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Vermont Travel Model 2013-2014

Final Report

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Vermont Travel Model 2013-2014 (Year 6) Report

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Disclaimer

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Table of Contents

List of Tables

List of Figures

1 Introduction

This report was prepared under the "Improvement and Operation of the Vermont Travel Model" contract with the Vermont Agency of Transportation (VTrans) for the 2013-2014 year (Year 6) of the contract. The primary objective of the project is to continue maintaining the Vermont Travel Model, ensuring that it remains a comprehensive, effective predictor of travel behavior of Vermonters. The purpose of this report is to document the activities which were completed in the 2013-2014 (Year 6) year of the contract. Other support activities undertaken in Year 6 of the contract using the Model to support VTrans efforts are documented separately.

The Vermont Travel Model is a series of spatial computer models which uses the land use and activity patterns within Vermont to estimate the travel behavior of Vermonters. Origin and destination tables are created which describe the number of expected trips between zones. Accommodations are made for commercial-truck trips and the occupancy characteristics of passenger vehicles. The final outputs are traffic volumes by roadway link in the state-wide roadway network. The Model currently includes 939 traffic analysis zones (TAZs) and 5,327 miles of highway-network links (Figure 1).

This report contains a description of the Vermont Travel Model (Section 2), including its history and its current functional capabilities, a description of the data used in this Year (Section 3), a description of the methods used to process data for use in improving the Model and the results of the update (Section 4), and a summary of the results of this year's improvements with recommendations for Year 7 (Section 5).

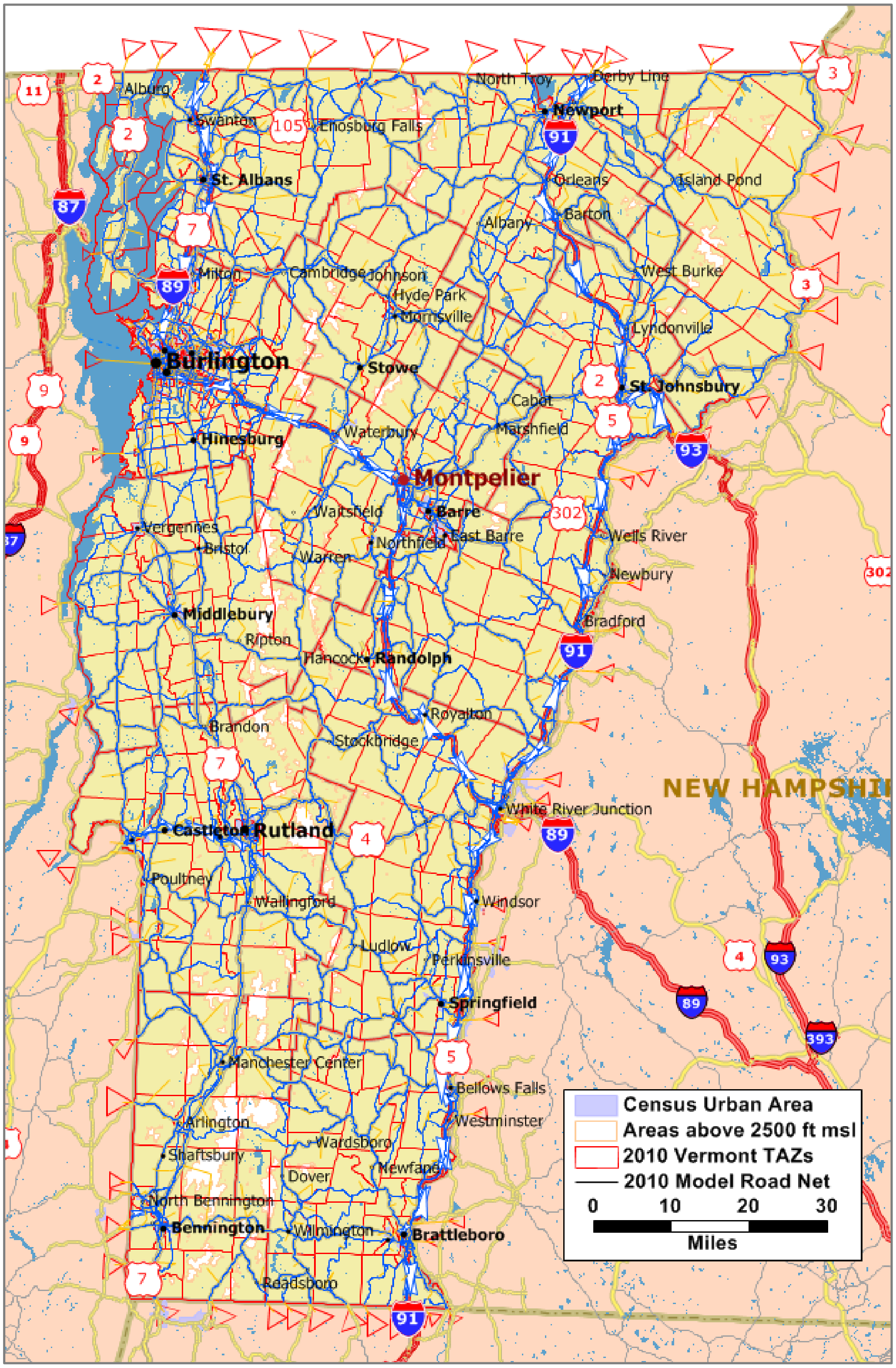

Figure 1 Zones and Road Network in the Vermont Travel Model

2 Description of the Model

The purpose of the Vermont Travel Model ("the Model") is to estimate travel demand and link flow throughout the state using general spatial characteristics of the Vermont population. The Model is an important planning tool, beneficial not only to the Agency of Transportation but to regional planning commissions, the Chittenden County Metropolitan Planning Organization (CCMPO) and the University of Vermont Transportation Research Center (UVM TRC) – all of which rely on the Model for transportation planning, research, and educational activities. Daily travel demand is estimated by the Model between TAZs by the purpose of a trip. From this travel demand, trips are routed and the flow of traffic on each link in the Model road network is estimated. Appendix A provides a schematic representation of the Model inputs (boxes) and model processes (block arrows).

Trip generation (productions and attractions) is estimated for each of five trip-purposes (home-based work, home-based shopping, home-based other (including school travel, social & recreational trips), non-home-based, and truck) based on the 2010 US Census, the 2009 NHTS, the 2006-2010 ACS, 2009 data from the Department of Employment and Training of the VDOL, and 2009 data from the BEA. Trip distribution is accomplished using a production-constrained gravity model. The traffic assignment module of the Model implements a multi-class user-equilibrium assignment process. The assignment proceeds with two classes – all passenger vehicles, and trucks. The multi-class assignment process is used because some of the minor links in the road network have truck exclusions. Therefore, the multi-class assignment is used to allow passenger cars to use the entire network while preventing trucks from using links with truck exclusions.

The Model includes truck traffic by incorporating "Truck" as a trip purpose. However, no comprehensive freight model has been developed to break truck travel down into medium- and heavy-commercial trucks, and to investigate commodities moved in an average day. Rail transport, passenger transit, and non-motorized travel modes are also not currently part of the functional sub-modules of the Model.

2.1 History of the Model

The original statewide model was developed in the 1990s. At that time, the Model processes were run in the SAS Model Manager 2000 platform, and the network was in the TRANPLAN software format. The base-year 2000 version of the statewide model was updated beginning in 2003. The update was completed by transitioning the Model into a GIS-based framework using the CUBE software package in 2007 (VHB, 2007). During the 2003 – 2007 update, newly proposed or constructed links, like the Circumferential Highway in Chittenden County and the Bennington By-Pass, were added to the road network. Minor adjustments were also made to trip generation coefficients to bring initial balancing factors closer to 1.0. Other adjustments were made to improve the relationship between model outputs and validation data, which was down to 50.2% after the 2007 improvements (VHB, 2007).

2.1.1 Year 1

In October of 2008, the Vermont Travel Model was moved to the Transportation Research Center at the University of Vermont. For most of the 2008-2009 contract-year, the TRC conducted an evaluation of the Model's utility, components, and current software platform. A report was completed in May of 2009 with details of the evaluation and its preliminary findings (Weeks, 2010). The goals of the evaluation were to:

- Identify the current and potential uses for the Model based on VTrans planning practices and needs.
- Recommend updates to the Model to meet future implementation.
- Compare the existing software platform with other widely-used software packages

The UVM TRC also conducted a literature review of statewide travel-demand modeling practices in other states, including general model structure, operation, and maintenance, and a discussion of emerging trends in travel-demand modeling (Weeks, 2010).

In addition, selected model applications were performed in 2008-2009 in response to requests from VTrans staff. Bridge closures were explored, comparing traffic volumes before & after the closure, for the following locations:

- Chester, Vermont
- VT-11 & VT-106
- Springfield, Vermont (2 locations)
- US-5 & US-11 (2 locations: I-91 SB & NB Ramps)

The UVM TRC also performed an emissions analysis of 5+–axle trucks along a segment of US-7 and a parallel route on I-89 in the Burlington area. A local trucking company was contacted to assist with the analysis and a data collection of truck driving cycles on the analysis segments was performed on July 21, 2009 using a tractor-trailer truck provided by a local shipping company. The truck drive-cycle data, including second-by-second velocity, acceleration, and grade was compiled and the emissions analysis was conducted using the Comprehensive Modal Emissions Model (USEPA, 2003) with eight drive cycles, two per route per direction. UVM TRC Report No. 09-006 was completed in September of 2009 with details of the analysis and the findings (Weeks, 2009).

2.1.2 Year 2

In 2009-2010, the UVM TRC conducted a travel analysis of the Burlington-Middlebury Corridor to evaluate the potential effects of the addition of the proposed Exit 12B. The travel analysis included four scenarios, two base-year scenarios (2000, with and without Exit 12B) and two forecast scenarios (2030, with and without Exit 12B). The results of the analysis indicated that the addition of Exit

12B would not have a significant effect on north-south corridor travel between Burlington and Middlebury.

A preliminary travel analysis was also conducted for the Route 22A Corridor near Fair Haven, Vermont in support of a consultant working for VTrans. The analysis provided a breakdown of travel in the corridor by trip purpose. The results of this travel analysis, which included queries of the Model for link-specific data, was delivered to Stantec and VTrans on July 2, 2010.

As the data from the NHTS was released in the late summer of 2010, the UVM TRC prepared a work plan for the task of updating the Model to a new base-year. The update was initiated by compiling statistics on auto-occupancy and trip generation rates from the NHTS and this stage was completed by the end of Year 2.

2.1.3 Year 3

The Model update continued in Year 3 of the UVM TRC contract with new information from the 1,690 households in Vermont surveyed in the 2009 NHTS, new demographic information from the 2005-2009 American Community Survey (ACS), new employment information for 2009 from the Vermont Department of Labor (VDOL) and new traffic counts for 2009 from VTrans. In addition, sub-modules in the Model were re-evaluated and process improvements were made. Of the four tables delivered with the NHTS (household, person, vehicle, and person-trip), only the household and the person-trip tables were used in this update. Using the household table from the NHTS, the trip-rate table for all home-based trip productions was updated. With the person-trip table from the NHTS, the following were updated:

1. Trip-production and attraction regression equations in the Model
2. Vehicle occupancy rates by trip purpose
3. External trip-fractions by trip-purpose
4. Truck percentages by TAZ
5. Friction-factors in the trip-distribution module of the Model

The 2009 Average Annual Daily Traffic (AADT) for most of the major roads in the state was also used to make updates to the Model. This data was obtained in a geographic information system (GIS) from VTrans and used to update the TRUCK purpose O-D using an ODME process on the AADTs for truck and the daily trip counts for all external TAZs in the Model. Finally the land-use characteristics in the Model were also updated using the 2005-2009 ACS (for numbers of households) and the employment statistics from the VDOL (for numbers of jobs by category).

The importance of these updates was immediately apparent in the fidelity of the Model. For example, the base-year 2000 Model included 240,637 households in its 628 TAZs, with an expected growth to 295,126 households by 2020. The 2009 update showed that there were closer to 250,000 households in Vermont at that time, indicating that the expected growth had been grossly overestimated. Employment growth, however, was underestimated in 2000. The total employment volume of 333,409 in 2000 was expected to grow to 428,353 by 2020. However, the 2009 update revealed a total of 431,280 jobs in Vermont, already surpassing the 2020 estimate. Part of this discrepancy could be due to improved job totals from the VDOL which may not have been readily available in 2000.

In addition, selected Model applications were performed in 2010-2011 in response to requests from VTrans staff.

2.1.4 Year 4

The Model updates completed in Year 4 brought its base year up to 2009-2010. Land-use characteristics were updated in Year 4 with new information from the 2006-2010 ACS, the 2010 US Census, and the 2009 employment estimates from the BEA. The improvements created by these updates were evaluated by checking the Model outputs for "reasonableness" in accordance with FHWA guidance (Cambridge Systematics, 2010). FHWA standards for comparing Model flows with traffic counts were achieved for 3 of the 4 roadway classes tested. The only exceedance of the FHWA standards was for freeways. Since most of the freeways in the Model are coded as two separate links, one for each direction of travel to accommodate coding of ramps at freeway interchanges. However, the AADT data used to validate the Model is coded as single-links throughout the state, even for freeways. This discrepancy creates a susceptibility for the traffic counts to be mistakenly applied when the coding of the links is not taken into account.

In addition, selected Model applications were performed in 2011-2012 in response to requests from VTrans staff.

2.1.5 Year 5

The Model improvements conducted in Year 5 included Model-process improvements, significant improvements to the network representation of the state-maintained roadways in the Model, and forecast-year Model runs for 2025 and 2035. Each of these improvements took advantage of data available in other Sections at VTrans, and much of the data had to be pre-processed for use in the Model's GIS environment. These improvements resulted in an overall improvement in the ability of the Model to simulate a typical day of travel in the state. The forecast-year Model runs were conducted with realistic representations of the state-maintained roadway network in 2025 and 2035, based on long-term transportation plans prepared by VTrans and the RPCs.

A TMIP peer review of the Model was conducted by FHWA in Year 5, resulting in a comprehensive set of recommendations for Model improvements for Year 6 and beyond. Selected subtasks were recommended based on the short-term recommendations from the peer review to achieve this goal:

1. Break up HBO and NHB trips in the Model with sub-categories (personal-discretionary, personal non-discretionary, and business) and/or distance classes (long and short) as data supports, in accordance with NCHRP guidance

2. Test the validity of leaving the trip matrices asymmetrical, particularly for NHB travel, since NHB trips do not necessarily return to their origin daily

3. Re-assess all centroid connectors locations and resolution of TAZs
4. Explore the need for seasonal trip tables
5. Develop a Validation Plan for the Model, along with a user's guide and technical reference
6. Expand the spatial boundary of the Model as necessary to include important "halo" populations
7. Develop a statewide model users' guide and technical reference.
8. Consider dynamic traffic assignment to assess traffic patterns in emergency response
9. Identify metrics for emergency scenario comparison to guide model development

This report includes descriptions of the Model improvement activities performed to address items 1., 2., and 3. above.

In addition, selected Model applications were performed in 2012-2013 in response to requests from VTrans staff.

2.2 Functionality of the Model

The figures in Appendix A illustrate the processes which comprise the Trip Generation, Trip Distribution, and Traffic Assignment modules of the Model.

2.2.1 Trip Generation

The trip-generation module starts by combining the TAZ-based land-use characteristics with the town-based fractions of no. of persons / no. of workers per household cross-classifications to calculate home-based trips produced by each internal TAZ. It then calculates trip attractions for each internal TAZ by purpose and trip-productions for the non-home-based (NHB) purpose using purpose-specific regression equations, each of which utilizes a different set of employment and/or population field(s) from the TAZ characteristics table. For example, the equation for home-based work (HBW) trips attracted is based on all of the employment fields in the TAZ characteristics table, but the equation for home-based shopping (HBSHOP) trips is based solely on the retail employment field. Truck (TRUCK) productions and attractions are calculated simply by multiplying the truck percentages from the TAZ characteristics table by the production and attraction totals for the other four trip purposes.

Productions and attractions for zones external to Vermont are calculated differently. First, external TRUCK trips are taken to be the Truck AADT for the external zones and split evenly as productions and attractions. The total for other passenger-car external vehicle-trips (VTs) is taken as the non-truck AADT for each external zone. The external vehicle occupancy rate (as an input) is applied to this total to derive non-TRUCK external person-trips (PTs). Total non-TRUCK external PTs are then subdivided into the other 4 trip purposes using the fractions in the external trip-fractions table.

Ultimately, this process outputs a table of productions and attractions for each of the five trip purposes in the Model for each of the 939 internal and external zones. However, since the production and attraction estimates for the internal TAZs came from different sources for each of the four home-based trip purposes, they do not match. This mismatch is typical for demand-forecasting models where separate regression models are estimated for production and attraction across a full study area with unique predictor variables. Balance factors are calculated as the ratio of trip productions destined for internal zones to the corresponding trip attractions in internal zones by trip purpose. Balancing is accomplished by zone by multiplying the balancing factors to the internal trip attractions only so that they match total productions (internal and external) by trip purpose. The end result is a table of balanced productions and attractions for each of the five trip purposes in the Model for each zone. Summary statistics of the balanced trip production/attraction table are provided in Table 1.

Table 1 Summary Statistics of the Balanced Trip Table

Trip Purpose	Class	Sum	Min	Max	Mean	Std Dev.
HBW	No. of Trips Produced	240,342	0	1,763	269	197
HBSHOP		397,668	1	5,402	443	357
HBO		710,439	1	7,249	791	597
NHB		612,523	0	18,268	652	976
TRUCK		240,342	0	1,763	269	197
HBW	No. of Trips Attracted	240,342	0	3,314	256	388
HBSHOP		397,668	0	7,800	424	840
HBO		710,439	0	7,249	757	873
NHB		612,523	0	18,268	652	976
TRUCK		240,342	0	3,314	256	388

2.2.2 Trip Distribution

The trip-distribution sub-module takes the balanced trip table, a matrix of free-flow travel times between TAZs and a set of impedance functions to develop a matrix of productions and attractions between all zones. The set of impedance functions for the production-constrained gravity-model used to distribute trips is shown in Table 2.

Table 2 Impedance Functions in the Vermont Travel Model

Trip Purpose	Impedance Function		a	b	c
HBO	Gamma	$f(c_{ij}) = a \times t_{ij}^{-b} \times e^{-c(tij)}$	19,954	1.42	0.068
HBSHOP	Exponential	$f(c_{ij}) = e^{-c(tij)}$			0.110
HBW	Gamma	$f(c_{ij}) = a \times t_{ij}^{-b} \times e^{-c(tij)}$	660	0.26	0.091
NHB	Gamma	$f(c_{ij}) = a \times t_{ij}^{-b} \times e^{-c(tij)}$	87,565	1.34	0.098

Trip Purpose	Impedance Function		a	b	c
TRUCK	Exponential	$f(c_{ij}) = e^{-c(tij)}$			0.065

The result of this step is a matrix of productions and attractions between all zones. Since the Model is a daily model, all trips are assumed to return, meaning that all trips originating in one zone and destined for another must also originate in the destination zone and terminate in the origin zone. This assumption requires that the final matrix be diagonally symmetric. To accomplish this, the matrix is added to its transpose and then all cells are halved. The result is a diagonally-symmetric O-D matrix of PTs.

In the past, the O-D matrix of PTs was reduced by the expected transit demand before allocating the remaining trips to passenger vehicles. However, the existing matrix of transit demand may date back as far as 1997, no defensible data source for transit demand could be located, and the 2009 NHTS does not support the development of a full O-D matrix of transit demand statewide. Therefore, transit demand is no longer considered directly in the Model. Instead, the full O-D matrices resulting from the trip-distribution step are divided by a vehicle-occupancy to convert them from person-trips to passenger vehicle-trips. The vehicle occupancies currently used in the Model, derived from the 2009 NHTS, are shown in Table 3.

Table 3 Vehicle Occupancy Rates in the Vermont Travel Model

Trip Purpose	Internal Trips	Internal to External & External to Internal Trips
Home-Based Work	1.13	1.05
Home-Based Shopping	1.48	1.93
Home-Based Other	1.75	1.85
Non-Home-Based	1.51	1.78
Truck	1.00	1.00

2.2.3 Traffic Assignment

The final matrix, including all external vehicle-trips, is assigned to the road network in the traffic assignment sub-module. Free-flow travel speed on each link is assumed to be the 5 miles per hour over the speed limit, and the user-equilibrium MMA traffic assignment is used.

3 Description of the Data

This section contains a description of the data sources used in the Model improvement activities for Year 6.

3.1 The 2009 National Household Travel Survey and the Add-On to the 2009 NHTS in Vermont

The 2009 NHTS is a public data set which provides information to assist transportation researchers, planners and policy makers who need comprehensive information on travel and transportation patterns in the United States. It contains travel-diary survey information regarding household travel behaviors, including the respondent's trips, modes of travel, and distances of travel throughout their surveyed day. It also includes general demographic information on its respondents, their household, and their community. The 2009 NHTS includes data on travel behaviors for 1,167,321 person-trips made by 308,901 people in 150,147 surveyed households.

The TRC, together with the Chittenden County Metropolitan Transportation Organization (CCMPO), and the Vermont Agency of Transportation (VTrans), funded an "add-on" to the nation-wide NHTS, with the goal of providing enough Vermont-specific data to allow comprehensive research focused on our state. The agreement for Vermont included 1,500 households, with Chittenden County oversampled with 500 households, rural Chittenden County towns oversampled from that 500, and rural Vermont Counties oversampled from the remaining 1,000. These sample results were received and compiled into a cleaned geo-coded database of 1,690 households. As part of the "add-on" program, the partners also received a private data set with the geographic locations of almost all of the origins (typically home) and some of the destinations (work, shopping, etc.) of recorded trips.

The geographic information was originally derived from the home addresses of survey participants, which were geo-coded to find spatial coordinates for the location of each household. So the final private data set includes coordinates for each household as well. The delivery of the 2009 NHTS Vermont Add-On came as five independent tables:

- Vermont Households (with geocoded household locations)
- Vermont Persons
- Vermont Vehicles
- Vermont Person-Trips
- Vermont Person-Trips Plus (with geocoded destination locations)

The five tables delivered in the 2009 NHTS Vermont Add-On were converted into a database, linked by the HOUSEID field and new key fields for the Persons Table (PERSONKEY, which concatenates HOUSEID and PERSONID) and the Vehicles

Table (VEHICLEKEY, which concatenates HOUSEID and ID). The database relationships amongst the four tables are illustrated in Figure 2.

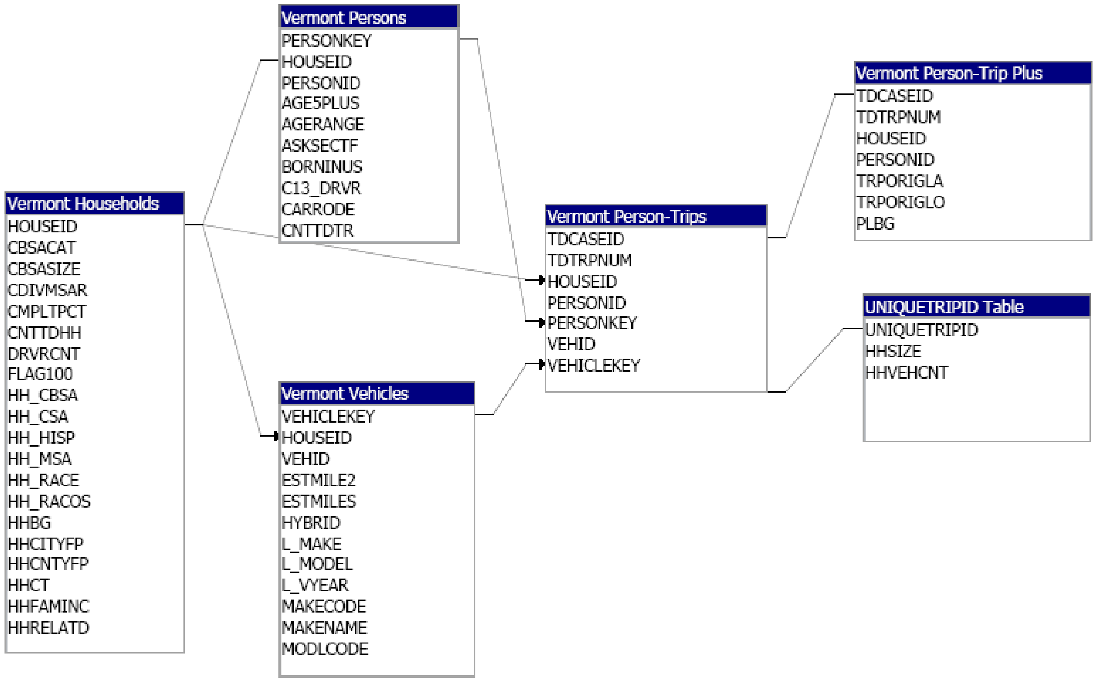

Figure 2 2009 NHTS Vermont Database Structure

The numeric, or continuous variables in the data set are designed to have weights applied when calculating statistics for these variables across the entire state. Weights are only used when making an aggregate estimation for the entire state of Vermont. There are four weights in the data set:

- Households and Vehicles use the Household Weight
- People use Person Weight
- Travel use Travel-Day Weight
- School children aged 6-12 participating in the safe routes to school section on the Person Table (one random school-age child household) use the Section F Weight

The weights include a correction for the probability of selection (representation bias) in addition to a non-response adjustment (non-response in screener phase or non-response in interview phase). Otherwise, samples distribution attempted to mirror population distribution in the state.

For Year 6 of this project, the team focused on the distribution of trip lengths to better understand differences between long- and short-distance trips. As shown in Figure 3, the cumulative frequency distribution for all trip purposes indicates a break in scaling on a semi-log cumulative frequency distribution at around 34 miles.

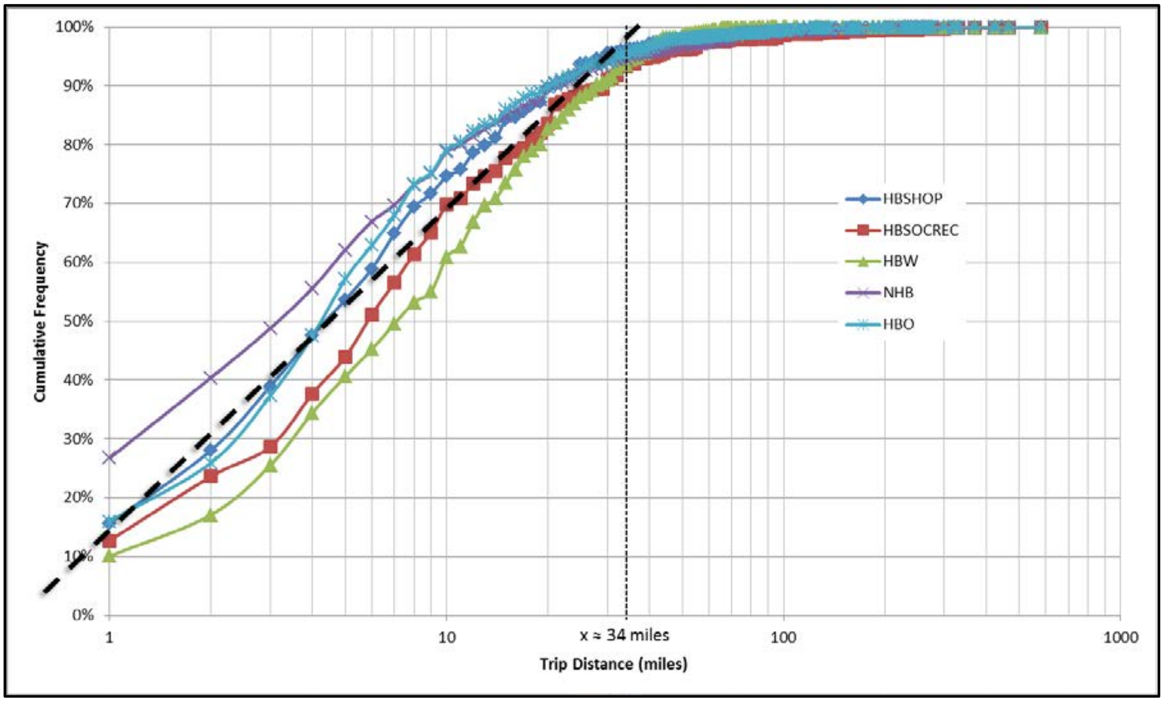

Figure 3 Semi-Log Cumulative Frequency Distributions of Trip Distances in the Model

This break suggests that this distance might be a suitable natural fit for classifying long- and short-distance trips. Consulting the NCHRP 735 report, other states distinguish long-distance trips somewhere between 50 and 100 miles. It is not surprising that Vermont's trips as used in the Model indicate a lower suitable cut-off point because air and rail trips, which tend to be longer than 100 miles, are omitted. However, to take advantage of the transferable parameters in NCHRP 735, a 100-mile cut-off distance must be used. The same distribution for Vermont trips over 100 miles is shown in Figure 4.

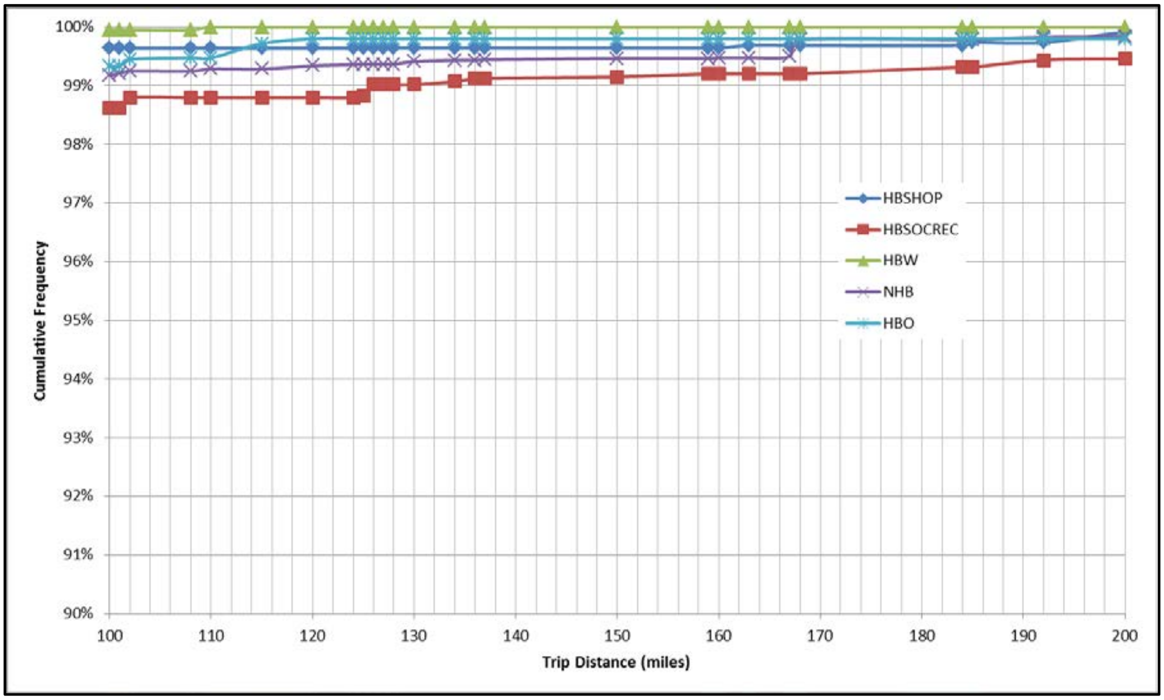

Figure 4 Cumulative Frequency Distributions of Trip Distances in the Model Over 100 Miles

The purposes that exhibit the largest portion of trips over 100 miles are HBSOCREC (included with HBO in the Model), HBO, and NHB. Also of note is the relative fraction of trips over 100 miles in Vermont, between 0.5% and 1.5%, which is consistent with the fraction for other states reported in NCHRP 735. Also consistent with NCHRP 735 is the tendency for NHB and HBO trips to be long-distance.

NHB trips especially seem to have unique distance characteristics when the various sub-purposes (according to the WHYTRP1S variable) are considered. As indicated in Figure 5, NHB trips that are tour stops (trips to access other modes of transportation) or social & recreational, seem to be more heavily constrained, meaning that travelers had to travel farther to satisfy demand.

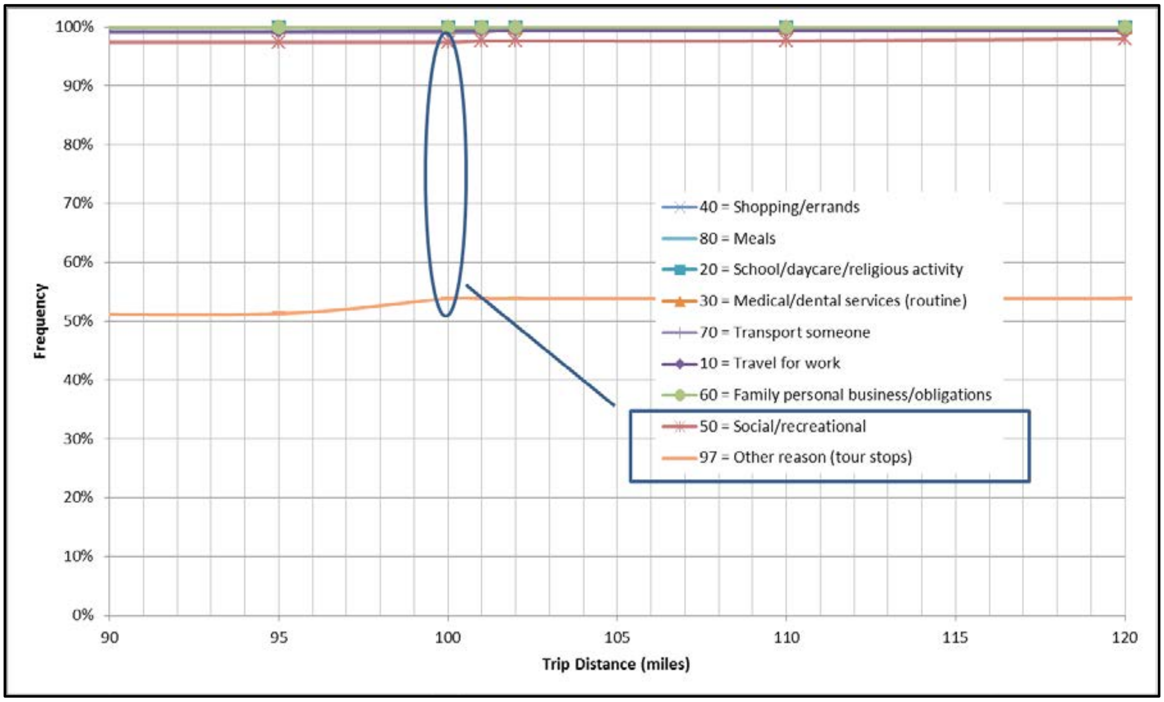

Figure 5 Cumulative Frequency Distribution of NHB Trips Between 90 and 120 Miles

For HBO trips, business travel, or trips *for* work, are the most constrained, as shown in Figure 6.

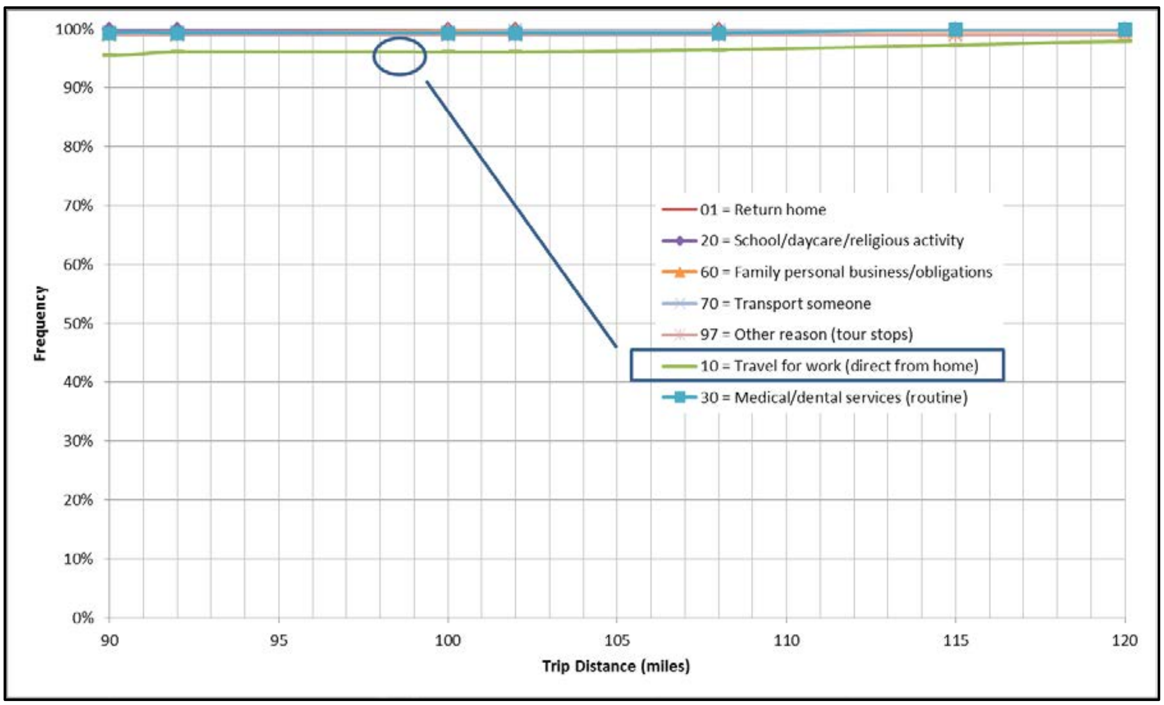

Figure 6 Cumulative Frequency Distribution of HBO Trips Between 90 and 120 Miles

This assessment is supported by the prevalent use of "Business", "Personal Business", and "Pleasure" trip purposes in other statewide models' typologies of long-distance travel in NCHRP 735. Using a long-distance typology that is consistent with other states would facilitate the transferability of parameters and reasonableness checking with other statewide travel models. Implementing a more disaggregated typology for the HBO and NHB trip purposes is supported by the finding that these purposes are over-represented in the existing Model (34% and 29% of all person-trips, respectively).

Several of the Model applications conducted in recent years have revealed a shortcoming in the distribution of truck trips, particularly external (E-E and E-I) truck trips. Therefore, the TRUCK trip purpose can benefit from being broken down into long-distance classes for external trips.

3.2 Google Maps and Google Street View Hyperlapse

Making speed adjustments to links in the Model has been greatly facilitated by a new free online application called the Google Street View Hyperlapse, created by Teehan + Lax Labs of Toronto, Ontario. The free application, at http://hyperlapse.tllabs.io/, allows the user to enter any two points in the world on the road network where Google Street View has obtained imagery, and see a time-lapse of the street-view images strung together (Figure 7).

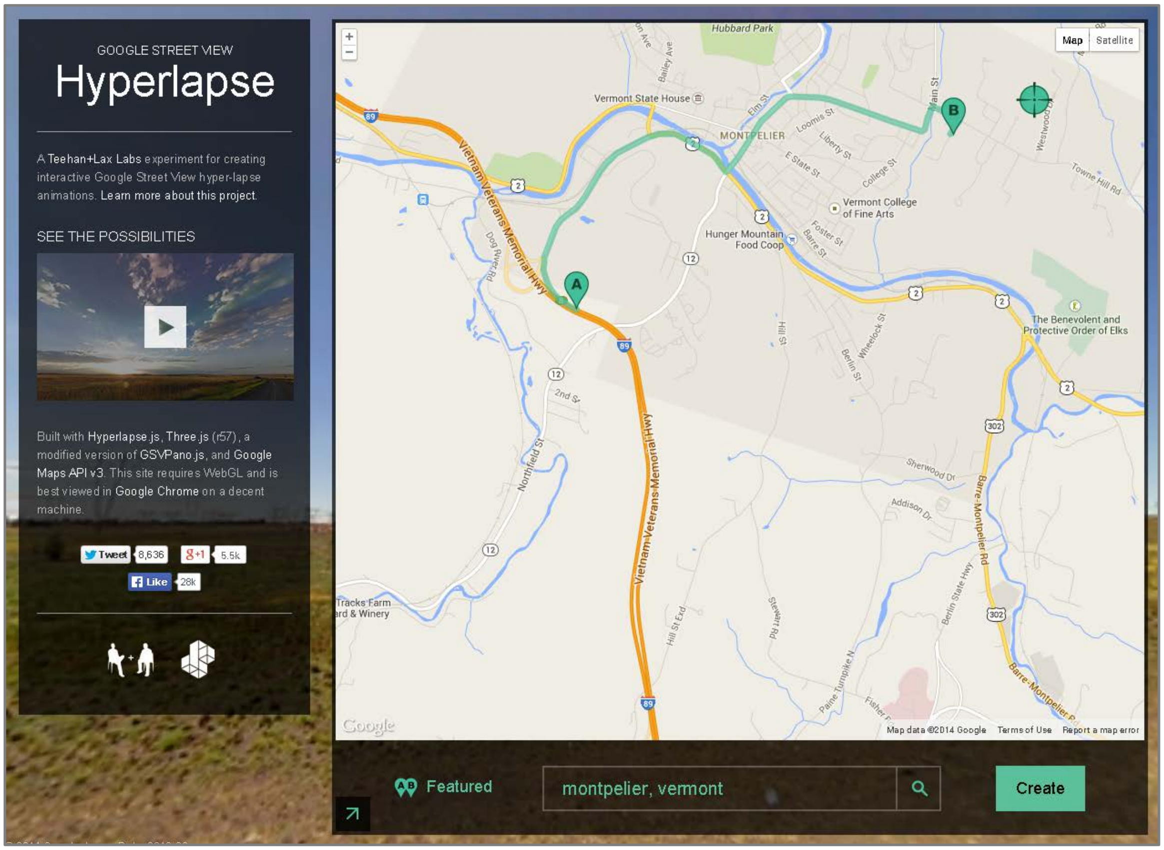

Figure 7 Google Street View Hyperlapse Application by Teehan + Lax

The time-lapse sequence allows the user to quickly locate street signs along the roadway, specifically the speed-limit sign, to obtain the posted speed limit. Since the Model's free-flow speeds are based on the posted speed limit, this application has been very useful in deriving accurate free-flow speeds and travel times for roadways in the Model.

3.3 Travel and Tourism Data for Vermont

Exploring long-distance travel behaviors in Vermont required gathering any available data on long-distance or overnight travel to/from Vermont. For validating the trip totals, travel and tourism data from 2011 in Vermont was used from a study conducted for the Vermont Agency for Commerce and Community Development (ACCD). The report, entitled, *Benchmark Study of the Economic Impact of Visitor Spending on the Vermont Economy – 2011: The Travel and Tourism Industry in Vermont*, includes aggregate totals for tourism travel to/from each Vermont County. The study used the following Vermont-specific data:

- A national survey on tourism trends with a Vermont module of follow-up questions in and around the 2011 period from TNS Global, Inc.
- Vermont-specific travel data for the year 2011 from STR Global, Inc.

- The Vermont Lodging Establishment Survey in 2010 and 2011 by the Vermont ACCD
- The Vermont Second Home Owner Survey in 2010 by the National Association of Realtors
- The Friends and Family Survey in 2009 by the Vermont ACCD
- Detailed tax records relating to meals and lodging and property taxes from the Vermont Department of Taxes
- Employment data from the Vermont Department of Labor
- Estimates of the number and spending of Canadians visiting Vermont and their mode of travel from Statistics Canada
- Border crossings into Vermont from the U.S. Department of Transportation Bureau of Transportation Statistics and Statistics Canada

Additional national-level travel and tourism data was provided by the U.S. Department of Commerce-International Trade Administration, Office of Travel and Tourism Industries, U.S. Travel Association, and the U.S. National Restaurant Association. In this study, Chmura Economics & Analytics utilized the IMPLAN Version 3.0 input-output (IO) model, which is designed to show the interconnection of industries, government, and households in a specified region—in this case the state of Vermont.

3.4 2009 Annualized Average Daily Traffic

AADT for 2009 in Vermont were obtained from a GIS developed and maintained by VTrans. This data layer includes data collected from 1990 through 2009 for interstate highways, federal highways, state highways, federal urban area routes and major collectors. Not all of the roadways in the model are represented with AADT counts or estimates. Procedures for estimating AADT are well established and rely on automated counting methods. VTrans had a total of 170 permanent, continuous traffic counters available in 2009 from which to calculate these AADTs.

4 Improvements Methodology and Results

Model improvements undertaken in Year 6 were in accordance with the recommendations provided by the peer review panel during the TMIP Peer Review during Year 5. The following Model improvements were completed:

1 Migrated the Model to the TransCAD Platform

2 Analyzed the Effects of Leaving Selected Model Matrices Asymmetrical

3 Assessed Centroid Connector Locations and Resolution of TAZs

4 Incorporated Long-Distance Travel Classification into the Model

4.1 Migration of the Model to the TransCAD Platform

The Agency decided to change the software platform for the Model in Year 6, from CUBE Voyager to TransCAD. This decision was based on the following points:

- The Chittenden County Regional Travel Demand Model is in TransCAD, so this change would facilitate synchronization of the two models
- The UVM TRC, which hosts the Model, has developed other transportation and land-use models, like the roadway snow and ice control routing model, for Vermont in TransCAD, so this change would facilitate potential integrations of those models and the Vermont Travel Model

In this section, the steps taken to migrate the Model from CUBE Voyager to TransCAD are described.

4.1.1 Code Migration

The first step in the migration of the Model into the TransCAD platform was to create a new TransCAD code file from the CUBE Voyager Model code. Each of the specific proprietary procedures within CUBE Voyager has a comparable procedure in TransCAD. Once each of those replacements had been, troubleshooting began until the Model was able to run successfully in TransCAD. An example of this replacement occurred for the trip distribution step. The following code is used to run CUBE Voyager's proprietary Gravity Model for trip distribution:

```
gravity purpose=1, los=mw[10], ffactors=ff
gravity purpose=2, los=mw[10], ffactors=ff
gravity purpose=3, los=mw[10], ffactors=ff
gravity purpose=4, los=mw[10], ffactors=ff
gravity purpose=5, los=mw[10], ffactors=ff
```

The following code is used to run the same process in TransCAD:

```
Opts = null
```

```
Opts.Input.[PA View Set] = {taz_layer_info[10] + "|" + taz_layer_info[11],
taz_layer_info[11],,}
Opts.Input.[FF Tables] = { , , , }
Opts.Input.[Imp Matrix Currencies] = {tazlyrids_mc_array.[Final Shortest TTs],
tazlyrids_mc_array.[Final Shortest TTs], tazlyrids_mc_array.[Final Shortest TTs],
tazlyrids_mc_array.[Final Shortest TTs]}
Opts.Input.[FF Matrix Currencies] = { , , , }
Opts.Global.[Constraint Type] = {"Production", "Production", "Production",
"Production"}
Opts.Global.[Purpose Names] = purpose_array
Opts.Global.Iterations = iterations_array
Opts.Global.Convergence = convergence_array
Opts.Global.[Fric Factor Type] = method_array
Opts.Global.[A List] = acoeff_array
Opts.Global.[B List] = bcoeff_array
Opts.Global.[C List] = ccoeff_array
Opts.Field.[Prod Fields] = {"HBW_P", "HBSHOP_P", "HBO_P", "NHB_P"}
Opts.Field.[Attr Fields] = {"HBW_A", "HBSHOP_A", "HBO_A", "NHB_A"}
Opts.Field.[FF Table Times] = {"None.", "None.", "None.", "None."}
Opts.Field.[FF Table Fields] = {"TripType", "TripType", "TripType", "TripType"}
Opts.Output.[Output Matrix].Label = "Gravity Matrix"
Opts.Output.[Output Matrix].[File Name] = out_path + "\\Gravity_Raw.mtx"
ret_value_grav = RunMacro("TCB Run Procedure", "Gravity", Opts, &Ret)
```

Note that the use of friction factors was replaced in the TransCAD code with the use of trip-distribution functions, whose coefficients A, B, and C are specified. This change makes the Model more adaptable to testing variations in the trip-distribution functional form.

Many of the procedures that were coded and run explicitly in CUBE Voyager had macro processes available in TransCAD that could decrease the Model runtime. So whenever macros were available in TransCAD, they were used. An example of this replacement occurred for the trip generation step. The following code is used to run the regression and cross-classification for trip generation in CUBE Voyager:

```
;Trip Rates

LOOKUP LOOKUPI=1,
        NAME=TRATE,
                LOOKUP[1]=RATENUM, RESULT=HBW,
                LOOKUP[2]=RATENUM, RESULT=HBO,
                LOOKUP[3]=RATENUM, RESULT=HBSH,
        FAIL[3]=0

; Townwide Stratification

LOOKUP LOOKUPI=2,
        NAME=HHV,
                LOOKUP[1]=CODE, RESULT=PER1WOR0,  ; 1 PERSON 0 WORKER
                LOOKUP[2]=CODE, RESULT=PER1WOR1,  ; 1 PERSON 1 WORKER
                LOOKUP[3]=CODE, RESULT=PER2WOR0,
                LOOKUP[4]=CODE, RESULT=PER2WOR1,
                LOOKUP[5]=CODE, RESULT=PER2WOR2,
```

```
            LOOKUP[6]=CODE, RESULT=PER3WOR0,
            LOOKUP[7]=CODE, RESULT=PER3WOR1,
            LOOKUP[8]=CODE, RESULT=PER3WOR2,
            LOOKUP[9]=CODE, RESULT=PER3WOR3,
            LOOKUP[10]=CODE, RESULT=PER4WOR0,
            LOOKUP[11]=CODE, RESULT=PER4WOR1,
            LOOKUP[12]=CODE, RESULT=PER4WOR2,
            LOOKUP[13]=CODE, RESULT=PER4WOR3,
      FAIL[3]=0

TC=ZI.1.TOWN_CODE

; HBW
P[1]=ZI.1.HHLD{NETWORKYEAR} *
(TRATE(1,1)*HHV(1,TC)+TRATE(1,2)*HHV(2,TC)+TRATE(1,3)*HHV(3,TC)+
TRATE(1,4)*HHV(4,TC)+TRATE(1,5)*HHV(5,TC)+
TRATE(1,6)*HHV(6,TC)+TRATE(1,7)*HHV(7,TC)+TRATE(1,8)*HHV(8,TC)+
TRATE(1,9)*HHV(9,TC)+TRATE(1,10)*HHV(10,TC)+
TRATE(1,11)*HHV(11,TC)+TRATE(1,12)*HHV(12,TC)+TRATE(1,13)*HHV(13,TC))

A[1]= 0.59 * (ZI.1.RET{NETWORKYEAR} + ZI.1.MAN{NETWORKYEAR} +
ZI.1.N_MAN{NETWORKYEAR} + ZI.1.GOV{NETWORKYEAR} +
ZI.1.E_SCH{NETWORKYEAR} + ZI.1.UNIV{NETWORKYEAR})

; HBSHOP
P[2]=ZI.1.HHLD{NETWORKYEAR} *
(TRATE(3,1)*HHV(1,TC)+TRATE(3,2)*HHV(2,TC)+TRATE(3,3)*HHV(3,TC)+
TRATE(3,4)*HHV(4,TC)+TRATE(3,5)*HHV(5,TC)+
TRATE(3,6)*HHV(6,TC)+TRATE(3,7)*HHV(7,TC)+TRATE(3,8)*HHV(8,TC)+
TRATE(3,9)*HHV(9,TC)+TRATE(3,10)*HHV(10,TC)+
TRATE(3,11)*HHV(11,TC)+TRATE(3,12)*HHV(12,TC)+TRATE(3,13)*HHV(13,TC))

IF (ZI.1.AREA_TYPE=2)
A[2] = 4.74 * ZI.1.RET{NETWORKYEAR}
ELSEIF (ZI.1.AREA_TYPE=3)
A[2] = 5.06 * ZI.1.RET{NETWORKYEAR}
ENDIF

; HBO
P[3]=ZI.1.HHLD{NETWORKYEAR} *
(TRATE(2,1)*HHV(1,TC)+TRATE(2,2)*HHV(2,TC)+TRATE(2,3)*HHV(3,TC)+
TRATE(2,4)*HHV(4,TC)+TRATE(2,5)*HHV(5,TC)+
TRATE(2,6)*HHV(6,TC)+TRATE(2,7)*HHV(7,TC)+TRATE(2,8)*HHV(8,TC)+
TRATE(2,9)*HHV(9,TC)+TRATE(2,10)*HHV(10,TC)+
TRATE(2,11)*HHV(11,TC)+TRATE(2,12)*HHV(12,TC)+TRATE(2,13)*HHV(13,TC))

A[3]= 0.96 * (ZI.1.RET{NETWORKYEAR} + ZI.1.MAN{NETWORKYEAR} +
ZI.1.N_MAN{NETWORKYEAR} + ZI.1.GOV{NETWORKYEAR} +
ZI.1.E_SCH{NETWORKYEAR} + ZI.1.UNIV{NETWORKYEAR}) + (0.67 *
ZI.1.HHLD{NETWORKYEAR})

; NHB
```

```
P[4]= 2.56 * ZI.1.RET{NETWORKYEAR} + 0.41 * ZI.1.N_MAN{NETWORKYEAR} +
0.86 * ZI.1.GOV{NETWORKYEAR} + 0.89 * ZI.1.HHLD{NETWORKYEAR}

A[4] =  P[4]

; TRUCKS
P[5]= P[4] * (ZI.1.TRKPER/100)
A[5]= P[4] * (ZI.1.TRKPER/100)
```

The following code is used to run the same processes in TransCAD:

```
TripRate_View = OpenTable("Trip Rates","FFB", {triprate_table,})
Opts = null
Opts.Input.[Trip Rate Set]  = {triprate_table, TripRate_View}
Opts.Input.[Zone View Set]  = {taz_layer_info[10] + "|" + taz_layer_info[11],
taz_layer_info[11], "Selection", "Select * where [TAZ ID] < 930"}
Opts.Input.[Output Field 1] = "HBO_P"
Opts.Input.[Output Field 2] = "HBSHOP_P"
Opts.Input.[Output Field 3] = "HBW_P"
Opts.Global.[Number Classifications] = 2
Opts.Global.[Number Purposes]        = 3
Opts.Global.[Number Units]           = 13
Opts.Global.[Urban Pop Option]       = "No"

//Unit Fields: HH Type breakdowns from the TAZ layer:
Opts.Field.[Unit Field1] = taz_layer_info[11] + "." + "H1W0"
Opts.Field.[Unit Field2] = taz_layer_info[11] + "." + "H1W1"
Opts.Field.[Unit Field3] = taz_layer_info[11] + "." + "H2W0"
Opts.Field.[Unit Field4] = taz_layer_info[11] + "." + "H2W1"
Opts.Field.[Unit Field5] = taz_layer_info[11] + "." + "H2W2"
Opts.Field.[Unit Field6] = taz_layer_info[11] + "." + "H3W0"
Opts.Field.[Unit Field7] = taz_layer_info[11] + "." + "H3W1"
Opts.Field.[Unit Field8] = taz_layer_info[11] + "." + "H3W2"
Opts.Field.[Unit Field9] = taz_layer_info[11] + "." + "H3W3"
Opts.Field.[Unit Field10] = taz_layer_info[11] + "." + "H4W0"
Opts.Field.[Unit Field11] = taz_layer_info[11] + "." + "H4W1"
Opts.Field.[Unit Field12] = taz_layer_info[11] + "." + "H4W2"
Opts.Field.[Unit Field13] = taz_layer_info[11] + "." + "H4W3"

//Purpose Fields: Identify the field in the trip rate table where the trip rates for
each trip purpose are located:
Opts.Field.[Purpose Field1] = TripRate_View + "." + "R_HBO"
Opts.Field.[Purpose Field2] = TripRate_View + "." + "R_HBSHOP"
Opts.Field.[Purpose Field3] = TripRate_View + "." + "R_HBW"

//Upper Bound of HH Members are in column 1 and Upper Bound of HH workers are
in column 2
Opts.Field.[Unit Class Value11] = 2
Opts.Field.[Unit Class Value12] = 1
Opts.Field.[Unit Class Value21] = 2
Opts.Field.[Unit Class Value22] = 2
Opts.Field.[Unit Class Value31] = 3
Opts.Field.[Unit Class Value32] = 1
```

```
Opts.Field.[Unit Class Value41] = 3
Opts.Field.[Unit Class Value42] = 2
Opts.Field.[Unit Class Value51] = 3
Opts.Field.[Unit Class Value52] = 3
Opts.Field.[Unit Class Value61] = 4
Opts.Field.[Unit Class Value62] = 1
Opts.Field.[Unit Class Value71] = 4
Opts.Field.[Unit Class Value72] = 2
Opts.Field.[Unit Class Value81] = 4
Opts.Field.[Unit Class Value82] = 3
Opts.Field.[Unit Class Value91] = 4
Opts.Field.[Unit Class Value92] = 4
Opts.Field.[Unit Class Value101] = 9
Opts.Field.[Unit Class Value102] = 1
Opts.Field.[Unit Class Value111] = 9
Opts.Field.[Unit Class Value112] = 2
Opts.Field.[Unit Class Value121] = 9
Opts.Field.[Unit Class Value122] = 3
Opts.Field.[Unit Class Value131] = 9
Opts.Field.[Unit Class Value132] = 7
Opts.Output.[Output Table] = out_path + "\\TripGenCross.bin"
ret_value_crosclas = RunMacro("TCB Run Procedure", "Crosclas", Opts, &Ret)

While t <= nTypes do

        type = type_vector[t]
        constant = constant_vector[t]
        hhs_coeff = hhs_vector[t]
        retails_coeff = retails_vector[t]
        manufs_coeff = manufs_vector[t]
        n_manufs_coeff = n_manufs_vector[t]
        govs_coeff = govs_vector[t]
        educ_coeff = educ_vector[t]

        Opts = null
        Opts.Input.[Zone Set] = {taz_layer_info[10] + "|" + taz_layer_info[11],
        taz_layer_info[11], "Selection", "Select * where [TAZ ID] < 930"}
        Opts.Field.Dependent = taz_layer_info[11] + "." + type
        Opts.Field.Independents = {taz_layer_info[11] + "." + "HHs_2010_Census",
        taz_layer_info[11] + "." + "RET2009", taz_layer_info[11] + "." + "MAN2009",
        taz_layer_info[11] + "." + "N_MAN2009", taz_layer_info[11] + "." +
        "GOV2009", taz_layer_info[11] + "." + "EDUC2009"}
        Opts.Global.Method = "Regression"
        Opts.Global.[Model File] = out_path + "\\" + type + "_RegCoeffs.mod"
        Opts.Global.Coefficients = {constant, hhs_coeff, retails_coeff, manufs_coeff,
        n_manufs_coeff, govs_coeff, educ_coeff}
        Opts.Global.[Output to Report File] = 1
        ret_value_regr = RunMacro("TCB Run Operation", "Linear Evaluation",
        Opts, &Ret)

        t_next = t + 1
        t = t_next
```

end

The lines containing the "RunMacro" command in TransCAD indicate proprietary macros that run faster than typical, equation-based code, as shown in the CUBE Voyager excerpt.

4.1.2 Other Refinements and New Features

In addition to migrating the code and replacing some explicit procedures with macros, other refinements were made to the Model code in TransCAD, and new features were added.

The most significant refinement was a change to the way that truck trips are estimated in the Model. Since TransCAD has a macro for utilixing an origin-destination matrix estimation (ODME) procedure, that procedure was incorporated and replaced the original procedure in the Model. The original procedure was less accurate, because it used truck traffic counts but in a more aggregate way, and then applied those counts to the overall trips counts to extract an estimate of truck trips by TAZ. With the ODME procedure, truck traffic counts are used directly to estimate truck trips for the entire state at once, based on an initial "seed" matrix. The seed matrix used for the ODME procedure is simply the previously estimated TRUCK trip matrix from the CUBE Voyager Model. This refinement improves both the speed and the accuracy of the Model. The accuracy improvement that comes about as a result of the ODME procedure was documented in the Year 3 Report.

The new features added to the Model include a menu-based user-interface with full specification of the input files, a forecast-period specification, and the addition of a root-mean-square percent error (RMSPE) output table. A new menu-interface was added to help the user explicitly understand how and when the Model is run, and to allow the user more explicit control over the Model runs. The new interface is called up by activating the GISDK Toolbox (Figure 8).

Figure 8 TransCAD GISDK Toolbox

Selecting the button on the far left allows the user to compile the Model code, then selecting the next button to the right (three overlapping arrows) opens the dialog box used to open the initial Model menu (Figure 9).

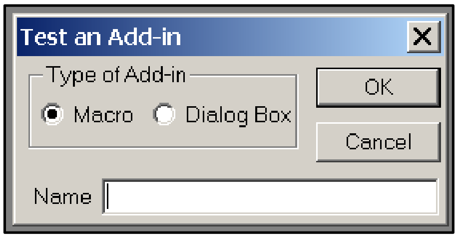

Figure 9 TransCAD Add-In Dialog Box

To open the initial Model menu, the user enters "The Vermont Travel Model" and clicks OK. Once this is done, the initial Model menu appears (Figure 10).

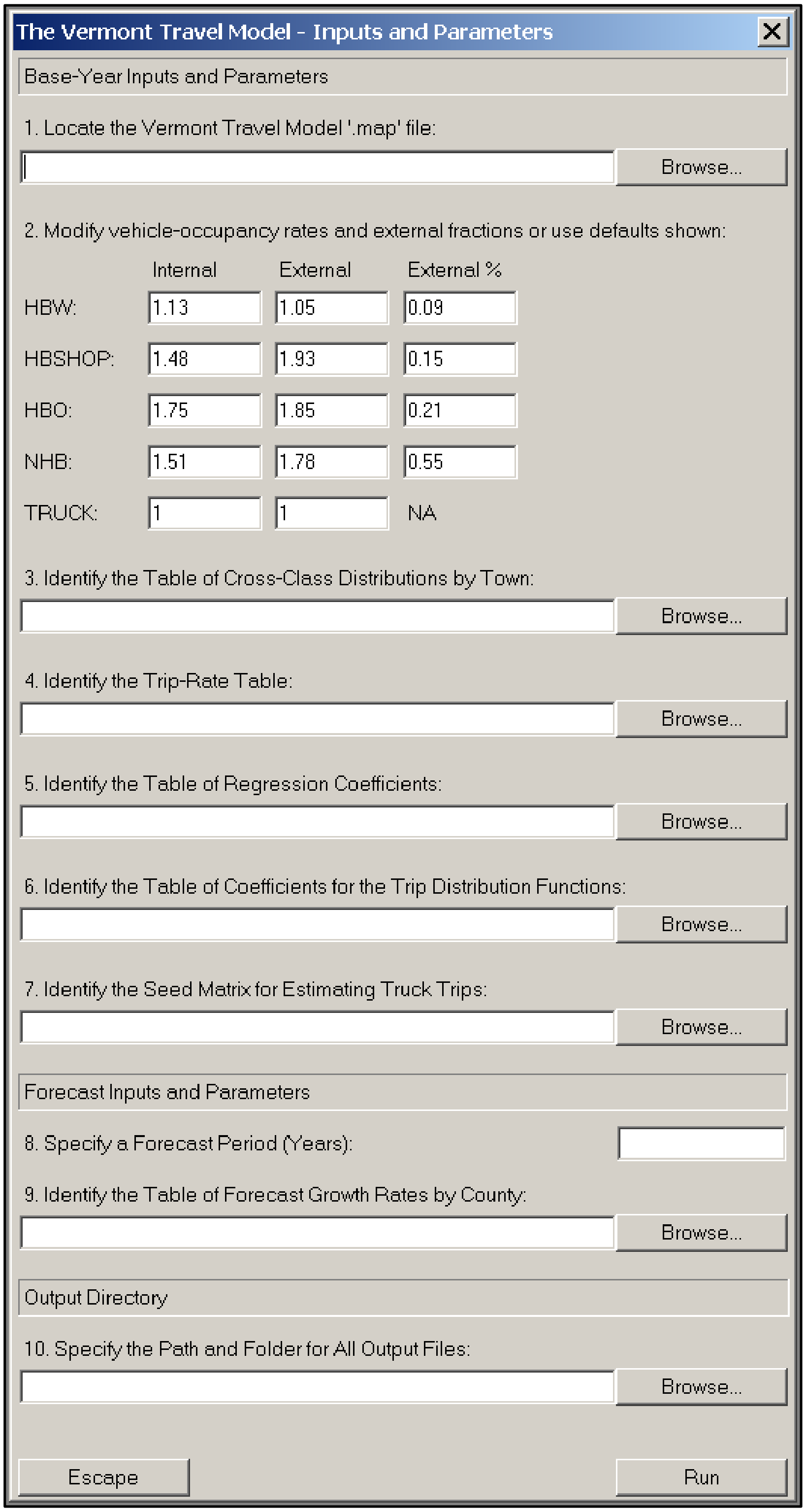

Figure 10 Initial Model Menu

The menu contains ten items for the user to enter for the Model run:

1. The Vermont Travel Model ".map" file – currently called "Vermont Travel Model.map" and contains the TAZ layer, the road network layer, and the base-year network file (.net)

2. Vehicle-occupancy rates and external fractions – defaults shown are taken from the 2009 NHTS, but they can be altered for a scenario run

3. Table of Cross-Class Distributions by Town – currently called "HHTypeByTown_2009.bin" and contains the breakdown of household-structures, by workers and members, for each town in the state

4. Trip-Rate Table – currently called "VTM Trip Rate Table.bin" and contains the trip-production rates for each of the household structures in the breakdown in "HHTypeByTown_2009.bin"

5. Table of Regression Coefficients – currently called "RegressionCoefficients.bin" and contains the coefficients for regression equations used to calculate trip productions and attractions

6. Table of Coefficients for Trip Distribution Functions – currently called "Gravity Model Coefficients.bin" and contains the coefficients to be used in the trip distribution to determine the destinations of trips from each TAZ

7. Seed Matrix for Estimating Truck Trips – currently called "2009-Truck-Seed.mtx" and contains the initial truck-trip matrix that the ODME procedure will use to estimate a new truck trip matrix

8. Forecast Period – user-specified number of years to forecast travel to, assuming a base year of 2010

9. Table of Forecast Growth Rates – currently called "Growth Rates.bin" and contains the annual growth rates for each employment category and households by Vermont County

10. Output Directory – user-specified directory where output files will be saved after the Model run

This full specification of the Model input files means that the files will not have to be in a specific location on the user's computer for the Model to run. The input files can be anywhere. As long as a path and filename is provided for each input file in this menu, the Model will run successfully.

The forecast-period specification is a new feature of the Model. It allows the Model to be run to any forecast year the user chooses, creating a sub-folder in the output folder identified by the forecast year with Model outputs for the forecast year. To run multiple forecasts, the user can repeat the Model run with a new forecast-period, and a new forecast-output folder will be created and populated.

Finally, a new output table was added to the Model to help see the RMSPE and link-specific squared errors (SE) more efficiently. These statistics are useful for validating the Model, so having them produced in a stand-alone output table will allow the Model to be re-estimated and/or updated more efficiently. Identification of specific links with high SEs guided the assessment of centroid connector locations and resolution of TAZs.

4.2 Analysis of Model Matrix Asymmetry

Once the Model had been migrated to TransCAD, it was used to test the effectiveness of leaving out the step which enforces symmetry in the trip matrices. This step is accomplished by adding the output matrices from the Trip Distribution module to their own transposes, then cutting all values in half. This procedure makes the matrices symmetrical – the number of trips leaving a certain TAZ destined for another TAZ is the same as the number of trips returning from the destination TAZ to the origin TAZ. The practical reason for this step is to create a logical progression for the daily-travel basis of the Model. The Model is supposed to be simulating a typical day of travel in Vermont, and includes primarily trips that are completed within a typical one-day timeframe. So a typical trip in the Model will end where it began.

This assumption is more relevant to home-based trips than it is to non-home-based or truck trips, which can be expected to be less likely to be completed in one day. Using this observation, Model runs were conducted in which the NHB trip matrix or the TRUCK trip matrix were left asymmetrical. However, for both of these tests, the RMSPE either got worse (increased from 44.4% to 44.8% for NHB) or stayed the same (for TRUCK).

Another possible assumption is that external trips and trips made by non-Vermonters are more likely to span more than one day, and would benefit from being treated asymmetrically. In order to test this assumption, several Model runs were conducted leaving the portion of the matrices representing trips to/from external TAZs asymmetrical. However, this change was also found to not effect the RMSPE, which is expected because of the way the Model handles external flows and external trips. An inconsistency in the way the Model handles external travel is discussed further in Section 4.3.

4.3 Assessment of Centroid Connector Locations and Resolution of TAZs

The Model implementation in TransCAD was next used to assess the locations of centroid connectors, and the resolution of TAZs. Locations and number of centroids connectors are important because they can lead to large discrepancies between Model traffic flows and real-world traffic counts, represented as AADT.

4.3.1 Centroid Connector Locations

Centroid connectors are present in the Model road network to represent groups of minor roads. However, when centroid connectors are connected to the road network at a location where there is no true intersection, then the Model flow volumes on that link may be higher than the traffic counts. This discrepancy is caused by the aggregation of multiple smaller flows on minor roads into a single flow on the connector, and it can often be fixed by adjusting the location where the connector meets the roadway, or by adding another centroid connector which allows flow to enter the network at a second location. Significant adjustments to the locations and number of centroid connectors were made in Year 4, and are summarized in the Year 4 Report (Sullivan and Conger, 2012). Therefore, additional centroid-connector adjustments were not expected to be necessary.

However, during the review of links with high SEs around the University of Vermont campus in Burlington, a problem with the centroid connector for TAZ 641 was identified (Figure 11).

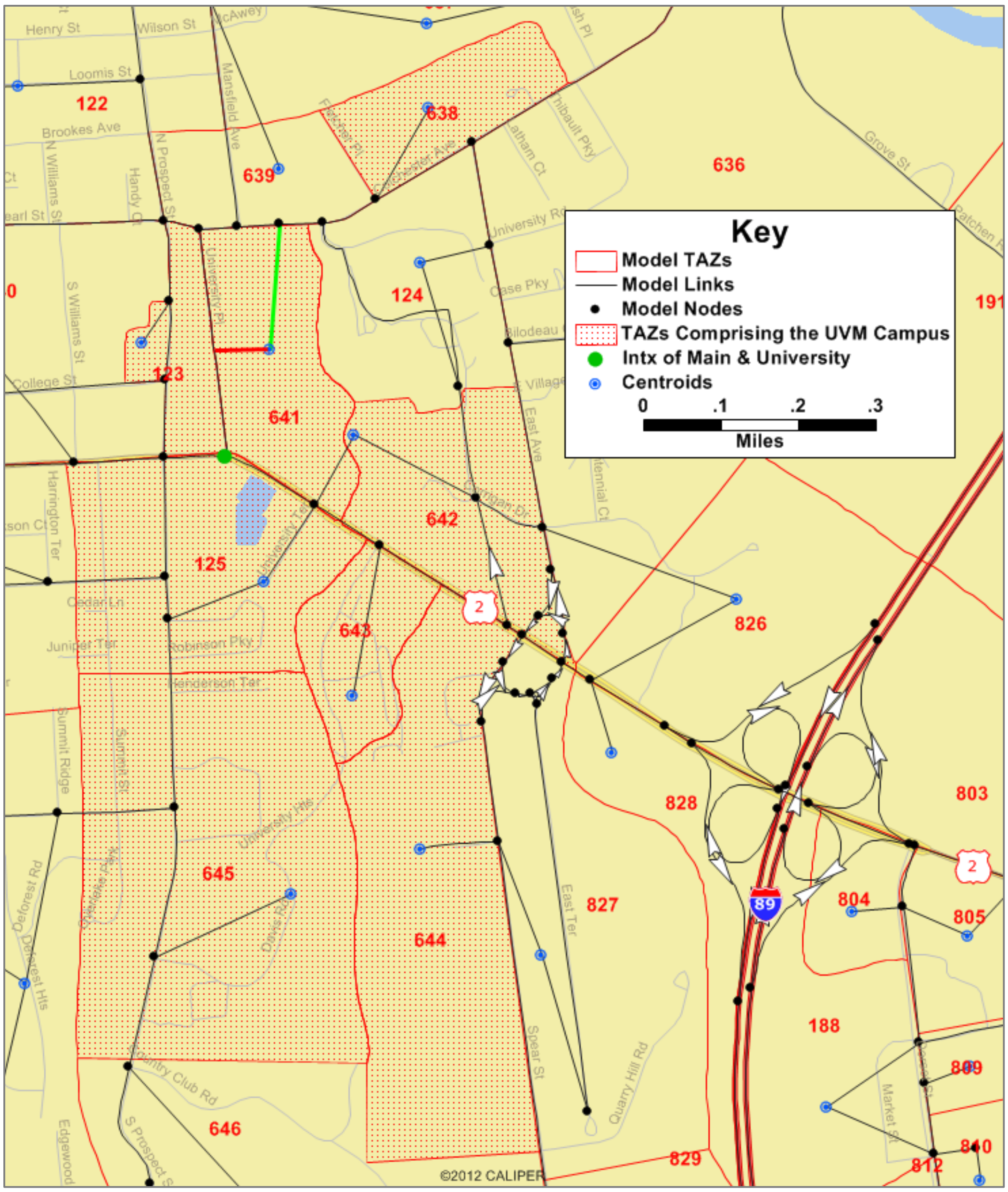

Figure 11 Model TAZs and Road Network Representing the UVM Campus

The connector for TAZ 641 shown in red was replaced with the connector shown in green because the major parking area for this TAZ is accessed from Colchester Avenue, and passenger vehicle access from University Place is not possible. Turn prohibitions were also added at the intersection of Main Street and University Place (large green dot) to represent real-world turn restrictions. These problems were contributing to the high SE for University Place, which was significantly reduced following the corrections.

Another high SE in this area was on South Prospect Street at TAZ 123. TAZ 123 contains the administrative offices for UVM, which is one of the largest employers in the state. However, all of the employment for the university is clustered into TAZ 123, which is inaccurate because employees are scattered throughout the campus (8 TAZs shown highlighted in Figure 11). Employment on the UVM campus was redistributed according to local knowledge of the campus, and the number of commercial buildings in each TAZ, significantly reducing the SE on South Prospect Street.

4.3.2 Other Road Network Corrections

4.3.2.1 Links with No Traffic Assigned

The first area of high discrepancy between Model flows and AADTs that was investigated was the occurrence of links with no traffic assigned to them. In other words, flow on the link after the Model run is 0 vehicles per day. This occurrence indicates that the link is not on a shortest path between any two centroids in the network. While this situation might be fairly common in the Model road network, it is unlikely to exist in the real world.

When these links were identified specifically, it appeared that most of them had been added to the network in Year 4 to improve the robustness of the network representation. So it is not surprising that these roads are not used in the "business-as-usual" state of the network, since the idea behind their robustness contribution is that they might become critical links if other links in the network are disrupted. Therefore, robustness links with no flow were not adjusted or removed from the network. Instead, they were removed from the RMSPE calculation to avoid high errors in the calculation. Most of these links were already not included in the RMSPE calculation due to the absence of an AADT.

A few other links with no flow were found to have incorrect speed limits, leading to unusually high assumed travel times across them. Speed limits were checked and fixed using the Google Street View Hyper-Lapse.

4.3.2.2 Other Links with High Squared Error

Other high discrepancies between Model flows and AADTs were identified using the new RMSPE output table, which includes the individual squared errors (SE) for each link in the network which is included in the overall RMPSE calculation. In other words, this tool points to the links that are contributing most the RMSPE.

Many of these links simply had the wrong AADT representing them. When they were checked closely, it was found that the spatial "tagging" process used to associate an AADT with a Model link incorrectly assigned the AADT of an adjoining or intersecting roadway to the link in question. Once these errors were fixed (by visually inspecting the 2009 AADT GIS) the discrepancies were reduced or eliminated.

In other areas where one or more links had high SEs, road network characteristics were to blame. Around the U.S. Route 7 & I-189 interchange on the Burlington / South Burlington border (see Figure 12), several high SEs were found.

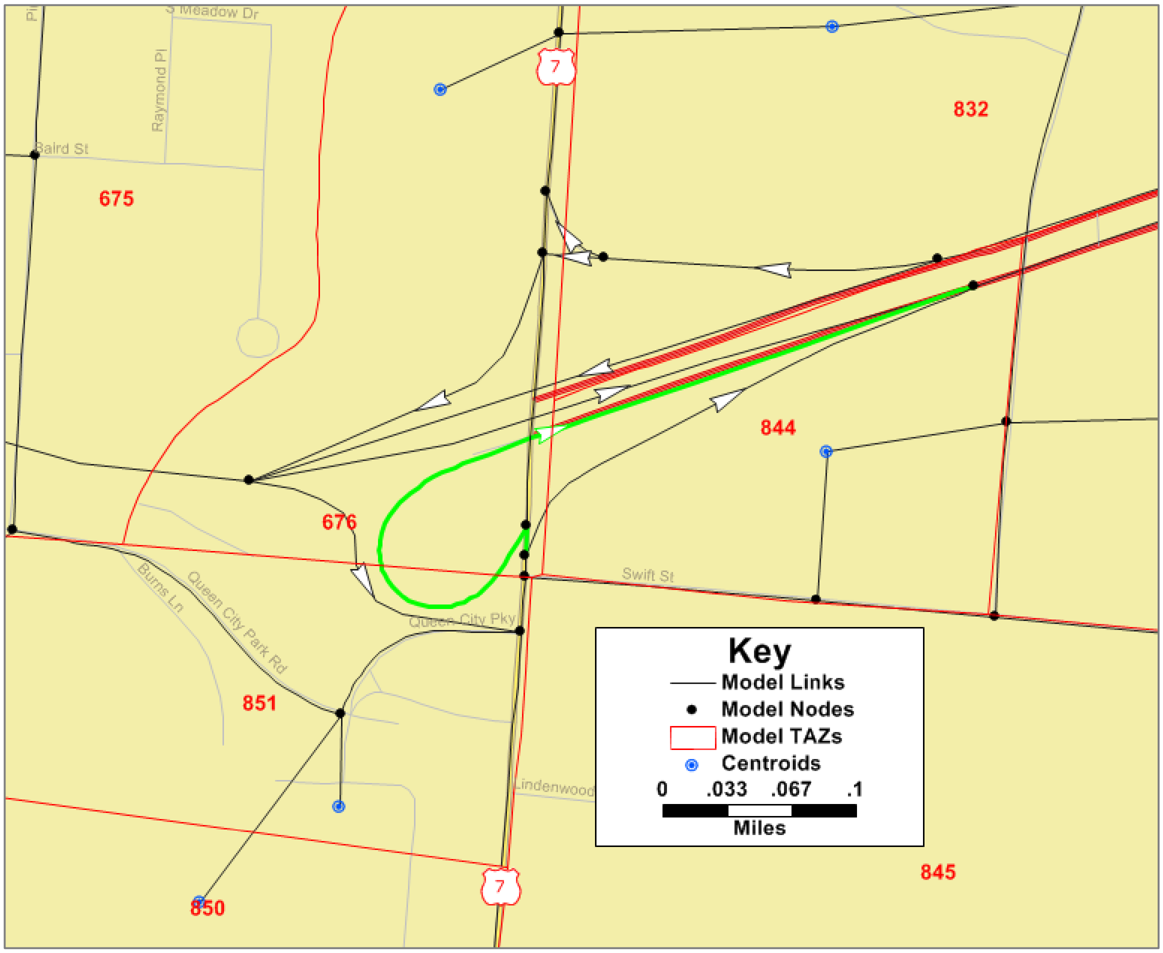

Figure 12 U.S. Route 7 & I-189 Interchange in Burlington, Vermont

The two links shown in green had high SEs contributing to the RMSPE. The southbound (SB) ramp from US 7 to get onto I-189 East was showing very low flow in the Model, but AADTs indicated considerable daily use, whereas the small section of US 7 between the northbound (NB) and SB ramps to I-189 East was showing flows in excess of the AADT. Further inspection revealed that SB flows on U.S Route 7 were ignoring the SB ramp and taking the shorter path to I-189 East by making an illegal left turn onto the NB ramp. This single maneuver was causing both of the high SEs. Once it was fixed by prohibiting turns from US 7 SB to the NB ramp, and preventing all u-turns on this section of US 7, the high SEs disappeared.

A similar correction to the Model road network was made at Exit 11 for I-91 in Hartland, Vermont.

Another area where high SEs required a correction was at the Winooksi Circulator Figure 13).

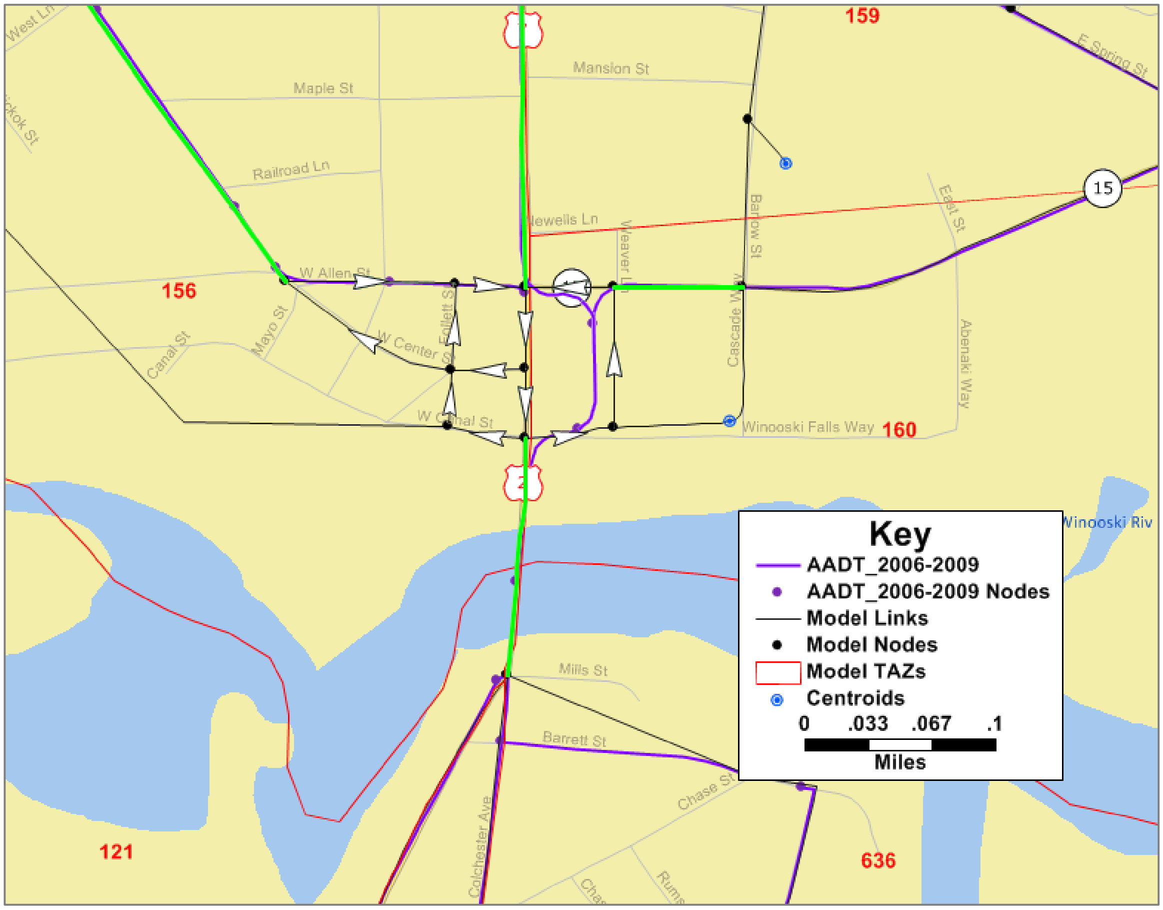

Figure 13 The Circulator in Winooski, Vermont

In this area, there is generally excellent agreement between Model flows and AADTs at the edges of the Circulator (shown in green). However, within the complex system of one-way, circulating links that mark the Winooski, Vermont downtown area, very high SEs were discovered. As shown by the representation of the AADT GIS (in purple), AADTs are not available for every link in the Circulator, and the AADTs that are available do not correspond exactly to the link topology of the Model road network. Therefore, it is impossible to tell which AADT values should apply to which Model links within the Circulator. So inside the green links shown in the figure, all of the links in the Circulator were removed from the RMSPE calculation.

4.3.3 Resolution of TAZs

The assessment of TAZ resolution was focused on those TAZs in the network with the highest total trip counts as an origin or a destination. The top 5 TAZs for trip counts are 242, 258, 437, and an external TAZ, 941.

TAZ 242 is on the eastern edge of the Census urban area representing St. Albans City, but it extends east of I-89 where sprawling of the Census urban area has taken place (Figure 14).

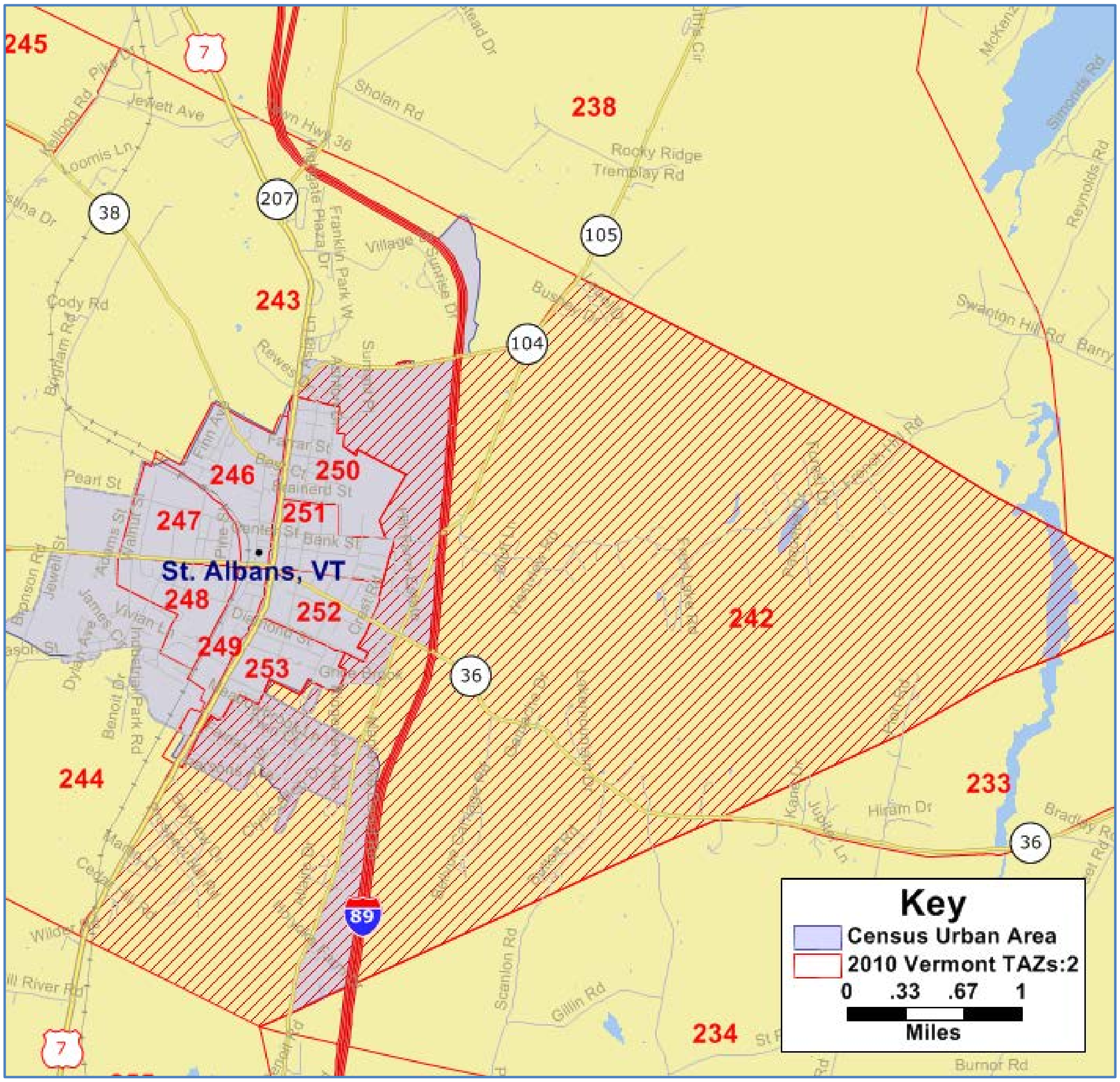

Figure 14 The Vicinity of TAZ 242

So this TAZ now includes portions of the Census UA, but also the development corridor around I-89 and a large rural area to the east of St. Albans. This TAZ includes over 20 individual Census blocks, and its boundaries may not have been adjusted since the Census UA expanded. Inconsistencies between Model flows and AADTs in the TAZ also indicate the need to provide additional centroids. In this case, splitting the TAZ makes sense.

In order to split the TAZ, appropriate new boundaries must be created spatially, and then the households and employment within each new TAZ must be calculated, using the totals for the original TAZ as control. New household counts can be easily divided by using the 2010 household counts by Census Block from the 2010 U.S.

Census. New employment counts will be more challenging because the employment information is only available at the town level. Therefore, splitting the employment totals for the original TAZ will be guided by the number of commercial buildings in each sub-divided unit. The most logical place to split the TAZ is at I-89, so that the Census urban area is separated from the more rural portions of the TAZ. However, travel corridors north and south of State Route 36 indicate that roadway as a natural divide as well. Therefore, TAZ 242 will be split into 3 new TAZs whose new IDs will be 242, 867, and 868 (Figure 15).

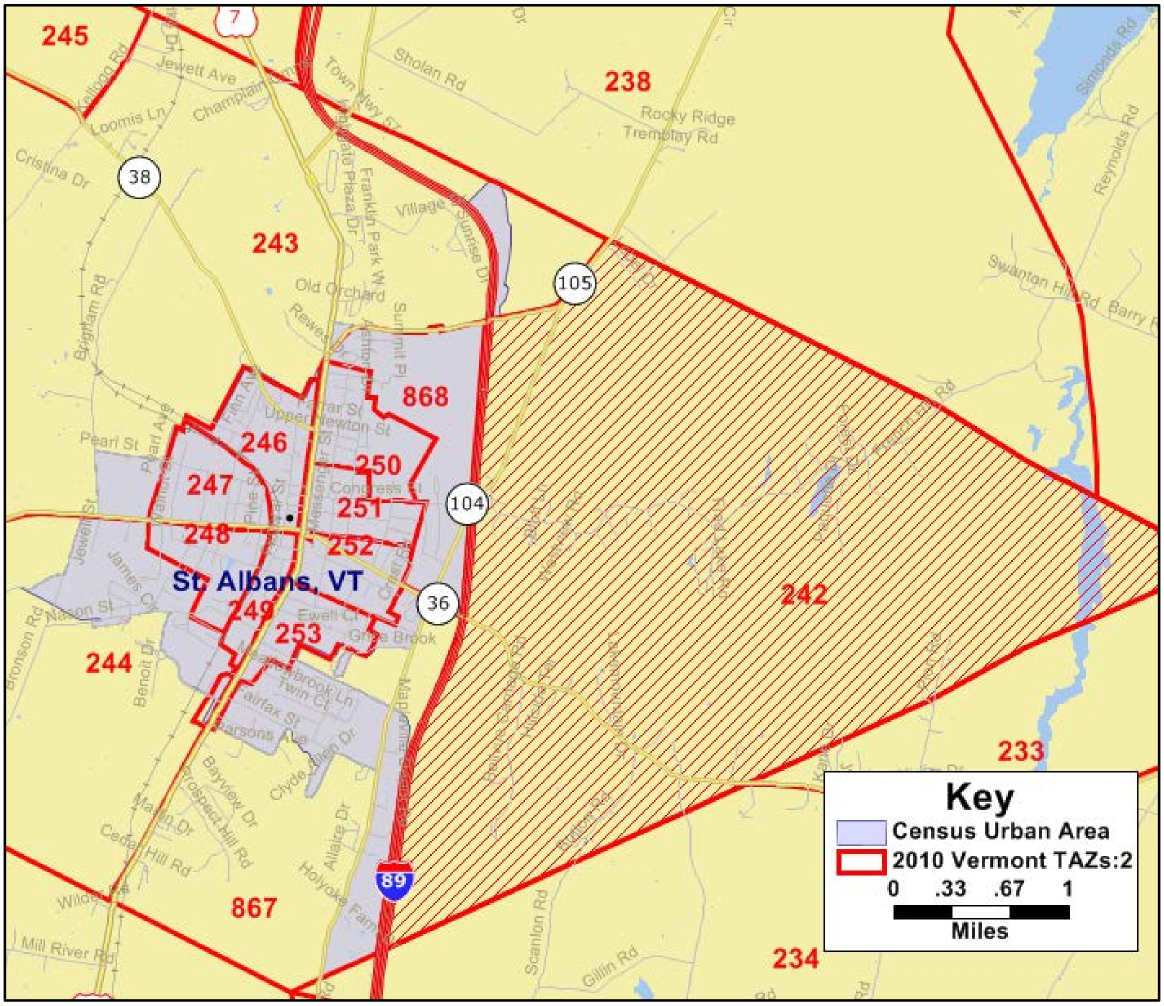

Figure 15 New Subdivided TAZs for Original TAZ 242

The new TAZs are consecutively numbered 867 and 868 from the highest existing TAZ ID, 866.

TAZ 258 is another TAZ at the periphery of a Census urban area that has experienced growth in recent years and may need to be split. However, upon further inspection, although employment and household totals are fairly high (both around 900) in TAZ 258, the way the centroid connector represents flow seems to be accurate, because all Model flows in the TAZ are in general agreement with AADTs. Therefore, no changes were made at this time.

A similar situation also exists for TAZ 437, which straddles the U.S. Route 302 linking the Census urban areas of Montpelier and Barre, Vermont (Figure 16).

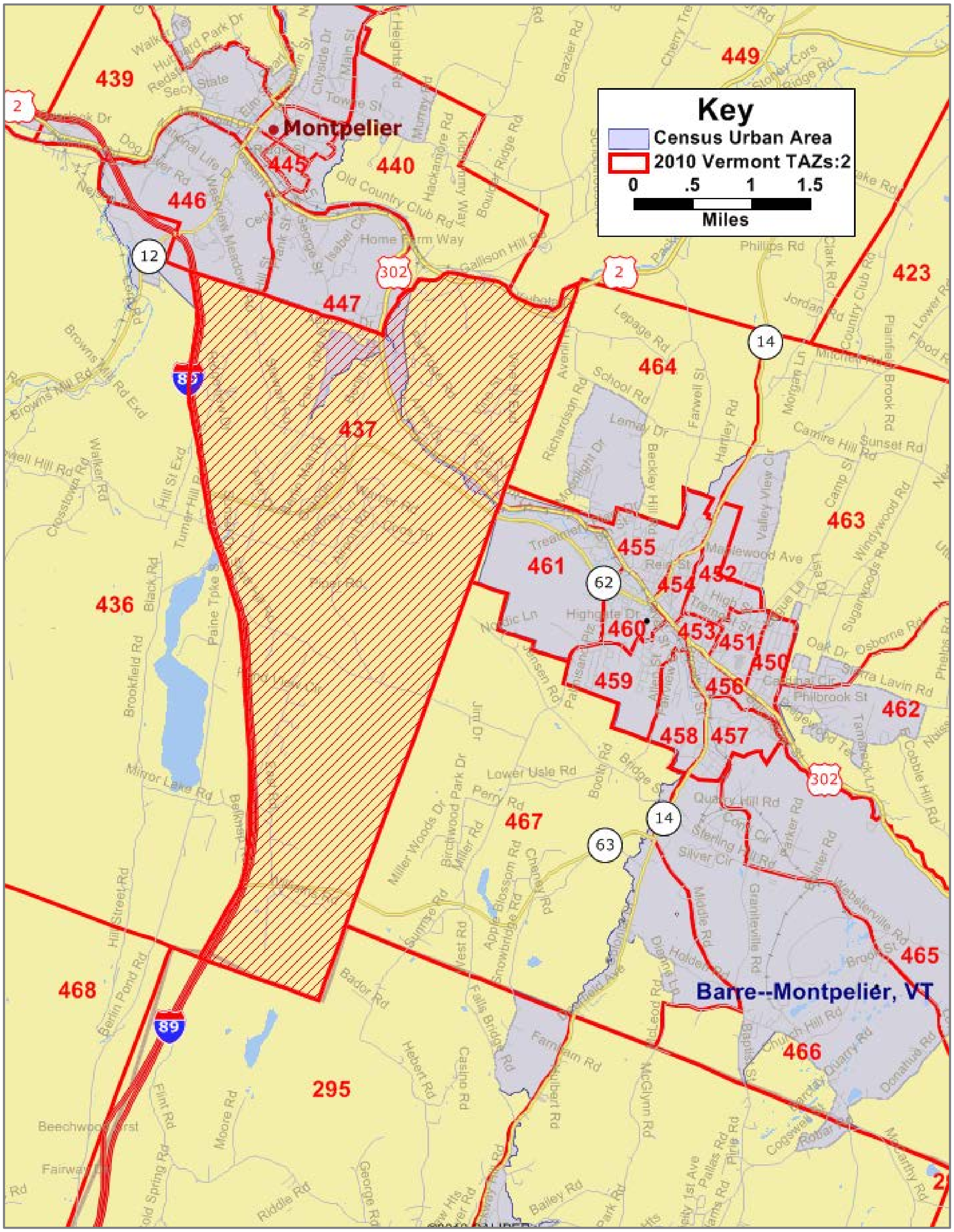

Figure 16 The Vicinity of TAZ 437

Development along the Route 302 corridor has necessitated the division of TAZ 437 to represent the increased growth and sprawl of the Census urban area. A similar procedure to that used for TAZ 242 was used, resulting in two new TAZs with IDs 437 and 869, one of which (new TAZ 869) includes all of the Census urban area that had been within TAZ 437 (Figure 17).

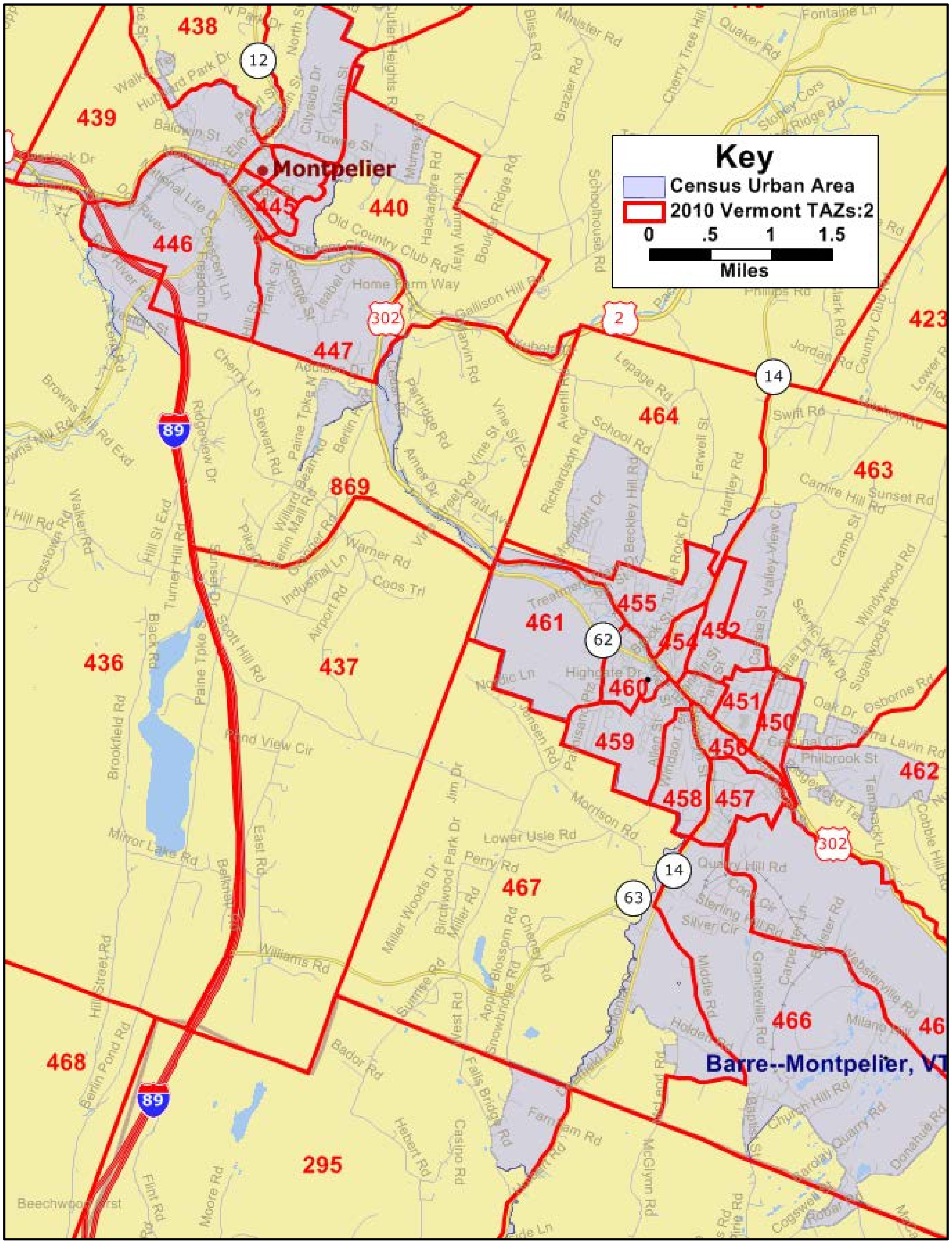

Figure 17 New Subdivided TAZs for Original TAZ 437

Employment was allocated amongst the two TAZs in proportion to the number of commercial buildings in each TAZ, but also recognizing the disproportionate influence of the Central Vermont Medical Center and the Berlin Mall on employment, which are both within TAZ 869.

For all new TAZs, a new centroid was created and new centroid connectors added to link the centroid to the road network. New centroid connectors were added to feed traffic onto the Model road network at locations that would minimize misalignment of Model flows and AADTs.

External TAZ 941 was investigated because it contains the highest number of trip origins and destinations in the Model (about 18,000 per day), due to the high external AADT where I-89 crosses from Vermont into New Hampshire. The elevated number of trips at this external TAZ not only indicates a need to split the TAZ, but it further indicates a need to distinguish more of the travel-shed outside of Vermont, particularly at this location. No changes were made at this time, but this Census urban area (Lebanon-Hanover, NH) will be the focus of the "halo" analysis that will be conducted in Year 7. For the "halo" analysis, portions of the Lebanon-Hanover, NH Census urban area will be added to the Model as internal TAZs until the external flows can be reduced to a more manageable level.

Other TAZs were investigated due to the presence of roadways with elevated SEs or high levels of employment that might be misallocated. TAZ 710 represents the campus of IBM, the largest employer in Vermont, in Essex Junction. However, the 5,000 manufacturing jobs located at IBM were inexplicably missing from this TAZ. Employment totals were adjusted in accordance with the employment totals in the CCMPO Regional Travel Model, which include the 5,000 manufacturing jobs due to IBM in TAZ 710. Most of the 5,000 jobs that are reportedly at the Fletcher Allen campus in Burlington were also missing, so non-manufacturing jobs were added to TAZs 640 and 124 in accordance with the CCMPO Model allocation.

TAZ 788 represents a retail location which includes a Home Depot and a Walmart in Williston, Vermont. Due to some elevated SEs in the vicinity of TAZ 788, retail employment totals for this TAZ were confirmed and adjusted slightly with values from the CCMPO Model. However, even after these adjustments, Mode flows continue to be significantly lower than AADTs in the vicinity of TAZ 788. Because this area is a mega-retail center, where square footage of retail is likely a better predictor of travel than employment, strict agreement between trip totals and AADTs may not be possible with the current Trip Generation structure in the Model. In future years, TAZ 788 and some of the surrounding TAZs should be made into Special Generators, with a unique sub-module to calculate trip totals, possibly using the VTrans Red Book to support Trip Generation rates.

Many of the roads around TAZ 555 seem to have higher Model flows than AADTs would indicate they should have. The employment total for Hartford (where TAZ 555, where White River Junction resides) seems higher than the major employers in the area would justify. When the numbers were checked, this discrepancy seems due to the factoring of Vermont Department of Labor (VDOL) employment totals with BEA factors. In this case, the increase (almost double) seems unjustified. In the future, a new source of employment totals for this TAZ (and possibly the entire state) should be considered.

4.4 Incorporation of a Long-Distance Travel Classification into the Model

Following the recommendation of the peer-review panel from Year 5, a comprehensive analysis of long-distance travel in Vermont was conducted, with the goal of creating a new classification of trips in the Model based on distance.

4.4.1 Long-Distance Trip Generation for Vermont

Adapting the trip rates from Table 4.15 in NCHRP 735 for three new long-distance purposes (LD-Business, LD-Pleasure, and LD-Personal Business) allows us generate a set of trip productions for long-distance travel. Using these trip rates creates the following daily person-trips for long-distance travel in Vermont:

- LD-Business: 1,676
- LD-Personal: 1,033
- LD-Pleasure: 4,068

The NCHRP 735 does not describe any procedure for creating a set of trip attractions for these trips. However, it does recommend considering tourist destinations as attractors. In Vermont, tourist destinations and intermediate multi-modal stops include airports, Amtrak stations, downhill ski resorts, and summer recreation sites (Figure 18).

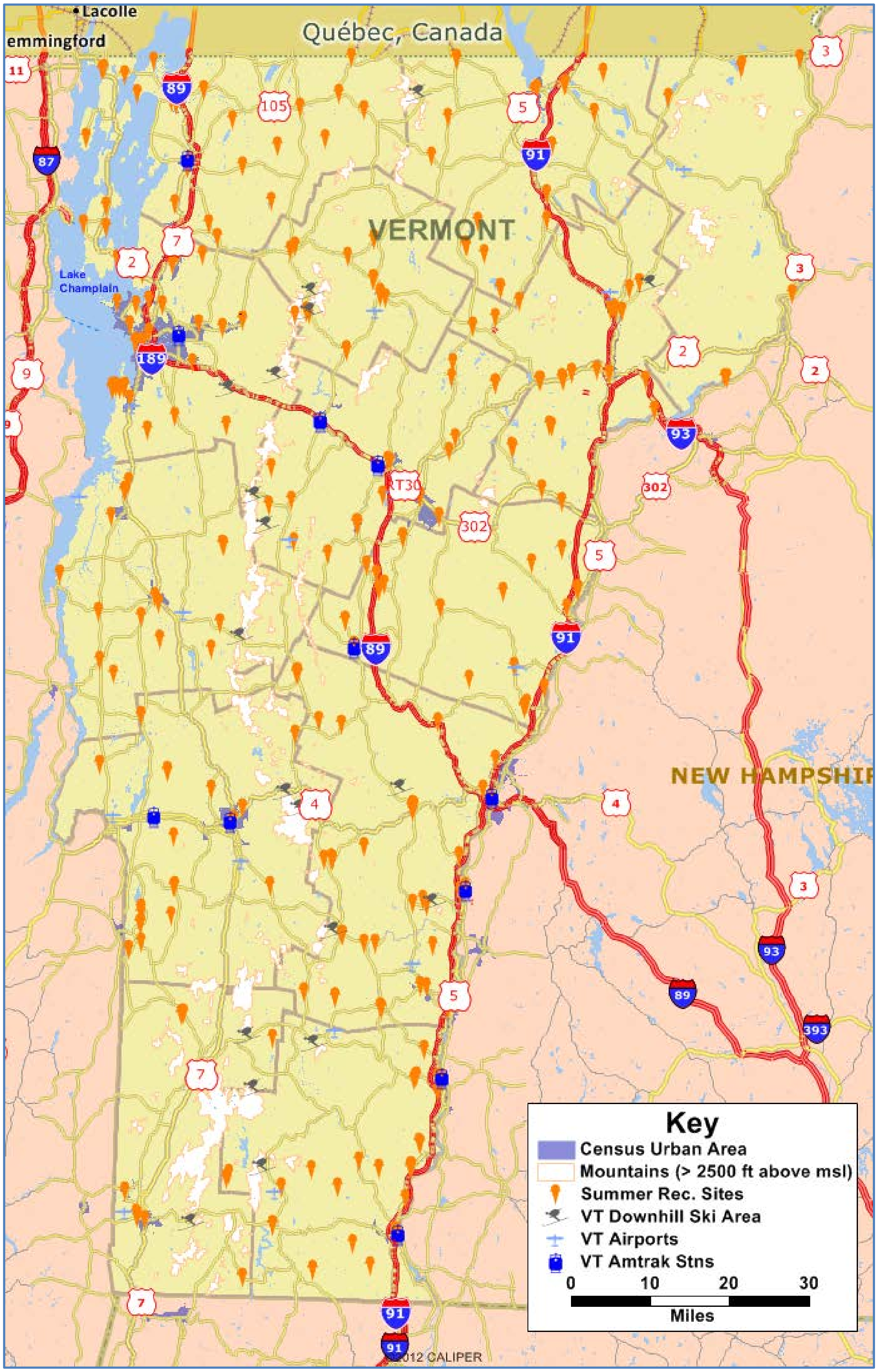

Figure 18 Airports, Amtrak Stations, Ski Resorts, and Summer Recreation Sites in Vermont

When specific counts of visitors or patrons of these destinations are considered, it would appear feasible to develop a set of trip attraction totals for TAZs in Vermont. However, there are many TAZs with none of these attractors, so a regression model is not possible and the count-based totals yield an estimate that is far lower than the trip productions (2,335 person-trips per day).

In addition, when both of these trip totals are compared with visitor and tourist data from the Vermont Travel and Tourism study (Chmura, 2012), both productions and attractions are vastly inaccurate. For example, the total number of visitors to Vermont from other parts of Vermont, other parts of the U.S, and other countries including Canada, in 2011 was 13.95 million. Most or all of these trips should have been over 100 miles, so we should expect daily long-distance trip-genration totals of at least 38,000. The totals generated using the NCHRP 735 rates are almost an order of magnitude lower than that figure. This validation number calls into question the effectiveness and accuracy of the trip rates provided in the NCHRP 735.

As a follow-up validation, the transferable HBW rural trip rate in Table 4.18 from the NCHRP 735 was compared to the current HBW trip rates in the Model, and the Model rates were found to be unilaterally lower for all household categories. One of our peer review panelists (Keith Killough, AZDOT) provided an explanation:

> *If your very rural areas are similar to our very rural areas (e.g., northern AZ and tribal areas), then these households tend to be more agrarian or self-employed – that is, they do not travel for employment. Consequently, your findings are not surprising.*

Based on these findings, NCHRP 735 was determined to unsuitable for use in creating long-distance classifications for the Vermont Travel Model.

4.4.2 Using the NHTS with Pooled-State Data

A second attempt at creating a long-distance classification for the Vermont Travel Model was inspired by a presentation at the innovations in Travel Modeling Conference in April of 2014 in Baltimore, Maryland on the use of pooled data from the NHTS to strengthen its use in modeling. This second attempt focused on the use of Vermont's 2009 NHTS data, and pooled data from similar states, to create a defensible long-distance trip classification.

Using the NHTS provided some flexibility in what is considered a long-distance trip in Vermont, so the 40-mile classification suggested by the analysis of the Vermont NHTS trip distances was used. Trips of 40-miles and longer were considered "long-distance", and trips of 39 miles and shorter were considered "short-distance". Although this classification of long-distance travel is not consistent with the widely held understanding of long-distance travel, as multimodal trips of 100 miles or more that normally span several days, it provides a sound basis for the Vermont Travel Model. The Model includes only highway travel by heavy truck and passenger vehicle, so very long (greater than 300 miles) trips are not considered. Even trips longer than 100 miles are likely to be under-represented in the Model due to the omission of passenger rail and bus. Therefore, the 100-mile classification for long-distance travel is not entirely consistent with the Vermont Travel Model, and a shorter distance is more suitable. If the classification is limited to trips longer than 40 miles and only those trips that are made in one day, then the 2009 NHTS is a very suitable source of data to calibrate the Model. However, acknowledging that the data set of highway trips over 40 miles in length in the 2009 NHTS in Vermont will be small (357 person-trips), additional data from the 2009 NHTS is required for defensible Model parameters.

Considering a collection of states with geographic and demographic features that are similar to Vermont, it was possible to increase the size of the data set of long-distance trips in the 2009 NHTS. Among Maine, New Hampshire, North Dakota, South Dakota, West Virginia, Wyoming, and Montana there are a total of 1,537 person-trips by passenger vehicle longer than 40 miles.

To support the use of data from these states to represent travel behavior in Vermont, a comparison-analysis was conducted. Four comparative measures were developed for the 2009 NHTS sample households from each state, and the similarities of these measures were evaluated. The comparative measures included (1) percentage of households in each cross-classification of household size and number of workers (weighted and unweighted), and (2) percentage of households in each cross-classification of residential density and urban/rural categorization (weighted and unweighted). The evaluation consisted of a qualitative comparison of polynomial curves fit to each distribution across household-type categories.

When each of these four comparative measures were evaluated, only Maine, North Dakota, South Dakota, and West Virginia were found to be similar to Vermont. Therefore, although the other states (New Hampshire, Wyoming, and Montana) might be similar to Vermont, their 2009 NHTS samples were not. Therefore, only Maine, North Dakota, South Dakota, and West Virginia were used to represent travel behavior in Vermont, providing a long-distance data set of 1,237 person-trips.

4.4.2.1 Revised Trip Rates

Using this expanded set of long-distance person-trips allowed a more defensible set of trip production rates to be calculated from the pooled-state data. The calculated trip rates were smoothed to promote increasing trends with increasing household size and number of workers. This smoothing was accomplished by merging categories where inconsistencies were present in the raw calculated rates. For HBW trips, the primary smoothing was conducted by merging categories for the number of workers, and the household size was a secondary smoothing characteristic. For other trip purposes, the household size was merged for the primary smoothing. A summary of the final long-distance trip rates from the set of pooled data is shown in Table 4.

Table 4 Long-Distance Trip Rates from the Pooled Data

Category	Household Size	Number of Workers	Long-Distance Home-Based Trip Rates for: Work	Shopping	Other	All
1	1	0	0.000	0.003	0.050	**0.052**
2	1	1	0.008	0.051	0.050	**0.109**
3	2	0	0.000	0.044	0.072	**0.116**
4	2	1	0.054	0.051	0.072	**0.176**
5	2	2	0.092	0.079	0.131	**0.302**
6	3	0	0.000	0.051	0.084	**0.136**

Category	Household Size	Number of Workers	Long-Distance Home-Based Trip Rates for: Work	Shopping	Other	All
7	3	1	0.054	0.051	0.084	**0.189**
8	3	2	0.092	0.079	0.131	**0.302**
9	3	3+	0.152	0.079	0.401	**0.633**
10	4+	0	0.000	0.053	0.132	**0.184**
11	4+	1	0.057	0.053	0.157	**0.267**
12	4+	2	0.092	0.079	0.374	**0.546**
13	4+	3+	0.152	0.079	0.401	**0.633**

To complement these new long-distance trip rates, a new set of trip rates for trips less than 40 miles was re-calculated from the Vermont data. These raw trip rates were smoothed in a similar way, by merging categories primarily for number of workers (for Work) or for household size (for Shopping and Other), resulting in the set of final short-distance trip rates shown in Table 5.

Table 5 Short-Distance Trip Rates from the Pooled Data

Category	Household Size	Number of Workers	Short-Distance Home-Based Trip Rates for: Work	Shopping	Other	All
1	1	0	0.000	0.783	0.623	**1.406**
2	1	1	0.514	0.927	0.781	**2.223**
3	2	0	0.000	1.445	1.340	**2.784**
4	2	1	0.823	1.445	1.340	**3.607**
5	2	2	1.802	1.623	1.629	**5.054**
6	3	0	0.000	1.836	2.433	**4.270**
7	3	1	0.935	2.039	2.433	**5.407**
8	3	2	2.312	2.039	3.467	**7.818**
9	3	3+	2.312	2.818	6.777	**11.907**
10	4+	0	0.000	2.585	2.476	**5.061**
11	4+	1	0.935	2.585	4.594	**8.115**
12	4+	2	2.312	2.585	6.055	**10.953**
13	4+	3+	2.312	3.103	6.777	**12.193**

4.4.2.2 Revised Regression Coefficients

In order to create complete Trip Generation Module, trip attractions next had to be re-estimated with the long- and short-distance classification. Since specific TAZ characteristics, like jobs by employment category, and specific destinations are necessary to estimate the Model's regression equations for trip attraction, the pooled-state data could not be used. Instead, only the Vermont NHTS data from 2009 was available for the regression equation specification. Due to the relatively small number of long-distance person-trips available in the Vermont NHTS (357), the regression models were estimated with data at the County level of aggregation. The coefficients of the regression models estimated for the all long-distance trip attractions and for NHB long-distance trip productions are shown in Table 6.

Table 6 Regression Model Coefficients for Long-Distance Travel

Variable	NHB (P&A)	HBW (A)	HBSHOP (A)	HBO (A)
Households				
Retail Jobs	0.373		0.253	
Manufacturing Jobs				
Non-Manufacturing Jobs		0.034		0.083
Government Jobs				
Primary School Jobs				
University Jobs				

The previous all-distance regression coefficients for the Model are shown in Table 7 for comparison.

Table 7 Previous Regression Model Coefficients for All Distances

Variable	NHB (P&A)	HBW (A)	HBSHOP Urban (A)	HBSHOP Rural (A)	HBO (A)
Households	0.890				0.670
Retails	2.560		4.740	5.060	
Manufacturing					
Non-Manufacturing	0.410	0.590			0.960
Government	0.860				
Primary School					
University					

As expected, the long-distance attraction coefficients are uniformly lower than those for all distances, representing the relatively small portion of overall travel that fits within the long-distance classification (greater than 39 miles). As with the all-distance regression estimates, manufacturing, primary school, and university employment are not individually significant in the Model, but only as aggregate contributors to HBW travel. In the long-distance regression estimates, government jobs are also not individually significant. The number of households was revealed to be insignificant in estimating long-distance trip attraction, as might be expected due to the nature of long-distance trip destinations, which can be expected to be less frequently a household. Only retail jobs, non-manufacturing jobs, and total employment were revealed to be significant predictive variables for trip attraction. The Urban/Rural distinction for HBSHOP trip attractions was removed from the Model with the expectation that the long-distance trip classification would adequately handle urban and rural differences in travel behavior for HBSHOP trips.

Excluding these long-distance trips from the data set allowed the re-estimation of regression coefficients for short-distance trip attractions in the Model. The coefficients of the regression models estimated for the all short-distance trip attractions and for NHB short-distance trip productions are shown in Table 8.

Table 8 Regression Model Coefficients for Short-Distance Travel

<table>
<tr><th>Variable</th><th>NHB (P&A)</th><th>HBW (A)</th><th>HBSHOP (A)</th><th>HBO (A)</th></tr>
<tr><td>Households</td><td>0.979</td><td></td><td></td><td>2.235</td></tr>
<tr><td>Retail Jobs</td><td>2.835</td><td rowspan="7">0.503</td><td>3.578</td><td></td></tr>
<tr><td>Manufacturing Jobs</td><td></td><td></td><td></td></tr>
<tr><td>Non-Manufacturing Jobs</td><td>0.410</td><td></td><td>0.129</td></tr>
<tr><td>Government Jobs</td><td>0.252</td><td></td><td></td></tr>
<tr><td>Primary School Jobs</td><td></td><td></td><td></td></tr>
<tr><td>University Jobs</td><td></td><td></td><td></td></tr>
</table>

As expected, the significant predictor variables for short-distance trip attractions are more similar to those for all distances. It is also noticeable that the influence of households on trip attraction is stronger for short-distance travel than it is for long-distance travel or all distances, indicating a prevalence of household-focused destination on shorter-distance trips. The magnitude of HBSHOP and HBW trip attractions are reduced, possibly indicating a greater tendency for those types of trips to be long-distance.

4.4.2.3 Revised External Fractions and Vehicle Occupancies

To complete the Model input specification for long- and short-distance classifications, new external fractions and new vehicle occupancies were required. Again, since specific trip destinations are necessary to isolate external trips in the NHTS, the pooled-state data could not be used. Instead, only the Vermont NHTS data from 2009 was used. Due to the relatively small number of long-distance person-trips available in the Vermont NHTS (357), external fractions and vehicle occupancies were estimated using the entire statewide data set.

New trip-purpose fractions for external trips were estimated from the 2009 NHTS for Vermont as shown in Table 9.

Table 9 New Distance-Classified Trip-Purpose Fractions for External Trips

Distance Class	Purpose	Weighted External Daily Trip Estimates from the NHTS	External Fraction
Short	HBW	13,702	10.0%
	HBSHOP	26,158	19.2%
	HBO	35,196	25.8%
	NHB	38,761	28.4%
Long	HBW	2,349	1.7%
	HBSHOP	3,650	2.7%
	HBO	8,288	6.1%
	NHB	8,362	6.1%
	Totals	**136,465**	**100.0%**

For this estimation, external trips are defined as those which either originate in Vermont destined for a location outside of Vermont, or originate outside of Vermont and end in Vermont. Trips recorded by the NHTS which begin and end outside of Vermont are not considered in the Vermont Travel Model. In addition, trips entering or leaving Vermont by non-Vermonters are not substantively included in the Model. These trips become incorporated into the Model through the direct use of AADTs to/from external TAZs as trip estimates in the Trip Generation module (see Appendix A). The discrepancy between the inclusion of these trips, but their exclusion from the 2009 NHTS, which is used to calibrate the Model, is evident in the disagreement between the total number of daily external trips estimated by the Model (136,465) and the total of all AADTs at external links (248,460). This discrepancy indicates that roughly half of all trips crossing Vermont's border each day are non-Vermonters. This discrepancy also attests to a continued source of disagreement between the Model flows and the AADTs throughout the state. Travelers within Vermont who are non-Vermonters are not fully accounted for by the Model, so their presence on the roads will create a natural discrepancy between Model flows (primarily Vermonters) and AADTs (all highway travelers).

New vehicle occupancies for the combination of internal/external and long- and short-distance trips were estimated from the 2009 NHTS for Vermont as shown in Table 10.

Table 10 New Distance-Classified Vehicle Occupancies

Distance Class	Internal / External	HBO	HBSHOP	HBW	NHB	All Purposes
Long	Internal	1.57	1.71	1.38	1.43	1.50
	External	1.95	**3.06**	**1.16**	1.94	2.04
Short	Internal	1.75	1.48	1.12	1.53	1.51
	External	2.00	1.79	1.05	1.52	1.67

Occupancies tend to be higher, especially for shopping and commuting, for long-distance trips, particularly for long-distance trips that cross the Vermont border. The rates in bold, for long-distance external shopping and commuting trips, are questionable because they are based on a small number of trips which fit this classification in the Vermont NHTS. To confirm the accuracy of these two rates, the pooled –state data was considered qualitatively. First, the long-distance occupancies were estimate from the NHTS data for the pooled states (excluding Vermont). These rates could not be separated into internal and external trips. So Vermont's long-distance occupancy rates were re-estimated without the internal/external distinction. These long-distance occupancy rates are shown in Table 11.

Table 11 Long-Distance Vehicle Occupancies without Internal/External Distinction

All LD Vehicle Occupancies	HBO	HBSHOP	HBW	NHB	Grand Total
Pooled-State Data	2.03	**2.42**	**1.19**	2.08	1.94
Vermont-Only Data	1.72	**2.24**	**1.34**	1.76	1.73

A qualitative examination of the rates in bold indicates how high or low the occupancy rates should be, considering the relationship between internal and external rates. In other words, the aggregate Vermont data indicates that all long-distance shopping trips average 2.24 persons per vehicle. So the external long-distance shopping trips, to follow the expected trend, should be higher than this number and the internal long-distance shopping trips should be lower. The pooled-state data confirms that 2.24 persons per vehicle is a reasonable rate for this category. Therefore, these aggregate rates suggest that 3.06 persons per vehicle is not an unreasonable occupancy rate for long-distance external shopping trips.

Interestingly, Vermont's long-distance commuting occupancy rate is the only one that is higher than the average for the pooled states, possibly indicating an increased focus on carpooling amongst commuters in Vermont. The pooled-state average occupancy rate (1.19) attests to the reasonableness of the questionable rate for external long-distance commuting trips in Vermont (1.16).

5 Summary and Recommendations

The Model improvements conducted in Year 6 included significant improvements to the network representation of roadways in the Model, to the Model platform, and to the Model processes. These improvements resulted in an overall improvement in the ability of the Model to simulate a typical day of travel in the state. The overall RMSPE of the Model is currently at 45%.

New rates and parameters were developed which include a long-distance classification in Year 6. These new rates and parameters will be incorporated into the Model platform in Year 7.

A TMIP peer review of the Model was conducted in Year 5, resulting in a comprehensive set of recommendations for Model improvements for the years ahead. Selected subtasks are recommended for Year 7 based on the short-term recommendations from the peer review and the accomplishments in Year 6:

- Develop a Validation Plan for the Model, along with a user's guide and technical reference
- Expand the spatial boundary of the Model as necessary to include important "halo" populations
- Develop a statewide model users' guide and technical reference.
- Consider dynamic traffic assignment to assess traffic patterns in emergency response
- Identify metrics for emergency scenario comparison to guide model development
- Explore the need for seasonal trip tables

Additional new recommendations were developed based on the analyses conducted in Year 6:

- Development a Trip Generation sub-module for Special Generators in the Model, ot handle the unique characteristics of the mega-retail destination in TAZ 788 and others in Williston, Vermont.
- Add portions of the Lebanon-Hanover Census urban area to the Model as internal TAZs until external flows can be reduced to levels comparable elsewhere in the state (as part of the "halo" analysis recommended for Year 7 above)
- Investigate new sources of employment control totals statewide to use in the Model to generate TAZ employment characteristics

Year 7 will include efforts to continue the improvement of the basic Model functionality, accuracy, and effectiveness, all within its base-year of 2009-2010. Continued improvements will bring the Model closer to its goals for functionality and effectiveness.

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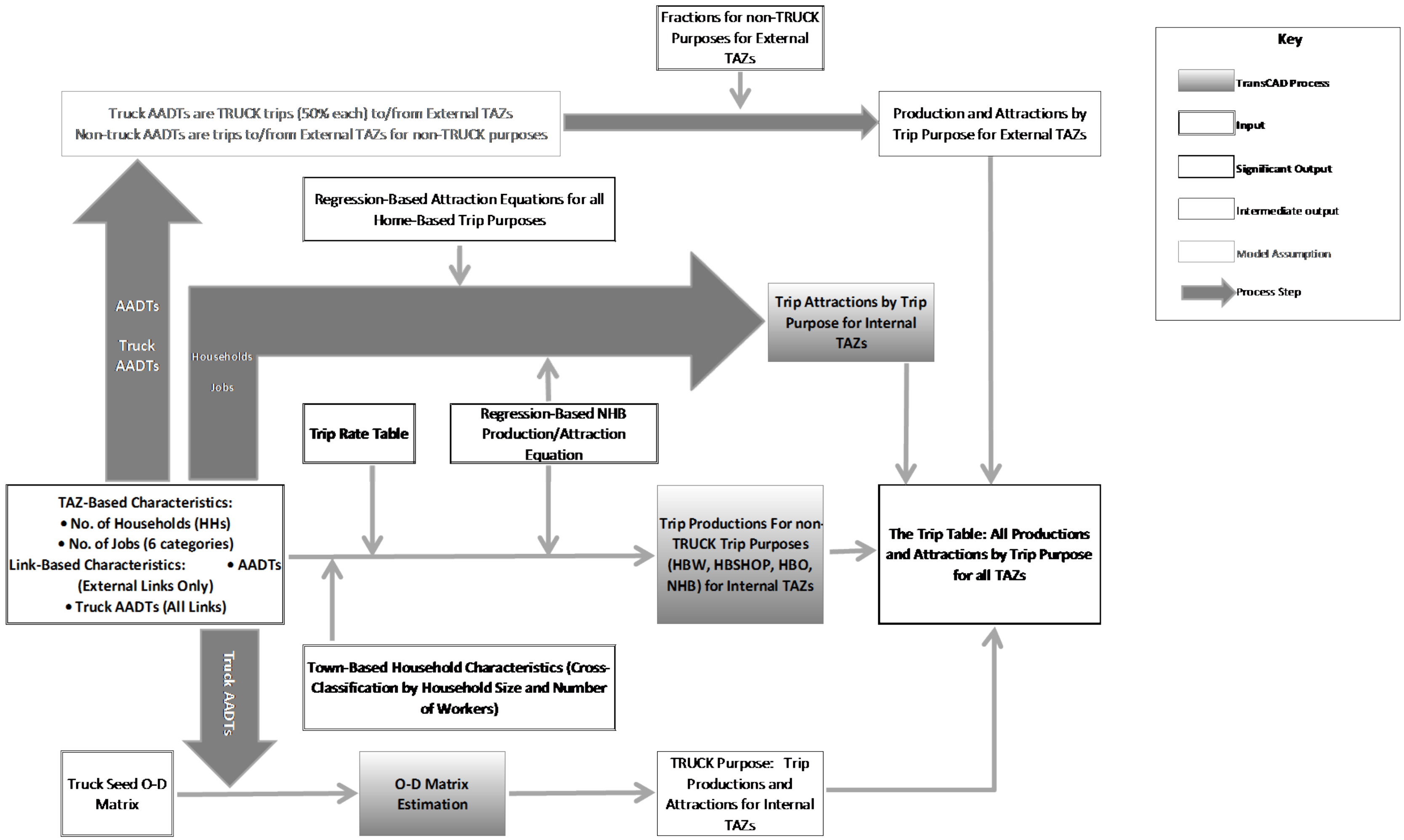
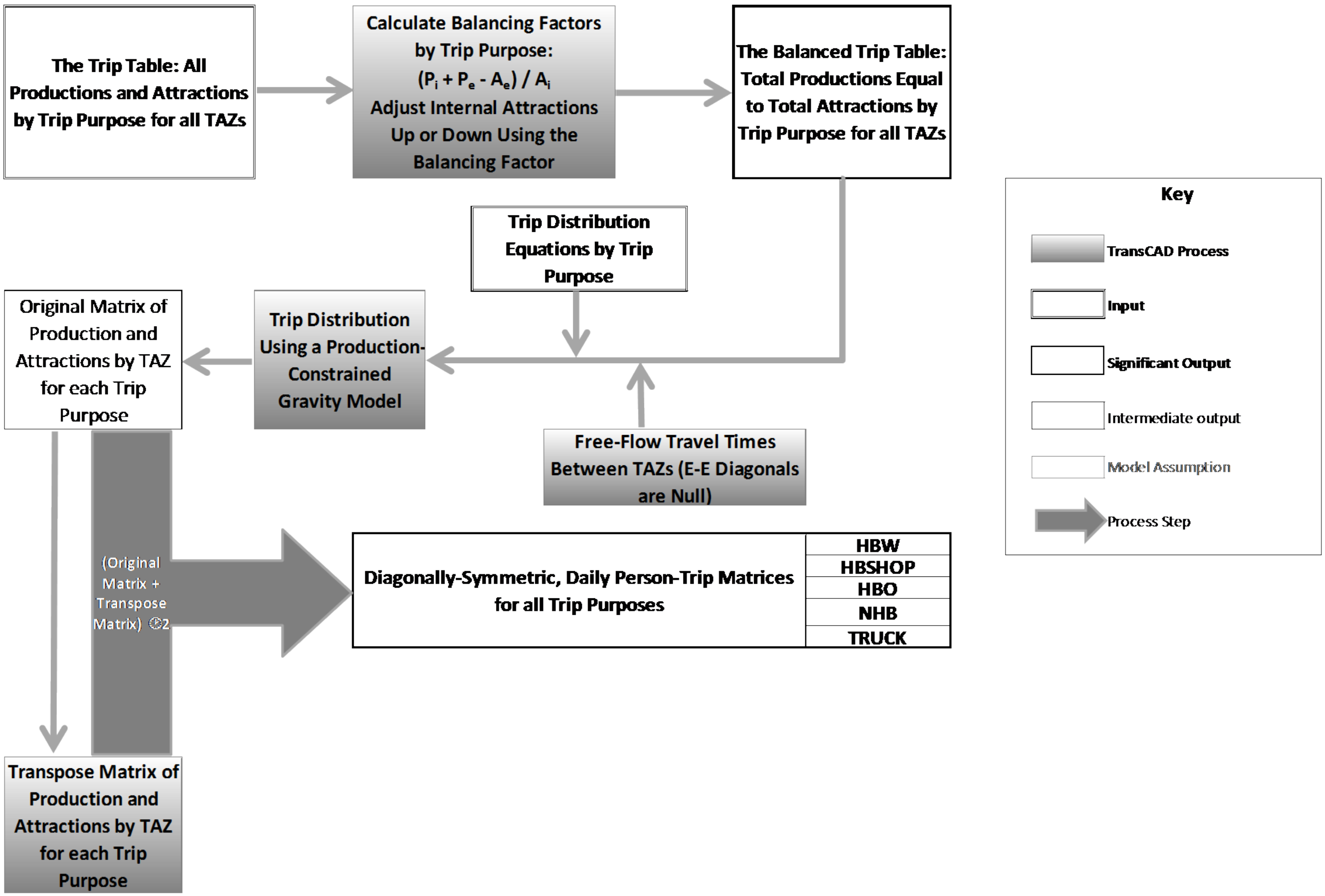
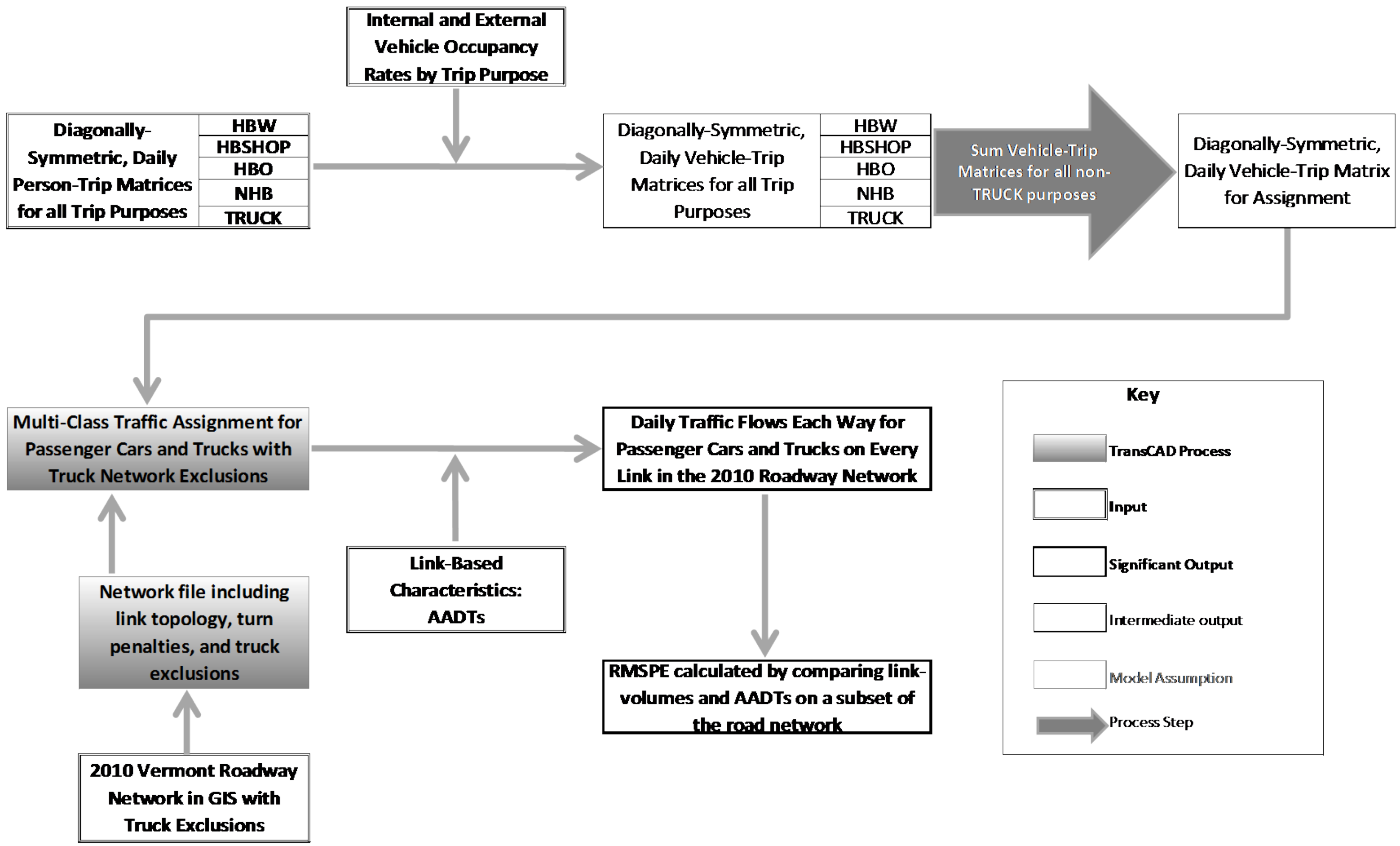
Appendix A


Fractions for non-TRUCK Purposes for External TAZs
Truck AADTs are TRUCK trips (50% each) to/from External TAZs
Non-truck AADTs are trips to/from External TAZs for non-TRUCK purposes
Production and Attractions by Trip Purpose for External TAZs
Key
TransCAD Process
Input
Significant Output
Intermediate output
Model Assumption
Process Step
Regression-Based Attraction Equations for all Home-Based Trip Purposes
AADTs
Truck AADTs
Households
Jobs
Trip Attractions by Trip Purpose for Internal TAZs
Trip Rate Table
Regression-Based NHB Production/Attraction Equation
TAZ-Based Characteristics:
• No. of Households (HHs)
• No. of Jobs (6 categories)
Link-Based Characteristics: • AADTs (External Links Only)
• Truck AADTs (All Links)
Trip Productions For non-TRUCK Trip Purposes (HBW, HBSHOP, HBO, NHB) for Internal TAZs
The Trip Table: All Productions and Attractions by Trip Purpose for all TAZs
Truck AADTs
Town-Based Household Characteristics (Cross-Classification by Household Size and Number of Workers)
Truck Seed O-D Matrix
O-D Matrix Estimation
TRUCK Purpose: Trip Productions and Attractions for Internal TAZs


The Trip Table: All Productions and Attractions by Trip Purpose for all TAZs
Calculate Balancing Factors by Trip Purpose:
$(P_i + P_e - A_e) / A_i$
Adjust Internal Attractions Up or Down Using the Balancing Factor
The Balanced Trip Table: Total Productions Equal to Total Attractions by Trip Purpose for all TAZs
Trip Distribution Equations by Trip Purpose
Original Matrix of Production and Attractions by TAZ for each Trip Purpose
Trip Distribution Using a Production-Constrained Gravity Model
Free-Flow Travel Times Between TAZs (E-E Diagonals are Null)
(Original Matrix + Transpose Matrix) 2
Diagonally-Symmetric, Daily Person-Trip Matrices for all Trip Purposes
HBW
HBSHOP
HBO
NHB
TRUCK
Transpose Matrix of Production and Attractions by TAZ for each Trip Purpose
Key
TransCAD Process
Input
Significant Output
Intermediate output
Model Assumption
Process Step



Internal and External Vehicle Occupancy Rates by Trip Purpose
Diagonally-Symmetric, Daily Person-Trip Matrices for all Trip Purposes
HBW
HBSHOP
HBO
NHB
TRUCK
Diagonally-Symmetric, Daily Vehicle-Trip Matrices for all Trip Purposes
HBW
HBSHOP
HBO
NHB
TRUCK
Sum Vehicle-Trip Matrices for all non-TRUCK purposes
Diagonally-Symmetric, Daily Vehicle-Trip Matrix for Assignment
Multi-Class Traffic Assignment for Passenger Cars and Trucks with Truck Network Exclusions
Daily Traffic Flows Each Way for Passenger Cars and Trucks on Every Link in the 2010 Roadway Network
Key
TransCAD Process
Input
Significant Output
Intermediate output
Model Assumption
Process Step
Network file including link topology, turn penalties, and truck exclusions
Link-Based Characteristics: AADTs
RMSPE calculated by comparing link-volumes and AADTs on a subset of the road network
2010 Vermont Roadway Network in GIS with Truck Exclusions