
NHBO	190,373	175,860	**166,465**
Truck	46,636	55,936	**67,812**

Table 5.16: Total Daily Productions and Attractions by Purpose

The production and attractions numbers seem to be within reasonable 10% limits and match the survey trips as well.

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 (7 AM and 10 AM) and the PM Peak (3 PM and 6 PM). Likewise the OP period is sub-divided into the MD period (10 AM and 3 PM) and the night period NT (6PM until 7 AM the following day). For each purpose, the peak and off-peak trip splits were obtained from the survey as below:

Purpose	Peak Split	Off Peak Split
HBW	55.0%	45.0%
HBCollege	55.0%	45.0%
HBSch	75%	25%
HBShop	45%	55%
HBO	48.5%	51.5%
NHBW	45%	55%
NHBO	43%	57%
Truck	17.5%	82.5%

Table5.17: Peak and Off-peak percentages by Purpose

External Trips

Trips from external zones that use the Whatcom network are obtained as inputs to the model. The eight entry/exit points (used in the 2008 model) were found to be sufficient.

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 5:18: List of 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 5.19. Entry trips are those trips that enter Whatcom County (EI Trips) and exit trips are those that leave Whatcom County (IE trips). This data was assimilated with great care from the latest count information including border crossing counts.

TAZ	AM Entry	AM Exit	MD Entry	MD Exit	PM Entry	PM Exit	NT Entry	NT Exit	Through Trips Pct	Truck Trips Pct
1001	3,651	4,505	6,451	6,811	5,367	4,657	6,966	6,007	5%	0%
1002	862	901	1,900	2,261	1,070	1,474	1393	1,952	19%	0%
1003	662	449	1,147	1,067	606	723	732	1,210	21%	19%
1004	319	153	914	645	465	553	366	601	7%	12%
1005	471	437	994	899	661	723	816	834	7%	6%
1006	128	114	356	423	325	344	309	269	0%	0%
1007	113	259	220	354	202	238	298	482	0%	0%
1008	0	0	0	0	0	0	0	0	0%	0%

Table 5.19: 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

All purposes except the Home Based School trips were balanced to productions. The HBSchool purpose was balanced to attractions. In each case, the external productions and attractions are left untouched.

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	57,504	49,902
HBShop	24,766	30,537
HBSchool	39,179	13,060
HBCollege	3,747	3,066
HBO	125,175	134,295
NHBW	30,798	38,569
NHBO	84,396	112,394
Truck	8,502	39,001
Total	**374,067**	**420,824**

Table 5.20: 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.

Figures 5.1 and 5.2 give a sense of the daily trip productions and attractions within Whatcom County. In general, the trip productions in Bellingham are higher than the rest of the County.

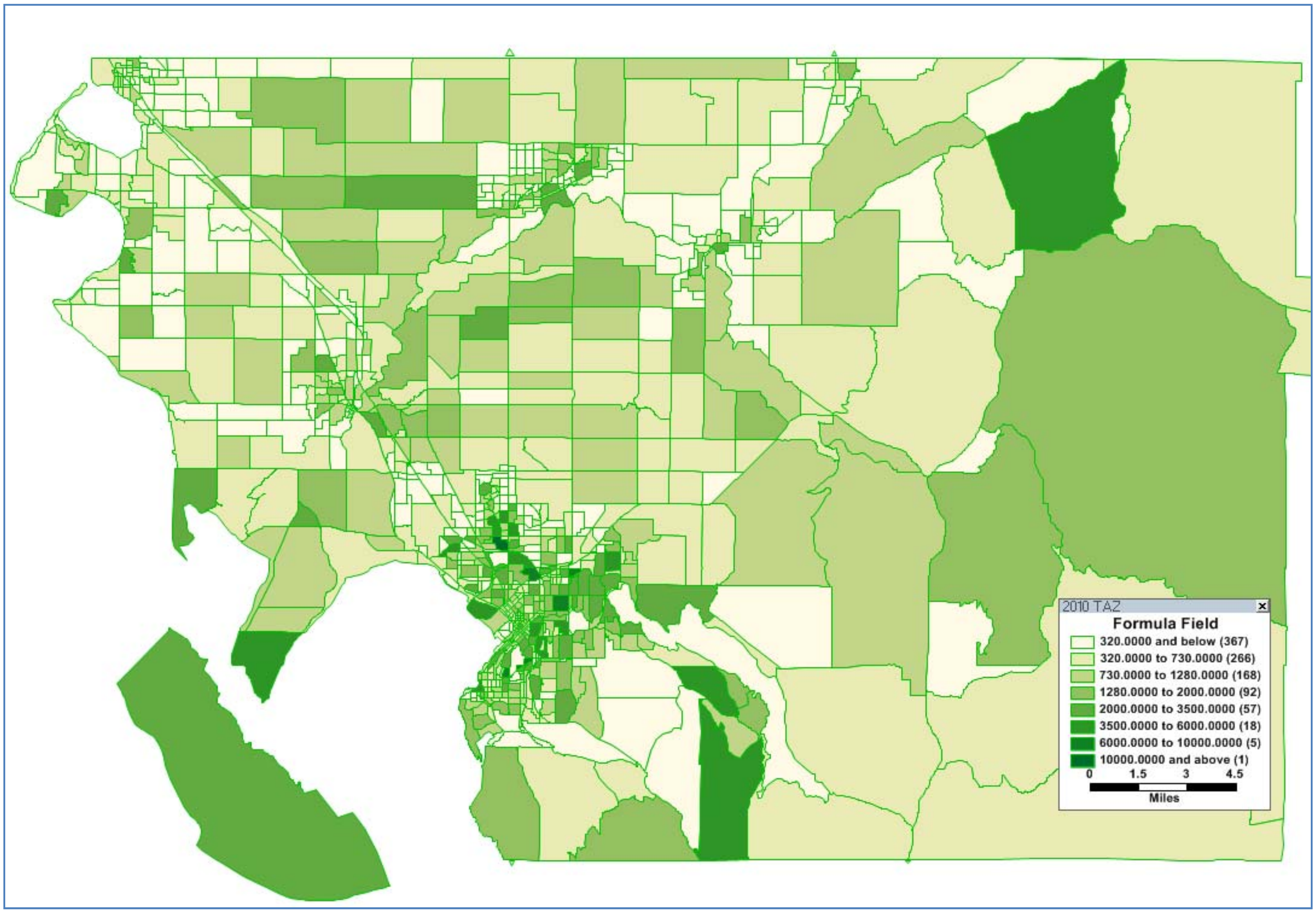

Figure 5.1: Daily Productions in Whatcom County

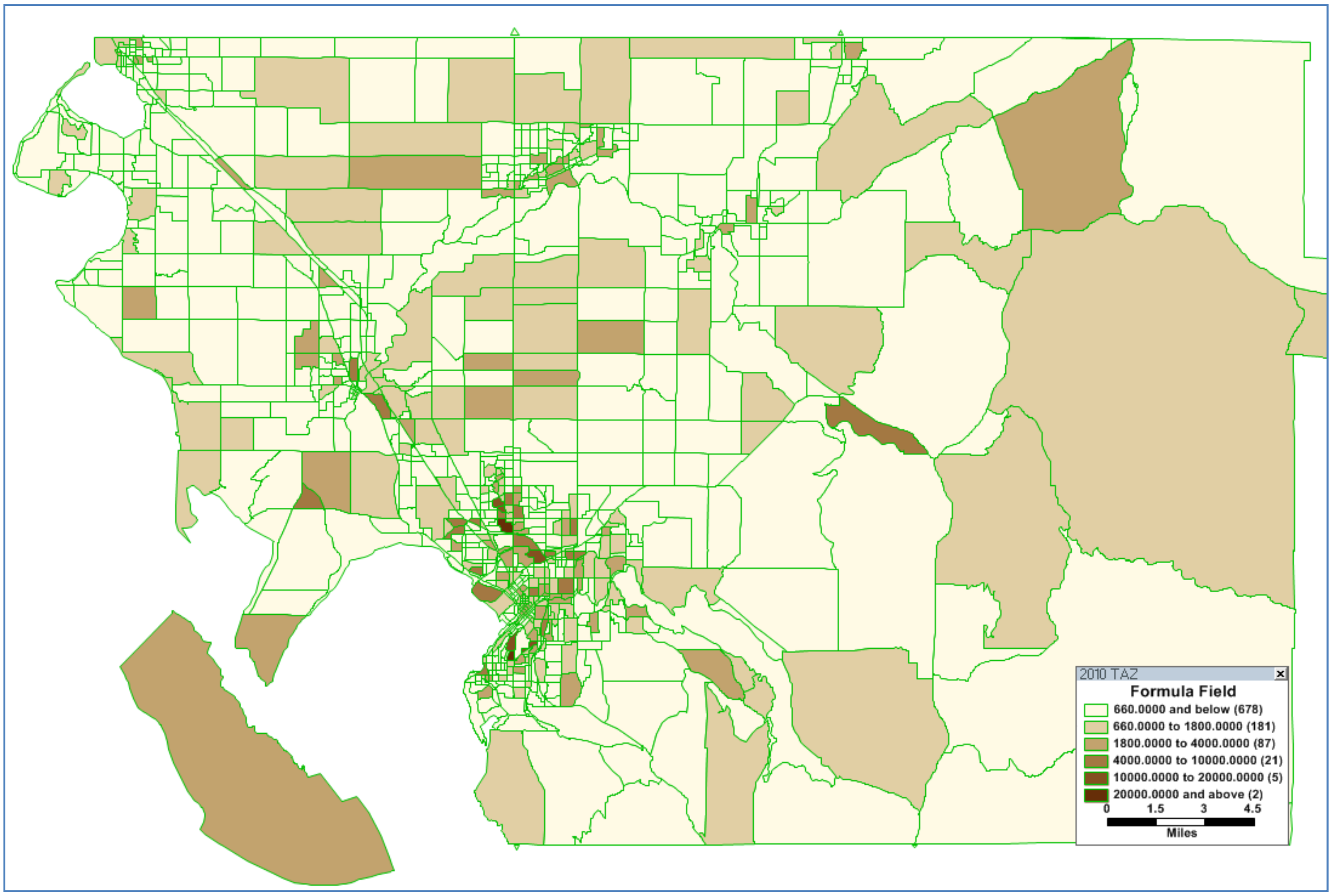

Figure 5.2: Daily Attractions in Whatcom County

Chapter 6: 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 as repeated from the 2008 documentation 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.

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.

During the previous model calibration round, gamma curves based on the functional form below were used to fit curves for every trip purpose:

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

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

It was observed during the 2010 calibration phase that the trip lengths obtained using the previous friction factor curves were still close to the updated survey trip lengths. Also, the Whatcom area in general is not pretty congested and the trip patterns from 2008 to 2010 have not changed significantly. The friction factors were therefore not modified. For sake of brevity, the friction factor equations are shown below.

HBW Friction Factors

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

Table 6.1: HBW Gamma Parameters

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

HBSchool Friction Factors

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

Table 6.2: HBSchool Gamma 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.

HBCollege Friction Factors

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 6.3: HBCollege Gamma Parameters

In addition, for values of time between 12 and 14 minutes, a linear interpolation is assumed

HBShop Friction Factors

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

Table 6.4: HBShop Gamma Parameters

HBO Friction Factors

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

Table 6.5: HBO Gamma Parameters

NHBW Friction Factors

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

Table 6.6: NHBW Gamma Parameters

In addition, for values of time between 6 and 9 minutes, a linear interpolation is assumed

NHBO Friction Factors

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

Table 6.7: NHBO Gamma Parameters

In addition, for values of time between 5 and 9 minutes and between 28 and 31 minutes a linear interpolation is assumed

Truck Friction Factors

The truck friction factors were retained from the previous model as shown in Table 6.8

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

Table 6.8: Truck Gamma 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 (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 table 6.9 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. These number match the trip length from the updated survey using the final skim matrices.

Trip Purpose	Average Trip Time PK (min)	Average Trip Time OP (min)
HBW	14.45	14.78
HBSch	9.94	9.95
HBColl	11.86	11.68
HBShop	11.92	11.99
HBO	12.04	12.09
NHBW	10.21	10.57
NHBO	6.43	6.51
Truck	16.22	15.83

Table 6.9: Model Trip Times (including IX and XI trips)

The average trip lengths are shown in Table 6.10

Trip Purpose	Average Trip Length PK (miles)	Average Trip Length OP (miles)
HBW	9.94	10.60
HBSch	6.38	6.44
HBColl	7.28	7.31
HBShop	8.08	8.30
HBO	7.91	8.12
NHBW	7.44	7.82
NHBO	4.14	4.21
Truck	11.25	10.96

Table 6.10: Model Trip Lengths (including IX and XI trips)

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

Chapter 7: Mode Choice

The mode choice module in the Whatcom model is applied for the PK and the OP trip distribution matrices.

An extensive mode choice modeling effort including model specification, estimation, calibration and application were done in the 2008 model update. During the current phase of the modeling effort, the mode choice estimations were revisited numerous times and the models were modified. Further, the mode choice utility Alternate Specific Constants (ASC's) were adjusted several times during the calibration process to match regional survey shares.

In general, the same mode choice tree structure as developed in the 2008 model update was retained. Some experimentation with the tree structure was nevertheless done but the current structure yielded a better fit. Some new variables were introduced especially to capture transit mode share and will be discussed appropriately. The next section shows the estimated mode choice models after the adjustment of the ASC's to match regional shares. Key differences with respect to the previous model update are pointed out. For a detailed description of the technique of mode choice model estimation, please refer to the 2008 model document[1].

Mode Choice Model Set

Table 7.1 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 7.1: Availability of Modes by Trip Purpose - * indicates the mode is only available for the Peak Period

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.

HBW Peak Model Tree

In the diagrams below, the θ parameter indicates that there is a co-efficient associated with the logsum term from the sub-tree below. The symbol **C** indicates the presence of an alternative specific constant (ASC).

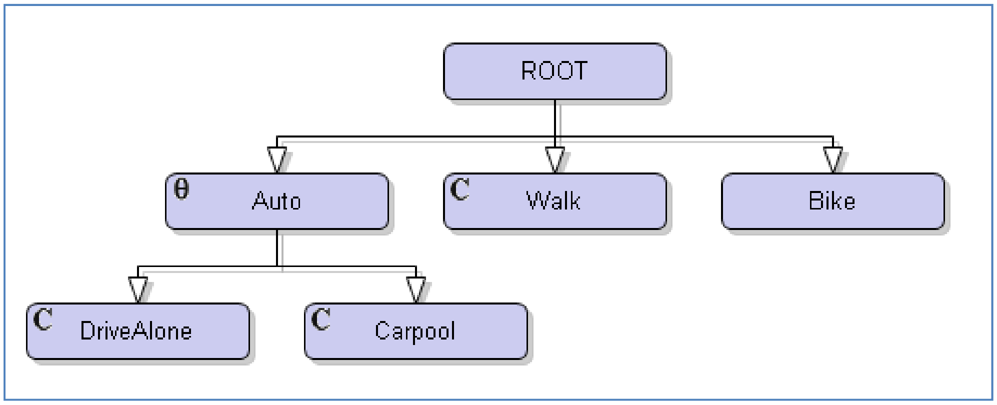

Figure 7.1: HBW Peak Mode Choice Tree Structure

HBW Peak Model Utilities

θ_{Auto} = 0.1166

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.4240	1			
ASC_CP	0.1470		1		
ASC_Bike				Base	
ASC_Walk	2.3980				1
B_IVTT	-0.0548	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.2: HBW Peak Mode Choice Model Specification

HBW OffPeak Model Tree

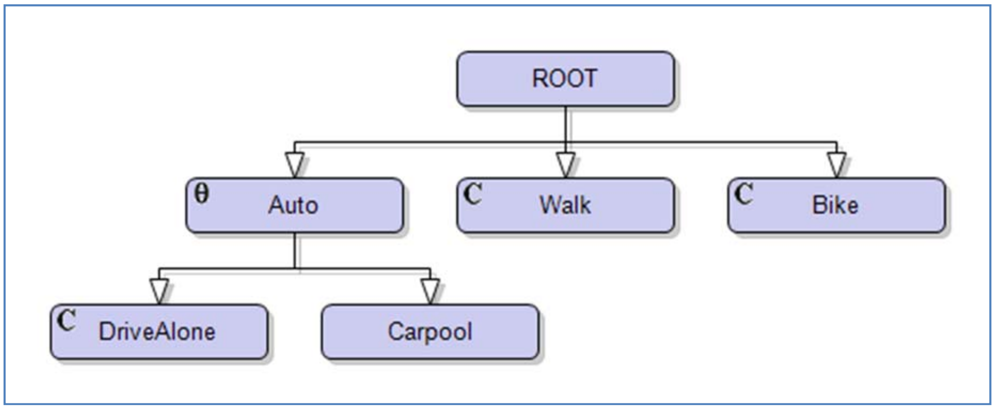

Figure 7.2: HBW OffPeak Mode Choice Tree Structure

HBW OffPeak Model Utilities

$\theta_{Auto} = 0.1179$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.2155	1			
ASC_CP			Base		
ASC_Bike	-1.0161			1	
ASC_Walk	2.5685				1
B_IVTT	-0.1328	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.3: HBW OffPeak Mode Choice Model Specification

HBSchool Peak Model Tree

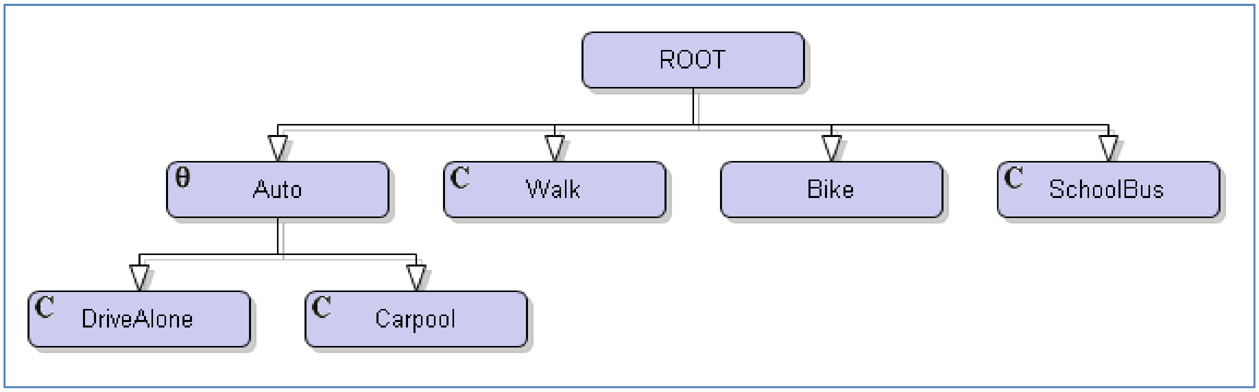

Figure 7.3: HBSchool Peak Mode Choice Tree Structure

HBSchool Peak Model Utilities

θ_Auto = 0.4858

Coefficient	Value	DA	CP	Bike	Walk	School Bus
ASC_DA	-0.7870	1				
ASC_CP	0.2770		1			
ASC_Bike				Base		
ASC_Walk	4.1342				1	
ASC_SchoolBus	-0.9055					1
B_IVTT	-0.0704	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	

Table 7.4: HBSchool Peak Mode Choice Model Specification

HBSchool OffPeak Model Tree

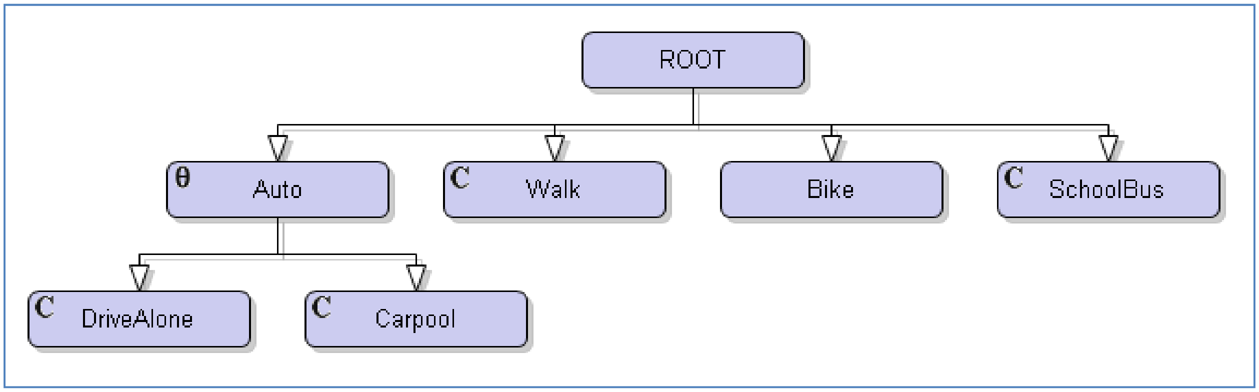

Figure 7.4: HBSchool OffPeak Mode Choice Tree Structure

HBSchool OffPeak Model Utilities

θ_Auto = 0.1293

Coefficient	Value	DA	CP	Bike	Walk	School Bus
ASC_DA	-0.0115	1				
ASC_CP	0.2180		1			
ASC_Bike				Base		
ASC_Walk	0.9055				1	
ASC_SchoolBus	-0.5034					1
B_IVTT	-0.0142	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	

Table 7.5: HBSchool OffPeak Mode Choice Model Specification

HBCollege Peak Model Tree

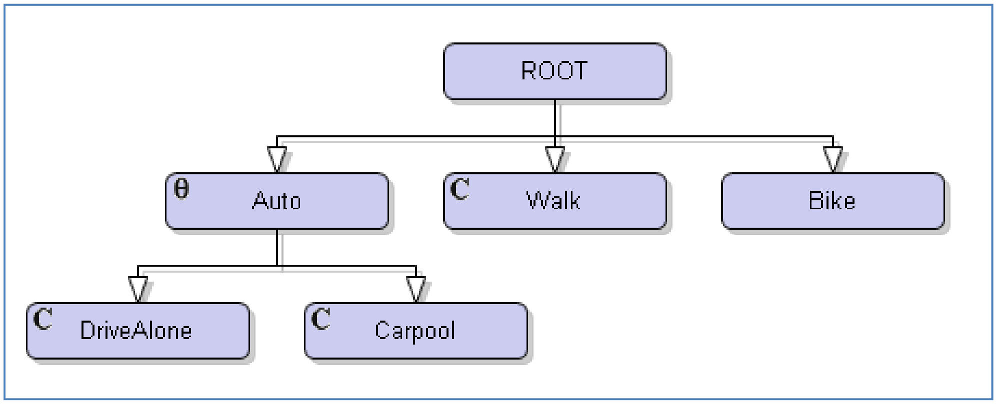

Figure 7.5: HBCollege Peak Mode Choice Tree Structure

HBCollege Peak Model Utilities

$\theta_{Auto} = 0.1166$

Coefficient	**Value**	**DA**	**CP**	**Bike**	**Walk**
ASC_DA	0.1611	1			
ASC_CP	0.0860		1		
ASC_Bike				Base	
ASC_Walk	1.1975				1
B_IVTT	-0.0548	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.6: HBCollege Peak Mode Choice Model Specification

HBCollege OffPeak Model Tree

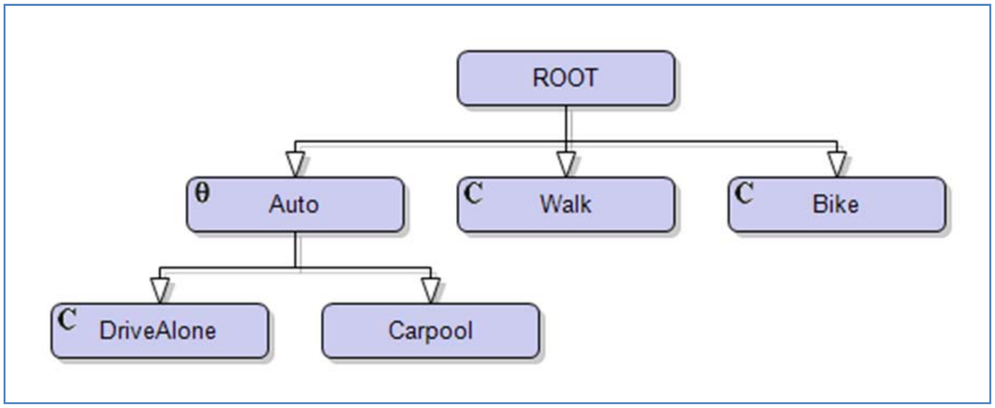

Figure 7.6: HBCollege OffPeak Mode Choice Tree Structure

HBCollege OffPeak Model Utilities

$\theta_{Auto} = 0.1179$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.2924	1			
ASC_CP			Base		
ASC_Bike	-0.5555			1	
ASC_Walk	4.4758				1
B_IVTT	-0.1328	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.7: HBCollege OffPeak Mode Choice Model Specification

HBShop Peak Model Tree

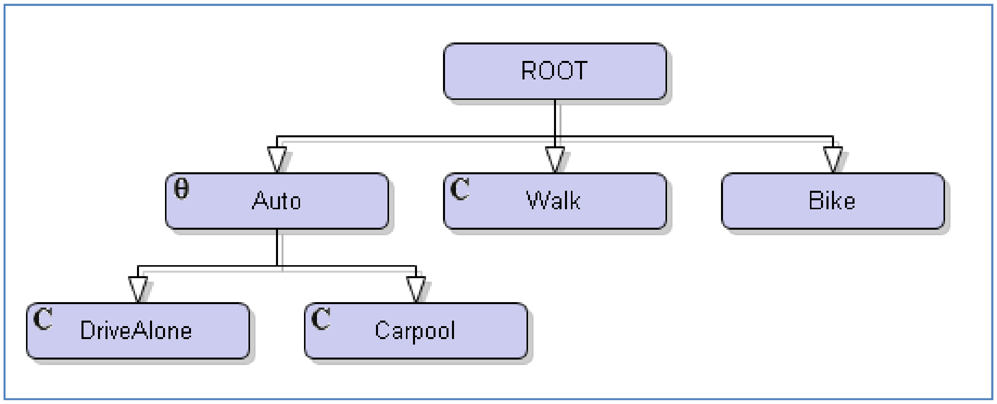

Figure 7.7: HBShop Peak Mode Choice Tree Structure

HBShop Peak Model Utilities

$\theta_{Auto} = 0.8133$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.1485	1			
ASC_CP	-0.0810		1		
ASC_Bike				Base	
ASC_Walk	5.7237				1
B_IVTT	-0.2170	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.8: HBShop Peak Mode Choice Model Specification

HBShop OffPeak Model Tree

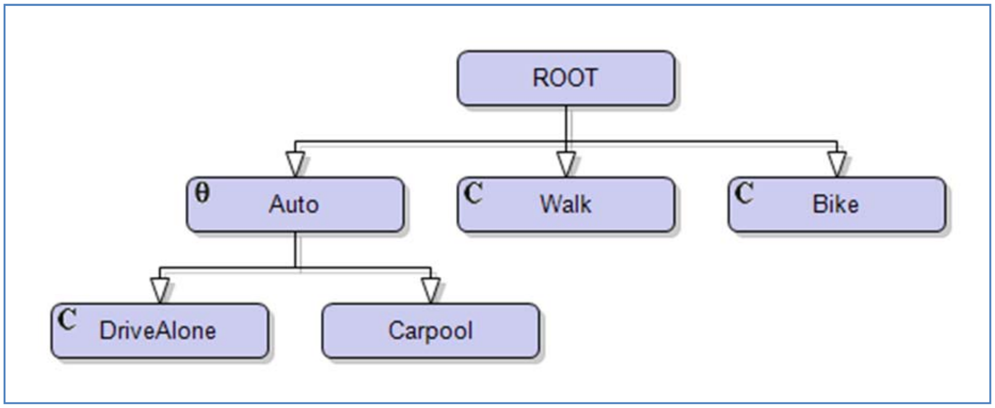

Figure 7.8: HBShop OffPeak Mode Choice Tree Structure

HBShop OffPeak Model Utilities

$\theta_{Auto} = 0.1234$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.0200	1			
ASC_CP			Base		
ASC_Bike	-1.2614			1	
ASC_Walk	2.9603				1
B_IVTT	-0.2120	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.9: HBShop OffPeak Mode Choice Model Specification

HBO Peak Model Tree

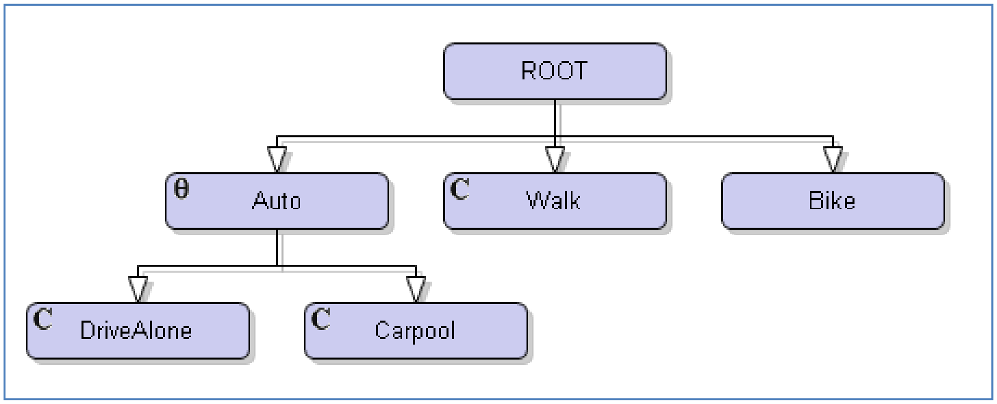

Figure 7.9: HBO Peak Mode Choice Tree Structure

HBO Peak Model Utilities

θ_{Auto} = 0.1153

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.1271	1			
ASC_CP	0.2000		1		
ASC_Bike				Base	
ASC_Walk	6.1054				1
B_IVTT	-0.1583	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.10: HBO Peak Mode Choice Model Specification

HBO OffPeak Model Tree

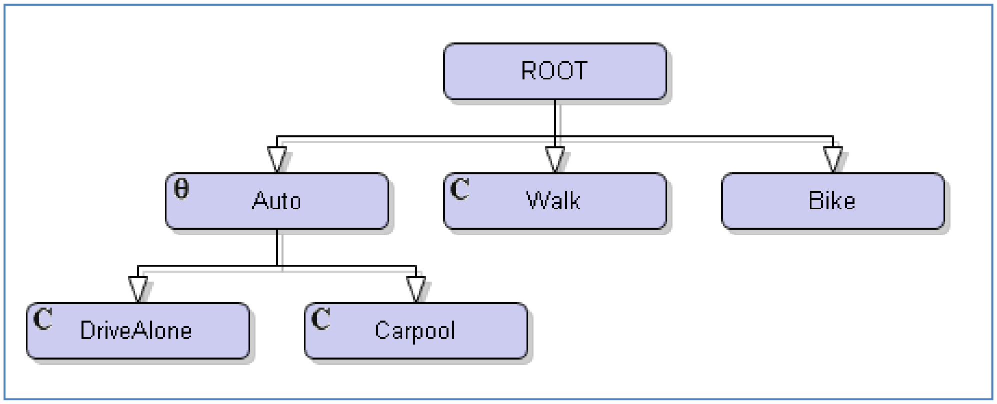

Figure 7.10: HBO OffPeak Mode Choice Tree Structure

HBO OffPeak Model Utilities

$\theta_{Auto} = 0.8880$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	-0.3216	1			
ASC_CP	-0.0200		1		
ASC_Bike				Base	
ASC_Walk	3.8214				1
B_IVTT	-0.1838	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.11: HBO OffPeak Mode Choice Model Specification

NHBW Peak Model Tree

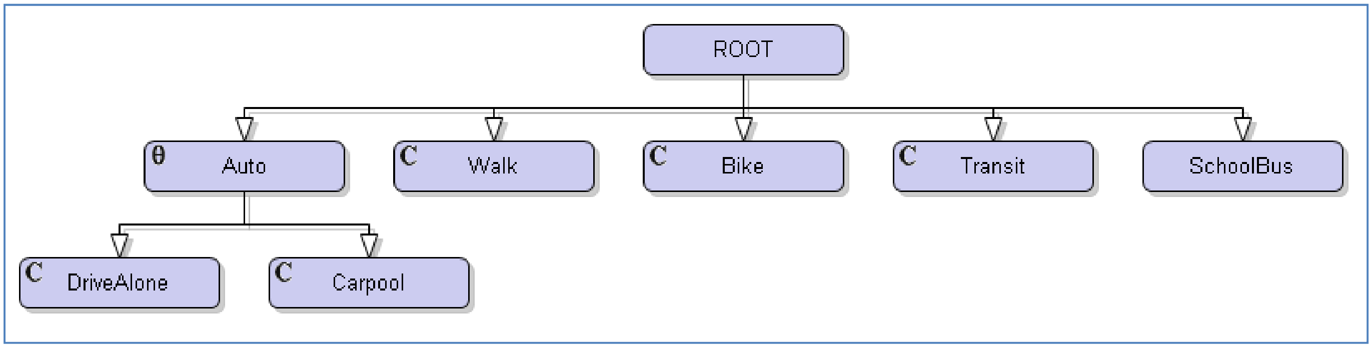

Figure 7.11: NHBW Peak Mode Choice Tree Structure

NHBW Peak Model Utilities

θ_Auto = 0.8642

Coefficient	Value	DA	CP	Bike	Walk	Transit	School Bus
ASC_DA	3.9038	1					
ASC_CP	2.5550		1				
ASC_Bike	1.9027			1			
ASC_Walk	3.7500				1		
ASC_Transit	0.7750					1	
ASC_SchoolBus							Base
B_IVTT	-0.0824	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	Transit_IVTT	

Table 7.12: NHBW Peak Mode Choice Model Specification

NHBW OffPeak Model Tree

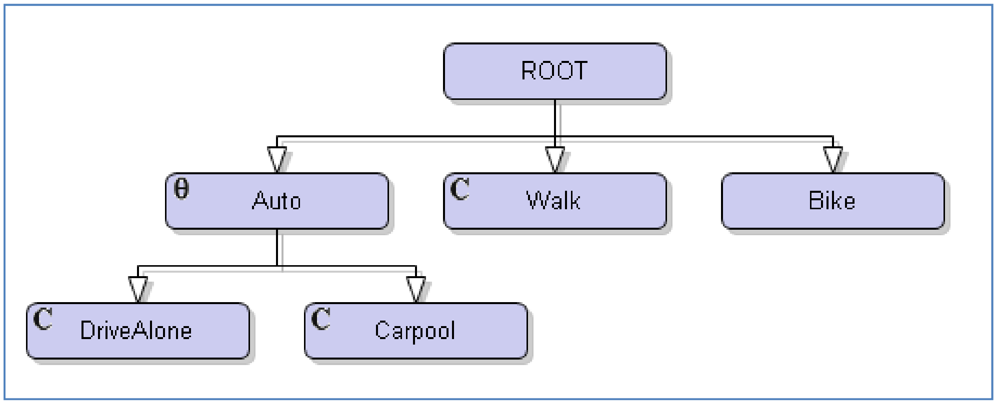

Figure 7.12: NHBW OffPeak Mode Choice Tree Structure

NHBW OffPeak Model Utilities

$\theta_{Auto} = 0.6022$

Coefficient	Value	DA	CP	Bike	Walk
ASC_DA	0.7233	1			
ASC_CP	-0.0100		1		
ASC_Bike				Base	
ASC_Walk	3.2082				1
B_IVTT	-0.2098	Auto_Time	Auto_Time	Bike_Time	Walk_Time

Table 7.13: NHBW OffPeak Mode Choice Model Specification

NHBO Peak Model Tree

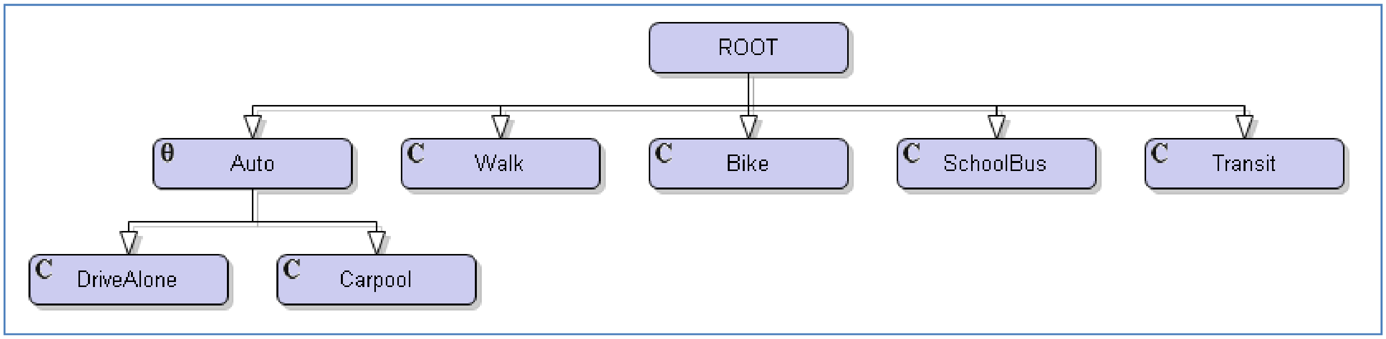

Figure 7.13: NHBO Peak Mode Choice Tree Structure

NHBO Peak Model Utilities

θ_Auto = 0.9385

Coefficient	Value	DA	CP	Bike	Walk	Transit	School Bus
ASC_DA	0.3437	1					
ASC_CP	0.8250		1				
ASC_Bike	-1.2500			1			
ASC_Walk	1.8670				1		
ASC_Transit	-0.6579					1	
ASC_SchoolBus	-1.9577						1
B_IVTT	-0.1059	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	Transit_IVTT	
B_Atype	-0.8023					Rural_Dummy	
B_UnivZone	3.8358					Univ_Dummy	

Table 7.14: NHBO Peak Mode Choice Model Specification

Based on observed transit ridership, a couple of new variables are added to the mode choice equation. These are to capture increased or concentrated transit ridership around urban and university centers. For a given OD pair, the Rural_Dummy is 1 if the destination (D) zone is marked as rural. Likewise, the Univ_Dummy is equal to 1 if the destination (D) zone is marked as a university zone. Thus, logically, the co-efficient of the rural dummy is negative (does not attract transit) and the co-efficient of the university dummy is positive (attracts transit).

Also in the equations above, note that there are ASC's for all alternatives. The model was estimated without the constant for School Bus but was introduced while trying to match region shares.

NHBO OffPeak Model Tree

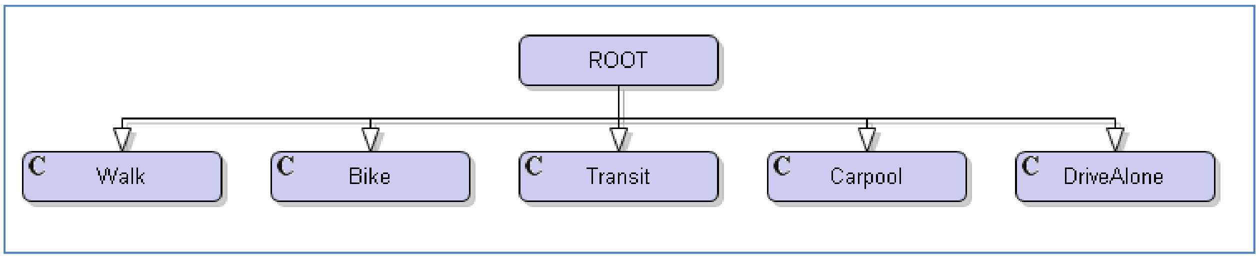

Figure 7.14: NHBO OffPeak Mode Choice Tree Structure

NHBO OffPeak Model Utilities

Coefficient	Value	DA	CP	Bike	Walk	Transit
ASC_DA	-0.4413	1				
ASC_CP	-0.1250		1			
ASC_Bike	-3.2246			1		
ASC_Walk	1.7177				1	
ASC_Transit	-1.2645					1
B_IVTT	-0.1788	Auto_IVTT	Auto_IVTT	Bike_Time	Walk_Time	Transit_IVTT
B_Atype	-0.5299					Rural_Dummy
B_UnivZone	1.1940					Univ_Dummy

Table 7.15: NHBO OffPeak Mode Choice Model Specification

Application of 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. For all the models, the walk mode is unavailable if the walking skim distance is greater than 2 miles, the bike mode is deemed unavailable if the skim distance is greater than 5 miles. The transit availability is determined by the transit skim settings and outputs. Missing transit skim values for an OD pair indicate lack of transit availability. Drive and Carpool modes are always available. 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

Tables 7.16 and 7.17 compare model and survey shares by purpose, for the peak and offpeak periods respectively. The tables indicate a reasonably close match to the survey shares. In general, it was difficult to match walk shares for the peak period and due to the availability variable, increasing the walk ASC beyond any value had no effect. It was similarly difficult to allocate between walk and bike shares but the combined non-motorized share match the survey very well.

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). Therefore the transit totals were lowered to better match the WTA data.

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.

Purpose	Drive Share	Carpool Share	Walk Share	Bike Share	Transit Share	School Bus Share
HBW Survey	80.2%	8.3%	4.4%	7.0%	0.1%	-
HBW Model	77.9%	7.2%	4.6%	10.2%	-	-
HBColl Survey	49.1%	25.7%	3.9%	21.3%	-	-
HBColl Model	52.5%	27.6%	3.3%	16.6%	-	-
HBSch Survey	4.0%	43.4%	15.0%	3.9%		33.7%
HBSch Model	4.3%	38.7%	19.1%	7.8%		30.1%
HBShop Survey	48.3%	35.2%	12.3%	2.1%	1.3%	0.8%
HBShop Model	47.7%	36.0%	10.7%	5.6%	-	-
HBO Survey	28.0%	53.4%	16.1%	2.1%	0.2%	0.3%
HBO Model	26.7%	50.3%	16.2%	6.8%	-	-
NHBW Survey	68.7%	14.0%	8.2%	5.6%	2.7%	0.9%
NHBW Model	69.5%	14.6%	5.8%	4.5%	1.8%	3.9%
NHBO Survey	25.8%	41.9%	10.1%	1.3%	14.8%	6.1%
NHBO Model	26.9%	45.0%	9.7%	2.8%	9.1%	6.5%

Table 7.16: Comparison of Peak Mode Choice Shares by purpose

Purpose	Drive Share	Carpool Share	Walk Share	Bike Share	Transit Share	School Bus Share
HBW Survey	79.2%	11.3%	4.1%	5.2%	0.2%	-
HBW Model	80.1%	12.9%	3.4%	3.6%	-	-
HBColl Survey	77.0%	8.5%	6.9%	7.6%	-	-
HBColl Model	79.7%	6.7%	7.1%	6.5%	-	-
HBSch Survey	9.3%	46.1%	9.1%	5.5%	-	30.0%
HBSch Model	7.2%	42.3%	8.8%	13.9%	-	27.8%
HBShop Survey	47.1%	42.5%	4.4%	4.3%	1.0%	0.7%
HBShop Model	49.4%	42.0%	4.9%	3.7%	-	-
HBO Survey	36.7%	49.4%	11.6%	2.0%	-	0.3
HBO Model	35.1%	49.2%	8.6%	7.1%	-	-
NHBW Survey	62.9%	18.4%	15.4%	1.6%	0.3%	1.2%
NHBW Model	61.9%	18.3%	11.7%	8.0%	-	-
NHBO Survey	32.3%	44.7%	9.4%	0.7%	10.9%	2.0%
NHBO Model	34.4%	47.2%	9.6%	0.7%	8.1%	-

Table 7.17: Comparison of OffPeak Mode Choice Shares by purpose

Chapter 8: 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 8.1 below:

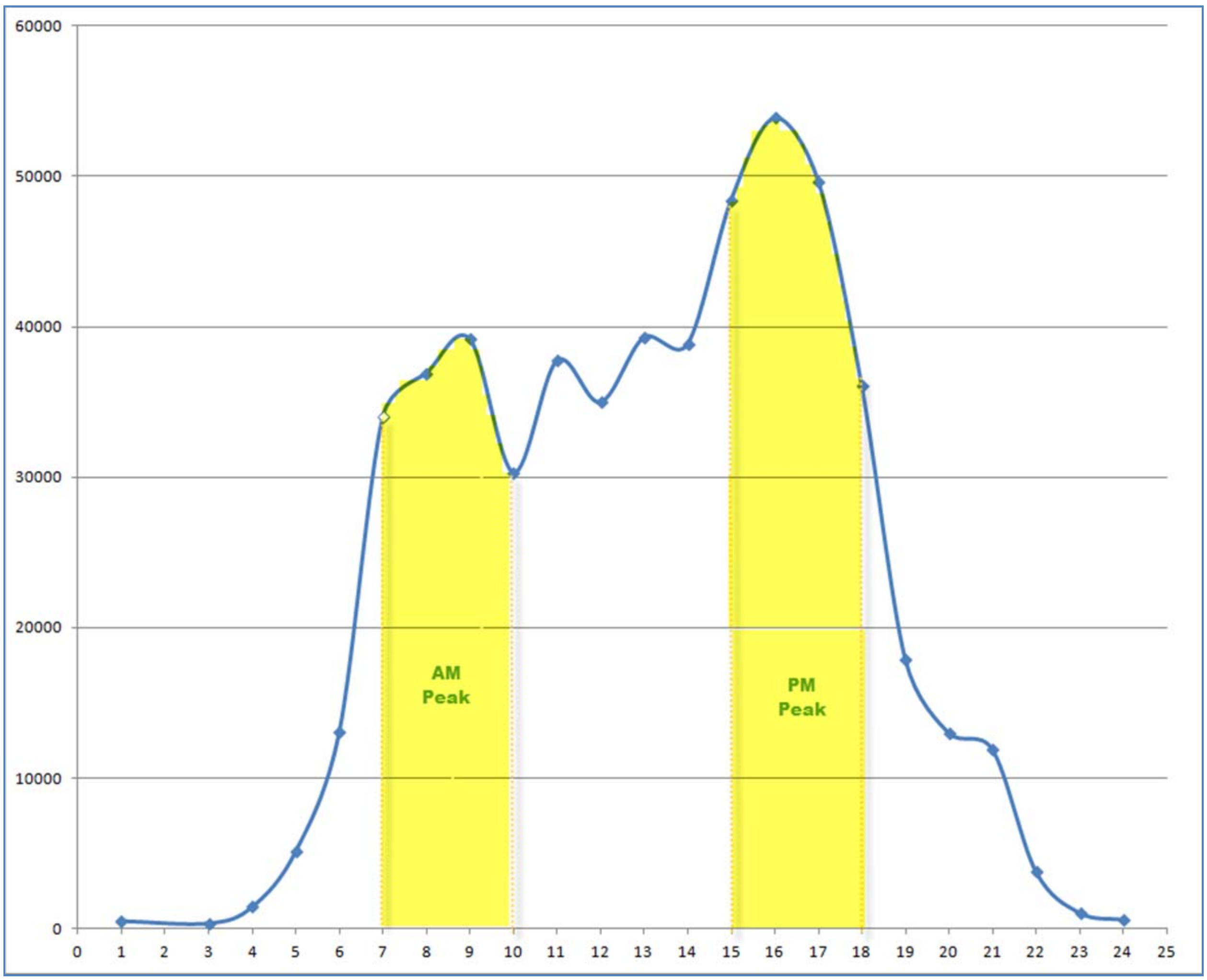

Figure 8.1: Time of Day Distribution

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 10 AM; MD – 9 AM to 3 PM; PM – 3 PM to 6 PM and the NT containing the rest of the hours

As in the previous model, 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 **hourly** 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 2.12, 2.60, 2.07, 2.11, 2.48, 2.29 and 2.29 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 Peak departure and return rates are obtained by looking at all the Auto trips from the survey that departed during the Peak period. The Auto Offpeak departure and return rates are obtained by looking at all the Auto trips from the survey that departed during the OP period Transit departure and return rates were determined from 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 8.1 shows the Auto departure and return rates for the peak period.

Purpose	AM_Dep	AM_Ret	PM_Dep	PM_Ret
HBW	46.1%	1.0%	3.9%	49.0%
HBColl	36.7%	6.8%	13.3%	43.2%
HBSch	48.2%	0.6%	1.8%	49.4%
HBShop	25.0%	6.9%	25.0%	43.1%
HBO	26.6%	11.3%	23.5%	38.6%
NHBW	17.5%	17.5%	32.5%	32.5%
NHBO	16.9%	16.9%	33.1%	33.1%
Truck	20.0%	20.0%	30.0%	30.0%

Table 8.1: Peak Auto Departure and Return Rates by Purpose

Some features of the above table are:

- The above departure and return percentages by purpose pertain only to the Peak Period (7 AM to 10 AM and 3PM to 6PM). 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 = 46.1 % of (HBW Drive Alone PA) + 1.0 % of (HBW Drive Alone PA transpose)
  - HBW Carpool AM OD = (46.1% of (HBW Carpool PA) + 1.0 % of (HBW Carpool PA transpose)/2.12, where 2.12 is the carpool 2+ occupancy rate for the HBW purpose.

Table 8.2 shows the Auto departure and return rates for the Off-Peak period (10 AM to 3PM and 6PM 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	20.2%	24.5%	29.8%	25.5%
HBColl	35.5%	14.1%	14.5%	25.9%
HBSch	15.3%	29.6%	34.7%	20.4%
HBShop	38.8%	33.1%	15.2%	16.9%
HBO	31.7%	23.1%	18.3%	26.8%
NHBW	42.7%	42.7%	7.3%	7.3%
NHBO	40.6%	40.6%	9.4%	9.4%
Truck	25.0%	25.0%	25.0%	25.0%

Table 8.2: OffPeak Auto Departure and Return Rates by Purpose

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 peak and offpeak 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 8.3 and 8.4 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	17.5%	17.5%	32.5%	32.5%

Table 8.3: Peak Transit Departure and Return Rates

Purpose	MD_Dep	MD_Ret	NT_Dep	NT_Ret
NHBW and NHBO	42.4%	42.4%	7.6%	7.6%

Table 8.4: OffPeak Transit Departure and Return Rates

Time of Day Results

The following tables show the auto and transit OD totals by time period and purpose after the Time of Day procedure and before the traffic assignment. The total trips without IX/XI trips and the total after the IX/XItrips make up the last two rows in Table 8.5.

Trip Purpose	AM OD Trips	MD OD Trips	PM OD Trips	NT OD Trips
HBW	19,376	15,161	21,767	18,729
HBSch	3,666	1,373	3,855	1,688
HBColl	1,070	1,259	1,395	1,282
HBShop	4,564	12,466	9,747	5,886
HBO	21,033	37,345	34,598	30,746
NHBW	6,647	17,763	12,317	3,042
NHBO	12,487	52,781	24,420	12,274
Trucks	3,428	19,551	5,138	19,547
Total	**72,271**	**157,699**	**113,236**	**93,195**
Total with IX/XI	**84,478**	**180,354**	**129,525**	**113,960**

Table 8.5: Auto and Truck OD by Time Period

Period	Transit OD Trips
AM	2,648
MD	7,178
PM	4,983
NT	1,292
Total	**16,101**

Table 8.6: Transit OD by Time Period

Chapter 9: Assignment

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

- The assignment method is TransCAD's super-efficient 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

Note that the assignment for each of the time periods is not a straight shot assignment. For example, the AM period is from 7AM to 10 AM and a static assignment for the three hours would yield only a rough solution and will muddle the congestion effects. Therefore, the AM flows are obtained by running two traffic assignments, one for the 7AM to 9AM period and one for the 9AM to 10AM period and the flows are added together. This captures the congestion effects better. Table 9.1 shows how the time period assignments are assembled. For each period, two assignments are done and the results are combined.

Time Period	Assignment 1	Assignment 2
AM	7AM-9AM	9AM-10AM
MD	10AM-1PM	1PM-3PM
PM	3PM-4PM	4PM-6PM
NT	6PM-7PM	7PM-7AM

Table 9.1: Time Period Assignments

Assignment Parameters

The volume delay function (VDF) is the 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, t_f is the free flow time and t is the congested time.

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

During this update, the alpha and beta values were calibrated to a more detailed level and vary based on both functional class and area type, as shown in Table 9.2 below

Type	Class	AreaType	Alpha	Beta
1	**Freeway**	**Urban**	0.75	10.0
1	**Freeway**	**Suburban**	0.50	9.5
1	**Freeway**	**Rural**	0.40	9.0
2	**Major Arterial**	**Urban**	1.50	5.0
2	**Major Arterial**	**Suburban/Rural**	1.25	5.0
4	**Minor Arterial**	**Urban**	1.50	5.0
4	**Minor Arterial**	**Suburban/Rural**	1.25	5.0
5	**Major Collector**	**Urban**	1.75	5.5
5	**Major Collector**	**Suburban**	1.50	5.5
5	**Major Collector**	**Rural**	1.25	5.5
6	**Minor Collector**	**Urban**	1.75	5.5
6	**Minor Collector**	**Suburban**	1.50	5.5
6	**Minor Collector**	**Rural**	1.25	5.5
7	**Ramp**	**All**	1.00	6.0
9	**Centroid Connector**	**All**	0.15	4.0

Table 9.2; BPR VDF Parameters

The plot of some of the VDF equations is shown in Figure 9.1. The horizontal axis shows the volume to capacity ratio and the vertical axis represents the ratio of congested time to free flow times.

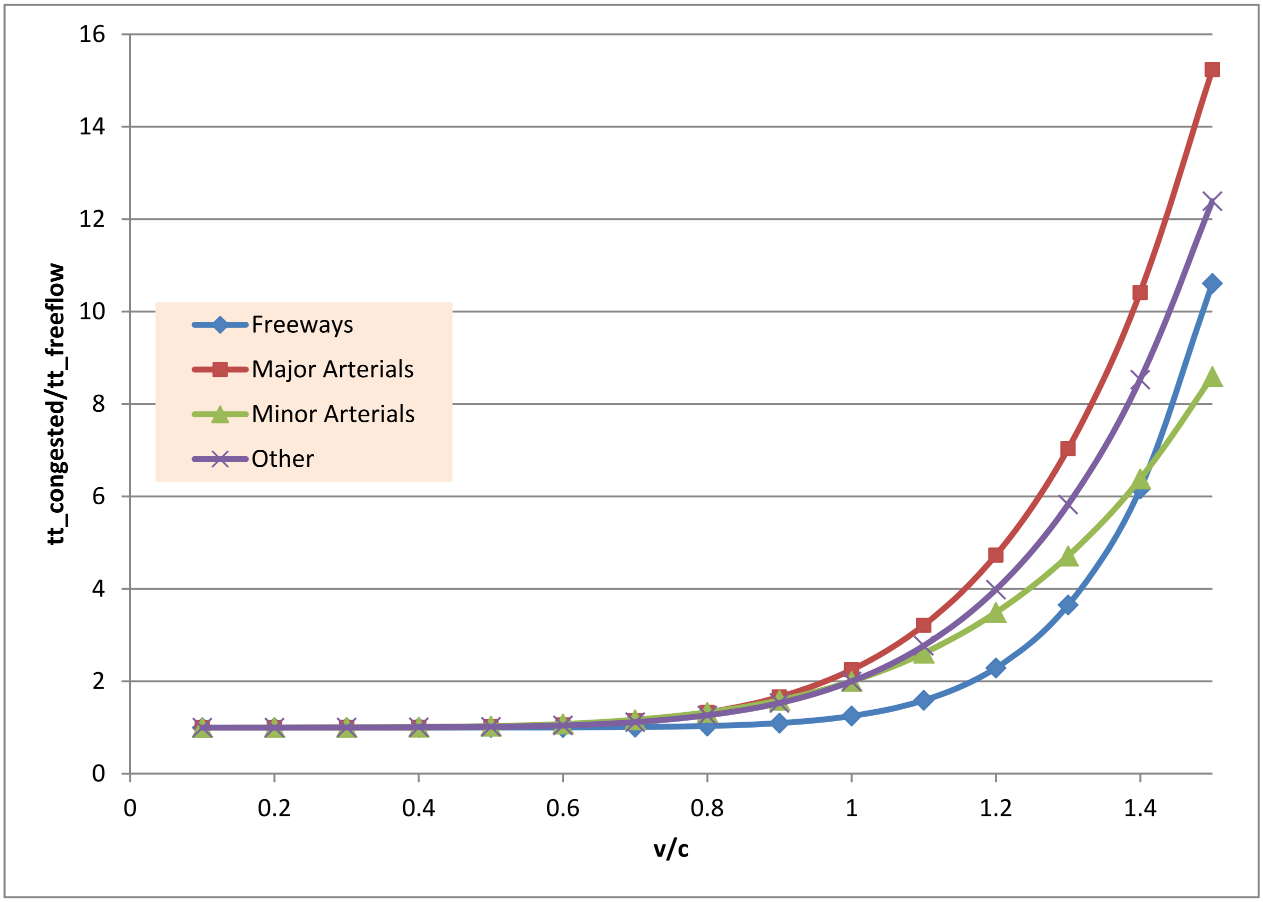

Figure 9.1: Sample Volume Delay Functions by Functional Class

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 9.2 to 9.5. The assignment results for each period were compared with traffic count data by period and the results are then discussed:

Figure 9.2 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.

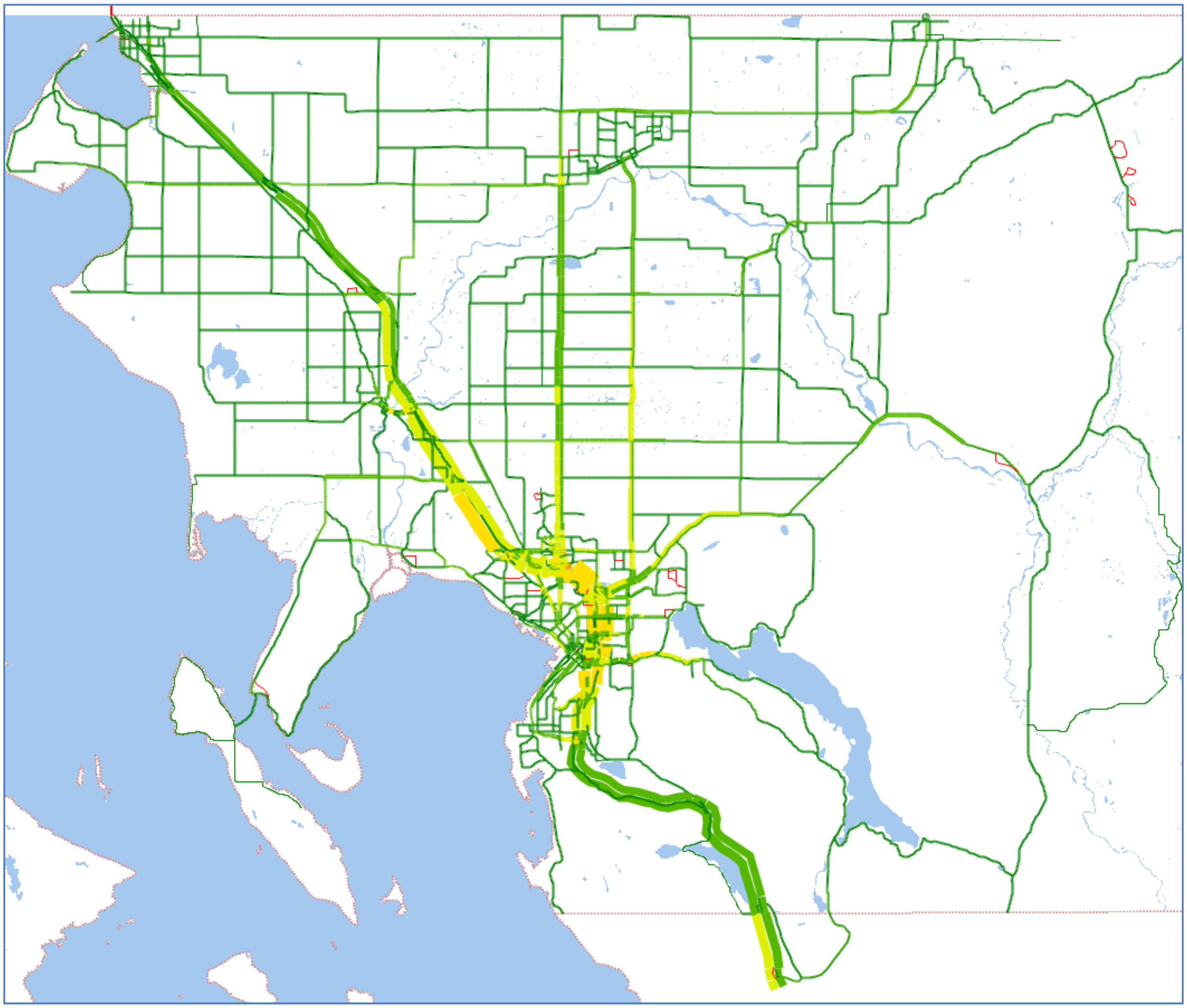

Figure 9.2: AM Flow Map and Congestion Pattern

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 9.3 shows a close up of the AM assignment in Bellingham.

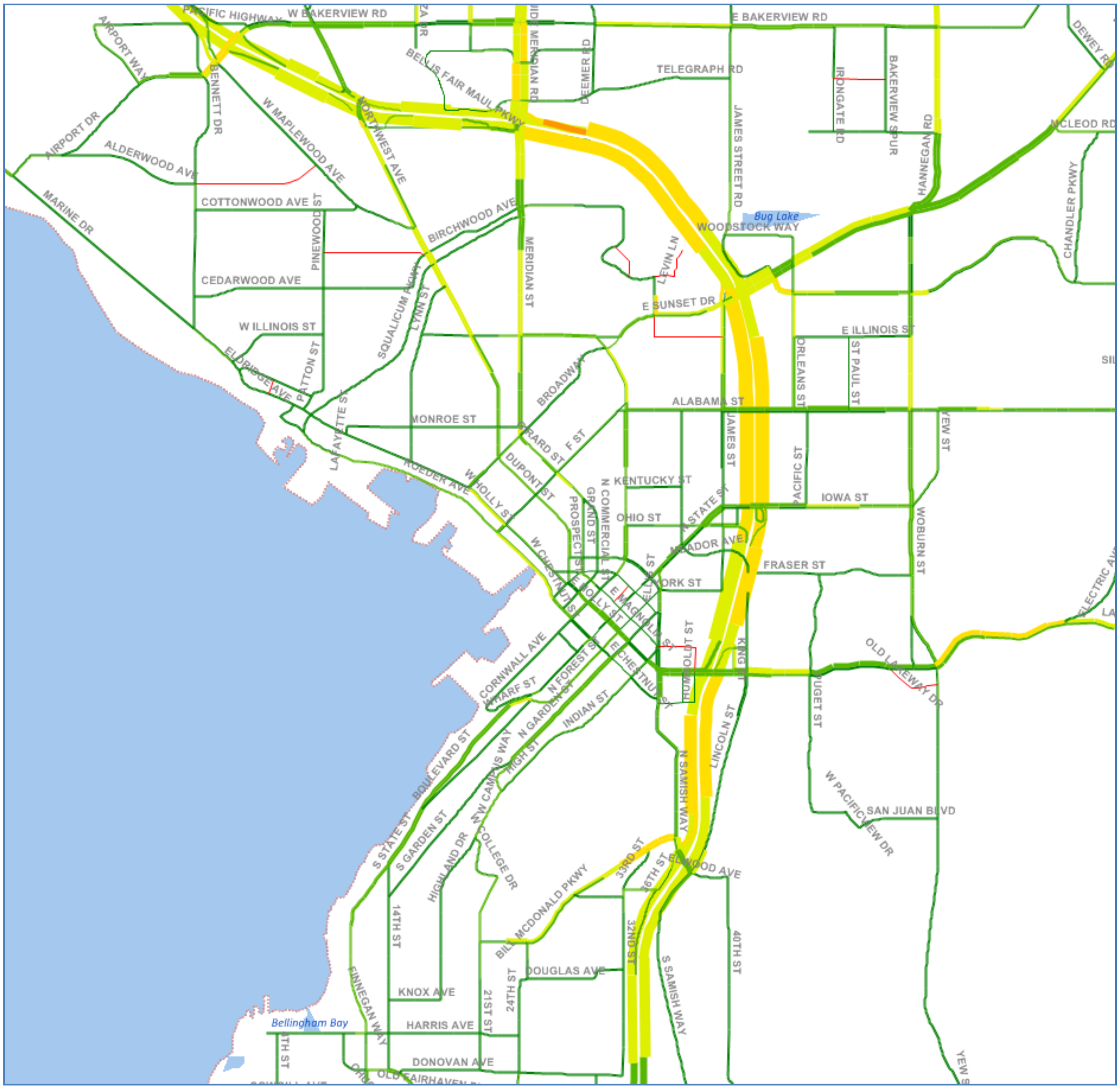

Figure 9.3: Close up of AM Flow Map and Congestion Pattern in Bellingham, WA

The congestion during the PM period is higher than during the AM period, as seen in Figures 9.4 and 9.5.

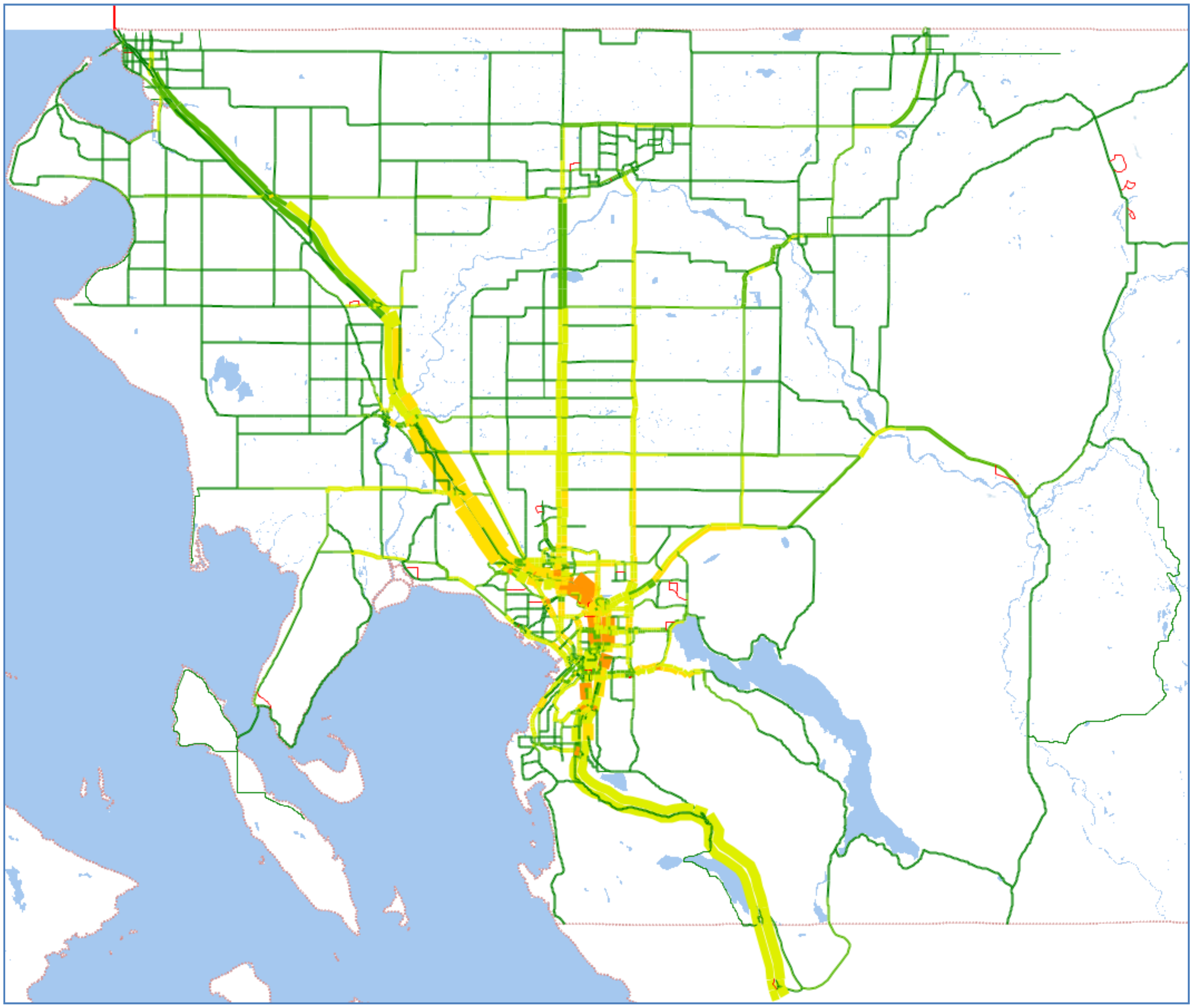

Figure 9.4: PM Flow Map and Congestion Pattern

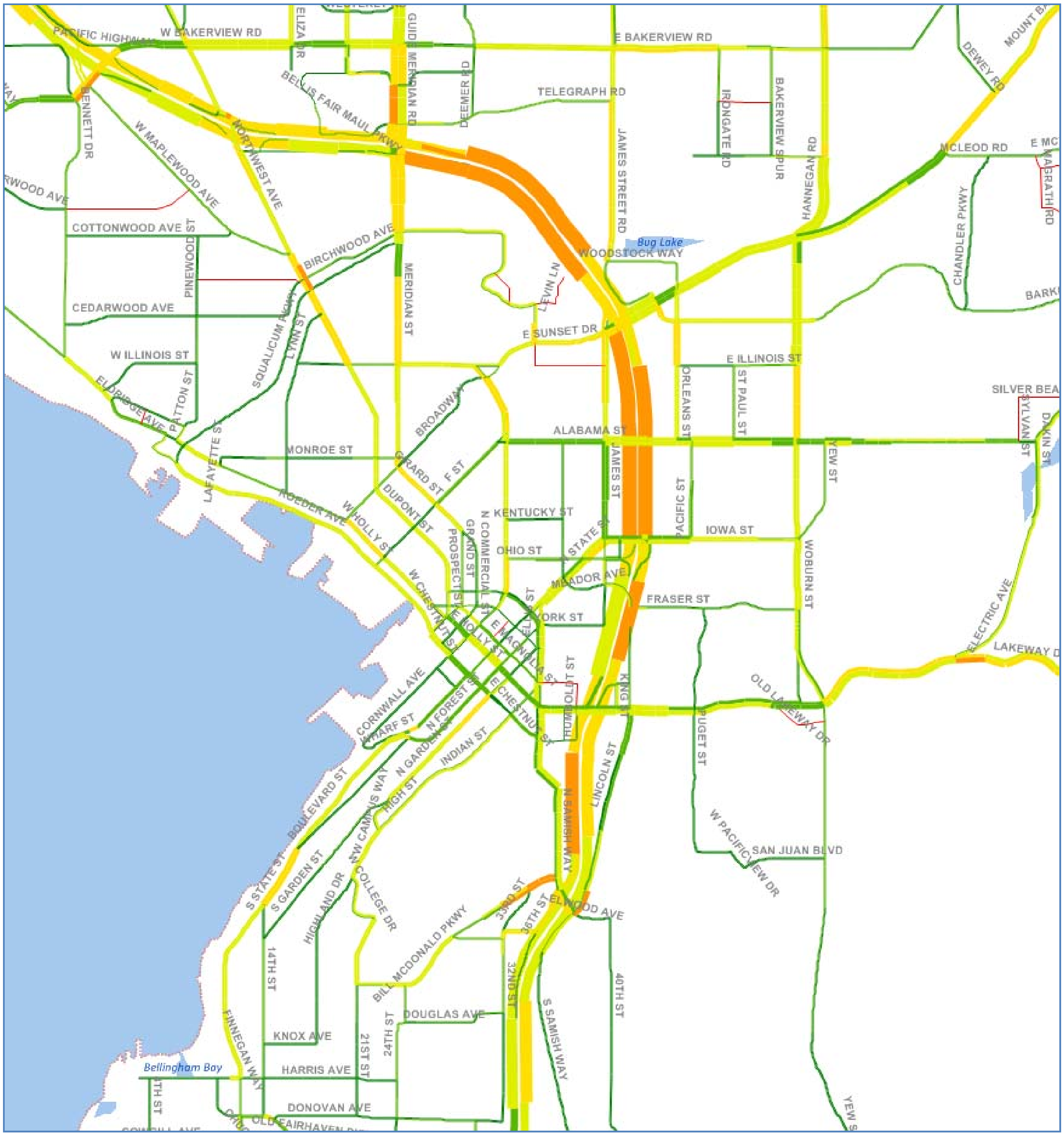

Figure 9.5: Close up of PM Flow Map and Congestion Pattern in Bellingham, WA

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 9.3 to 9.7 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 10%, 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	1240	5,487,608	5,429,806	1.1	**24.31**
Highway	75	1,670,912	1,653,578	1.0	**9.20**
Major Arterials	392	2,099,212	2,075,176	1.2	**23.08**
Minor Arterials	369	1,028,909	1,025,279	0.4	**33.00**
Major Collectors	264	323,687	323,683	0.0	**46.46**
Minor Collectors	63	36,470	37,788	-3.5	**55.30**
Ramps	77	328,415	314,302	4.5	**29.00**

Table 9.3: Daily Flow and Count Comparison

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	1240	943,580	939,523	0.4	**31.38**
Highway	75	299,079	299,335	-0.1	**10.81**
Major Arterials	392	354,634	348,152	1.9	**32.04**
Minor Arterials	369	172,469	175,012	-1.5	**42.46**
Major Collectors	264	51,990	54,014	-3.7	**62.86**
Ramps	77	59,153	56,607	4.5	**33.03**

Table 9.4: AM Flow and Count Comparison

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	1239	1,349,377	1,321,009	2.1	**32.86**
Highway	75	373,800	386,246	-3.2	**14.78**
Major Arterials	392	528,024	509,484	3.6	**30.40**
Minor Arterials	369	270,276	256,682	5.3	**38.04**
Major Collectors	263	93,185	81,478	14.4	**60.80**
Ramps	77	72,635	77,420	-6.2	**38.25**

Table 9.5: PM Flow and Count Comparison

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	1240	1,843,322	1,750,444	5.3	**30.27**
Highway	75	536,464	507,893	5.6	**13.12**
Major Arterials	392	721,563	694,040	4.0	**26.95**
Minor Arterials	369	353,097	335,059	5.4	**38.96**
Major Collectors	264	114,297	102,178	11.9	**59.32**
Ramps	77	106,230	99,570	6.7	**36.23**

Table 9.6: MD Flow and Count Comparison

Class	# Count Links	Total_Flow	Total_Count	Pct Diff	RMSE %
All	1239	1,351,012	1,418,603	-4.8	**29.25**
Highway	75	461,568	460,104	0.3	**10.31**
Major Arterials	392	494,990	523,500	-5.4	**27.79**
Minor Arterials	369	233,066	258,526	-9.8	**41.33**
Major Collectors	263	63,897	85,786	-25.5	**68.97**
Ramps	77	90,395	80,705	12.0	**34.83**

Table 9.7: NT Flow and Count Comparison

In general, both the period assignments and the daily assignments are well calibrated. Figure 9.6 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.

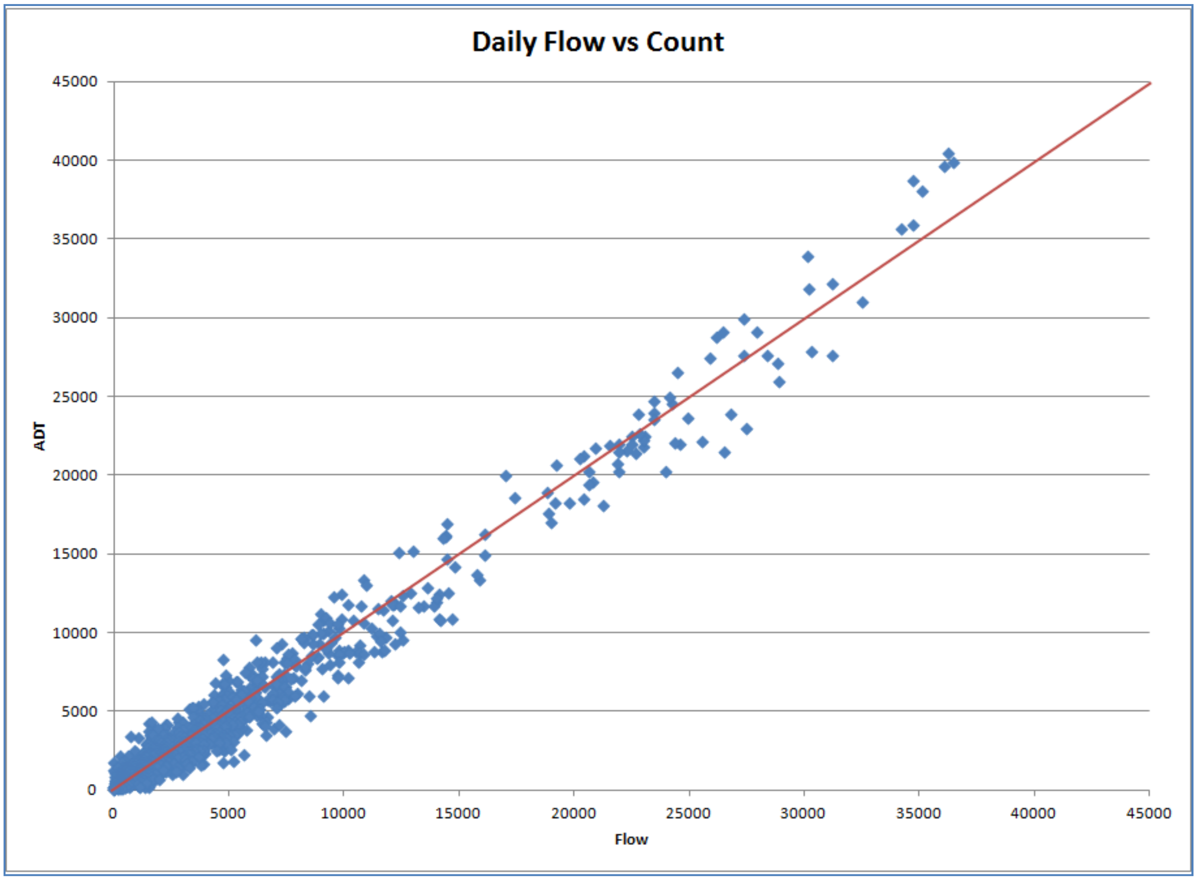

Figure 9.6: Daily Flow vs Count Scatterplot

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 9.8

Time Period	Total VMT	Total VHT
AM	773,870	18,508
MD	1,458,251	37,104
PM	1,120,818	30,436
NT	1,113,971	25,685
24-hour	4,466,910	111,733

Table 9:8: 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. During this model update, the equilibirum pathfinder assignment in transit (which is a relatively new procedure in TransCAD 6), has been adopted. Similar to the highway assignment, this is a multi-class equilibrium assignment that computes delays based on the assigned demand and readjusts the transit flows. Please refer to the TransCAD Travel Demand Modeling guide for details on this procedure[2].

As mentioned earlier, an origin to parking node input matrix is used for the assignment that determines the zones eligible for park and ride access.

The transit validation was done by three main criteria:

- Match Daily, Peak and OffPeak total Boardings and Alightings
- Match Boardings and Alightings at key stops (Cordata, Belligham and WWU University)
- Match Park and Ride usage

After calibration of the transit network setting parameters, some adjustments to the mode choice models, the above goals were sufficiently met. The total boardings for the day were 20,425. The year 2011 daily boardings reported by WTA was 18,125 but after discussions with WCOG staff, we determined that the boardings number in 2011 were a bit low and we aimed for a higher number as supported by the year 2010 boarding numbers.

The daily boardings and alightings from the model at Belligham station, Cordata center and the university are 3,187, 919 and 913 respectively which closely match the WTA numbers.

Figure 9.7 shows the AM 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).

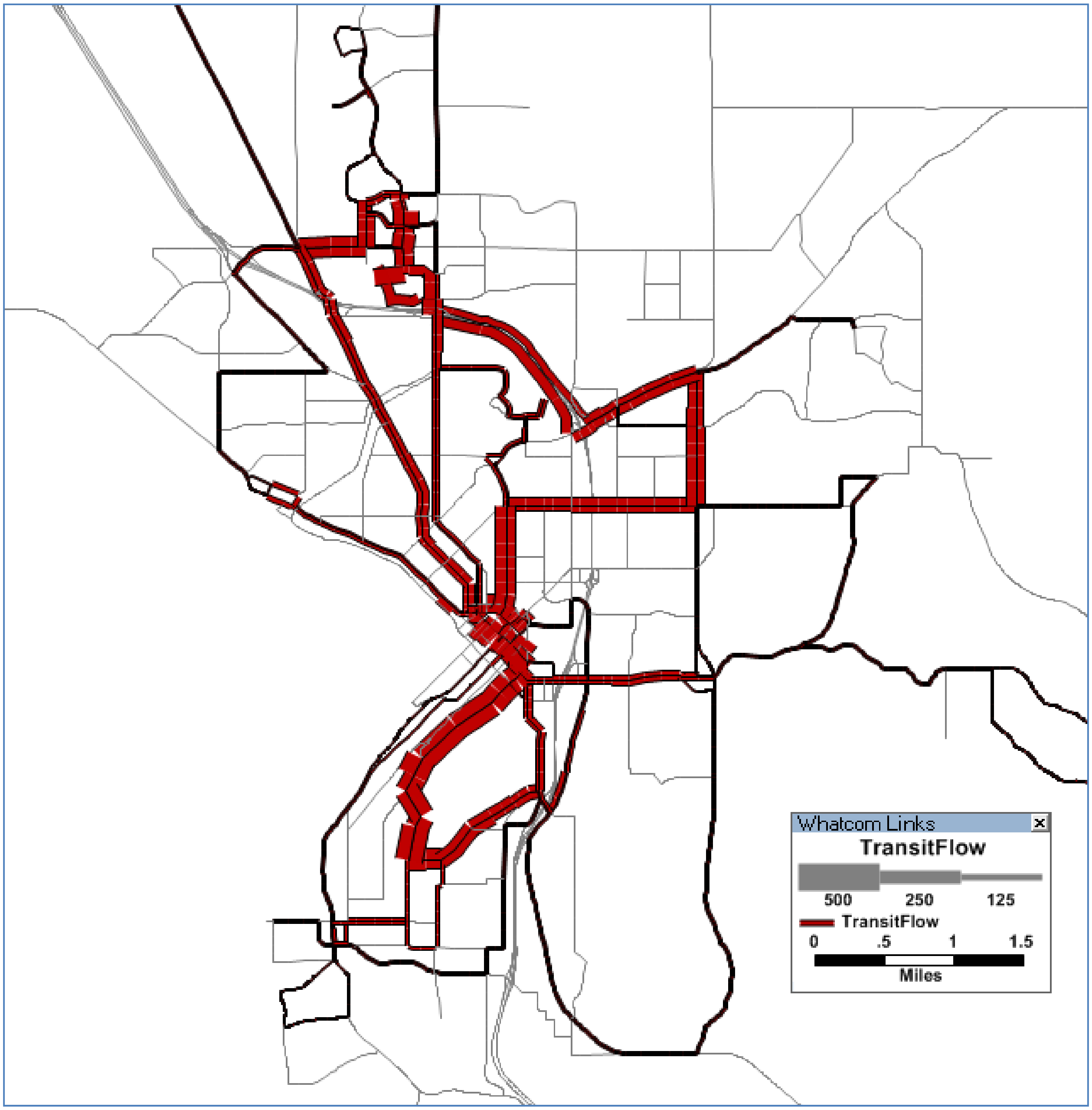

Figure 9.7: Transit AM Flow Map

Chapter 10: 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.

Both the highway and transit skimming procedure is run for the AM and the MD period. The highway skims are used for the trip distribution for the PK and OP periods respectively. The mode spilt is then executed, (using the AM highway and transit skims for the PK skim utility terms and the MD highway and transit 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 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.

References

1. "The Updated Whatcom Model - Project Final Report"; Prepared for the Whatcom Council of Governments by Caliper Coportation. March 31, 2010

2. "Travel Demand Modeling with TransCAD"; Caliper Corporation