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Vermont Travel Model 2015-2016

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Vermont Travel Model 2015-2016 Report

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Disclaimer

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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 2015-2016 year (Year 8) 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 Year 8 of the contract to improve the functionality and currency of the Model. Other activities undertaken in Year 8 of the contract using the Model to support VTrans efforts, particularly analyzing the effects of construction traffic controls on regional flows, are documented separately.

The Vermont Travel Model is a series of computer sub-models which uses the land use and activity patterns within Vermont and its neighboring urban areas to estimate a typical day of travel behavior. Origin and destination matrices are created which describe the number of expected trips between geographical areas, known as traffic analysis zones (TAZs). 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 946 TAZs and 5,600 miles of highway-network links (Figure 1).

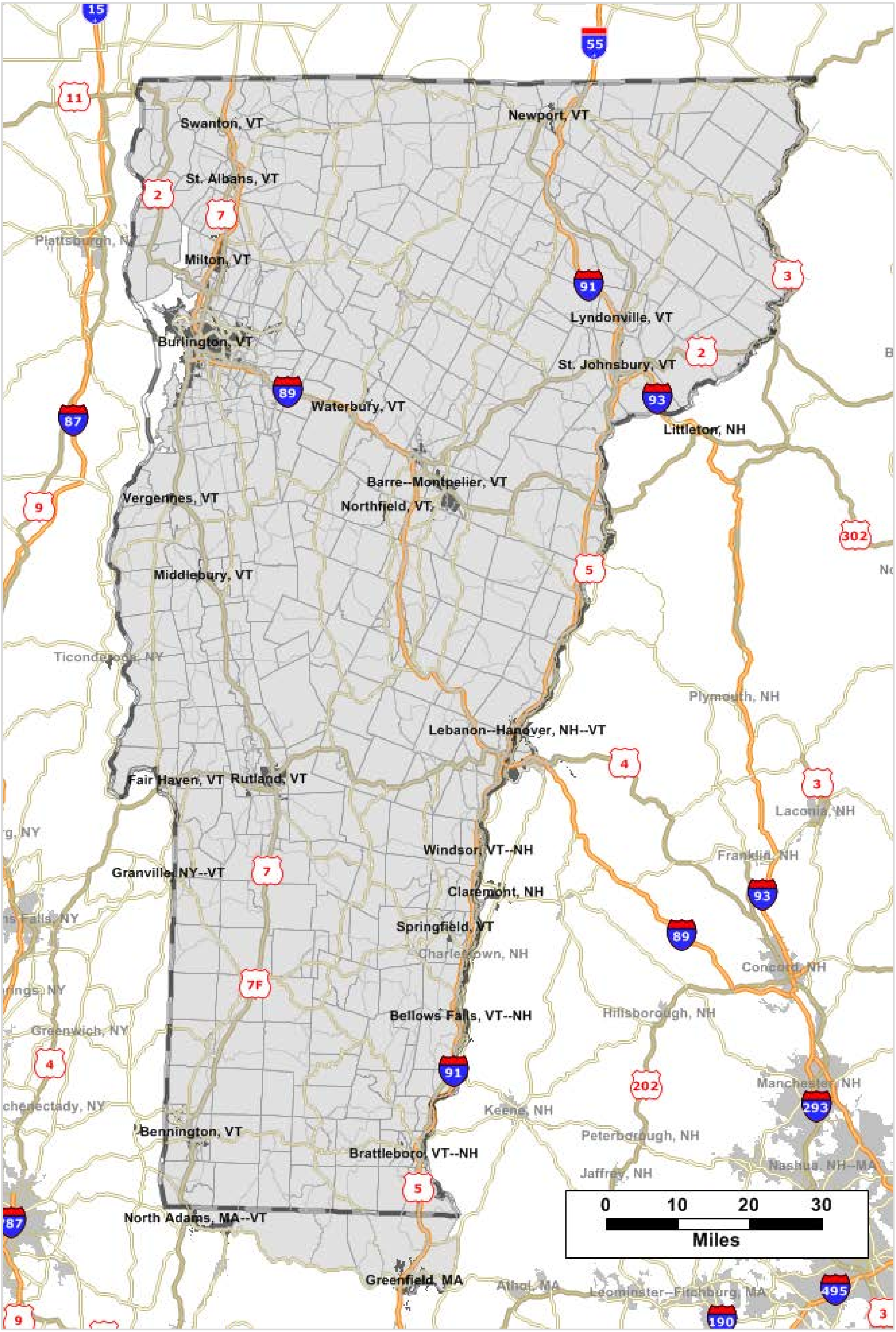

Figure 1 TAZs and Road Network in the Vermont Travel Model

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 and/or research. Daily travel demand is estimated by the Model between TAZs by trip purpose. 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) for its base-year, with a written description of its input data and a summary of its functions.

3 History of the Model and Summary of Previous Improvements

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).

In October of 2008, the 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 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).

As the data from the NHTS was released in the late summer of 2010, an 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. 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 ACS, new employment information for 2009 from the 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 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.

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. 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.

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

The Model improvements conducted in Year 6 included Model-process improvements and improvements to the network representation of the state-maintained roadways in the Model. 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:

1. The Chittenden County Regional Travel Demand Model is in TransCAD, so this change would facilitate synchronization of the two models

2. 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 addition to migrating the code, 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 utilizing an origin-destination matrix estimation (ODME) procedure, that procedure was incorporated into the Model code. 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 trip 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. This refinement improved both the speed and the accuracy of the Model.

New features added to the Model included 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 forecast-period specification 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 the associated Model outputs. A new output table was added to the Model to help users 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 allows the Model to be re-estimated and/or updated more efficiently.

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. A new distance-classification was explored with a cut-off distance of about 40 miles, with trips longer than 40 miles considered “long-distance” trips. However, existing data resources, like NCHRP 735, for creating a long-distance trip sub-model were found to be inaccurate for Vermont and inadequate for a complete specification of long-distance travel.

Continuing improvements to the network representation of the Model road network included adjustments to the locations of centroid connectors in the vicinity of the University of Vermont, one of the largest employers in the state. 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 a Google Street View Hyper-Lapse and the results improved significantly. The TAZ resolution was assessed by focusing 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 were found and two of them were split to create a new TAZ at each location. These splits were necessary because of significant development that has occurred in previously rural locations at the edges of the cities of St. Albans and Barre.

Model improvements conducted in Year 7 included significant improvements to the way trips are distributed to destinations, with the addition of new distance classifications for all non-TRUCK trip purposes. New rates and parameters which include the long-distance classification (and a "short-distance classification") were incorporated into the Model platform in Year 7. This improvement 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 was at 42.5% after the Year 7 improvements.

4 Description of the Data Used in 2015-2016

This section contains a description of the data sources used in the Model improvement activities for Year 8.

4.1 The 2010 U.S. Census Urban Areas

The new external-travel sub-module was built with the support of the GIS of 2010 U.S. Census Urban Areas (UAs) within 100 miles of Vermont (USCB, 2010a). These include UAs in Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, and Rhode Island. American Census Urbanized Areas (UA) having boundaries within 100 miles of Vermont's border and Census Urban Clusters (UC) having boundaries within 50 miles of Vermont's border were identified as potential origins or destinations of highway travel crossing Vermont's borders. The UAs and UCs selected are listed in Table 1.

Table 1 American Urbanized Areas and Urban Clusters

Urbanized Areas	Urban Clusters	
Albany-Schenectady, NY	Hoosick Falls, NY	**Lebanon-Hanover, NH**
Boston, MA-NH-RI	Ticonderoga, NY	Hudson, NY
Bridgeport--Stamford, CT-NY	**Greenfield, MA**	Keene, NH
Danbury, CT-NY	Warrensburg, NY	Corinth, NY
Dover-Rochester, NH-ME	Laconia, NH	Lake Placid, NY
Glens Falls, NY	Concord, NH	Saranac Lake, NY
Hartford, CT	Stafford Springs, CT	Catskill, NY
Kingston, NY	Granville, NY	Ravena, NY
Leominster-Fitchburg, MA	Valatie, NY	Gloversville, NY
Lewiston, ME	Coxsackie, NY	Greenwich, NY
Manchester, NH	Peterborough, NH	North Brookfield, MA
Nashua, NH-MA	Claremont, NH	Amsterdam, NY
New Bedford, MA	Hillsborough, NH	Charlestown, NH
New Haven, CT	Plattsburgh, NY	North Conway, NH
New York-Newark, NY-NJ-CT	Newport, NH	Franklin, NH
Norwich-New London, CT-RI	Athol, MA	Berlin, NH
Pittsfield, MA	Ware, MA	Malone, NY
Portland, ME	Littleton, NH	**North Adams, MA**
Portsmouth, NH-ME	Plymouth, NH	Great Barrington, MA
Poughkeepsie-Newburgh, NY-NJ	Jaffrey, NH	Lee, MA
Providence, RI-MA	Rumford, ME	South Deerfield, MA
Saratoga Springs, NY		
Springfield, MA-CT		

Urbanized Areas	Urban Clusters
Utica, NY	
Waterbury, CT	
Worcester, MA-CT	

The UA boundary files are simplified representations from the TIGER geographic database. When possible, generalization is performed with intent to maintain the hierarchical relationships among geographies and to maintain the alignment of geographies within a file set for a given year. To improve the appearance of UAs, areas are represented with fewer vertices than detailed TIGER equivalents. Some “holes” or discontinuities are removed for clarity at the regional level. Included in the GIS are the Name, Type (Urbanized Area or Urbanized Cluster), Area (sq. mi.), Land Area, and Water Area of each UA or UC (USCB, 2010a).

4.2 The 2006 – 2010 American Community Survey

The UA and UC boundaries were associated with demographic data from the American Community Survey (ACS) estimates for 2006 to 2010 (USCB, 2010b). The American Community Survey (ACS) is an ongoing survey by the U.S. Census Bureau that began in 2005 and provides data every year. The intention is to give communities the current information they need to plan investments and services. The ACS is conducted every year to provide up-to-date information about the social and economic needs of American communities between the decennial censuses.

The geographic representation of a single-year ACS for a rural state like Vermont will typically be very poor. However, ACS pooled-data can be used to obtain improved demographic, social, economic, and housing characteristics data. Since 2005, ACS data has been pooled over multiple years to produce stronger estimates for areas with smaller populations. Data are combined to produce 12 months, 36 months or 60 months of data. These are called 1-year, 3-year and 5-year data. Although single-year ACS estimates are typically only valid for areas with populations over 65,000, the pooled 5-year data is valid for populations of almost any size.

4.3 2011 Canadian Census Metropolitan Areas and Agglomerations

Canadian designated Census Metropolitan Areas (CMA) and Census Agglomerations (CA) having boundaries within 100 miles of the Vermont border were also selected as potential origins or destinations for trips crossing Vermont's borders (Statistics Canada, 2011a). A list of the CMAs and CAs selected is provided in Table 2.

Table 2 Canadian Census Metropolitan Areas (CMA) or Census Agglomerations (CA)

Name	Province
Cornwall	Ontario
Cowansville	Quebec
Drummondville	Quebec
Granby	Quebec
Hawkesbury	Ontario-Quebec
Joliette	Quebec
Lachute	Quebec
Montreal	Quebec
Ottawa-Gatineau	Ontario
Saint-Georges	Quebec
Saint-Hyacinthe	Quebec
Saint-Jean-sur-Richelieu	Quebec
Salaberry-de-Valleyfield	Quebec
Shawinigan	Quebec
Sherbrooke	Quebec
Sorel-Tracy	Quebec
Thetford Mines	Quebec
Trois-Riviures	Quebec
Victoriaville	Quebec

4.4 The 2011 Canadian Census and National Household Survey

As with the American Community Survey in the US, the National Household Survey in Canada provided a more thorough set of socioeconomic and demographic data than the Census for a sample of Canadian households. The Canadian NHS was introduced as an alternative to replace the long form of the Census and was first administered in 2011 as a supplement to the 2011 Census. Topics covered in the NHS include demographics, family structure, households, ethnicity, language, aboriginal peoples, mobility, education, labor, place of work, commuting, income, housing costs. The survey targeted 4.2 million households in Canada with a 77% response rate across the country (Statistics Canada, 2013). The information provided by the National Household Survey is weighted to the population Census and aggregated to represent each Census Metropolitan Area and Census Agglomeration geographical area. These data and the Census outcomes for

2011 were acquired from Statistics Canada for the selection of CMAs and CAs in Table 2. In addition, it is important to note that unlike the decennial US Census, the Canadian Census is administered every 5 years, so updated information will be available for 2016.

4.5 2010 Massachusetts and New Hampshire Employment Data

As the new external travel sub-module was being developed, it was determined that 3 of the urban clusters in Table 6 either included within Vermont (North Adams & Lebanon-Hanover) or represented a major uninterrupted destination with Vermont (Greenfield). Therefore, it was decided that these UCs should be absorbed into the internal structure of the Model. Due to the proximity of North Adams and Greenfield, Massachusetts, the non-urban towns between these two UCs were included also. Building TAZs to represent these new internal areas required access to employment data for Massachusetts and New Hampshire.

New Hampshire tracks employment similarly to Vermont, making its town-by-town data available online through its Economic and Labor Market Information Bureau of the New Hampshire Employment Security Division at http://www.nhes.nh.gov/elmi/statistics/qcew-data.htm. Covered employment & wage data by industry for workers covered by unemployment insurance was obtained for Lebanon and Hanover for 2010. This data is based on Quarterly Census of Employment and Wages (QCEW) program files extracted from quarterly tax and wage reports submitted by employers in the town. Massachusetts makes its employment and wage data available through the website of the Executive Office of Labor and Workforce Development (EOLWD) at http://lmi2.detma.org/lmi/lmi_es_a.asp. These data are derived from reports filed by employers subject to unemployment compensation laws, both state and federal. Industry employment and payroll information is produced both quarterly and annually and aggregated for the cities and towns by NAICS code.

4.6 Employment and Population Growth Forecast Data for New Hampshire and Massachusetts

Before these new UCs in Massachusetts and New Hampshire could be completely integrated into the Model, forecast growth rates were needed for population, households, and employment.

Both states publish 10-year growth projections for employment by 2-digit NAICS code by county through the same data sources as their historical employment data. The final growth rates obtained for the Franklin/Hampshire County Workforce Development Area in Massachusetts are shown in Table 3.

Table 3 Annual Growth Rates by Model Employment Category for Massachusetts TAZs

Model Employment Category	Annual Growth Rate to 2022
Retail	0.90%
Manufacturing	-0.34%
Government	1.20%
Education	0.79%
Non-Manufacturing	1.47%

The final growth rates obtained for Grafton County, New Hampshire are provided in Table 4.

Table 4 Annual Growth Rates by Model Employment Category for New Hampshire TAZs

Model Employment Category	Annual Growth Rate to 2022
Retail	0.41%
Manufacturing	-0.06%
Government	-0.08%
Education	0.71%
Non-Manufacturing	1.40%

Although many of our uses of the Model require a longer-term forecast than 2022, these rates will be used to represent growth for all of the Model forecasts, since better forecast rates are not available beyond 2022.

Population and household growth forecasts were obtained from a different source for each state. For Massachusetts, long-term forecasts were projected for the states regions and municipalities by the University of Massachusetts' Donahue Institute (Renski et. al., 2013). Forecast growth rate for households in the Model was assumed to correspond with predicted growth in population to 2030 for the Berkshire/Franklin County region, which is 0.00%.

For New Hampshire, a population projection was conducted in 2013 by RLS, Inc. (RLS, 2013). From this project, the specific forecasted growth rate for Grafton County of 0.30% per year to 2040 was used (RLS, 2013).

4.7 Traffic Counts for Massachusetts and New Hampshire

Traffic counts were needed to validate the traffic assignment step in the Model with the new links that had been added to the internal road network in New Hampshire and Massachusetts. A GIS with AADTs for 2010 was obtained for each of these states and those AADTs that corresponded with links added to the Model road network were imported so that they would be included in the calculation of the RMSPE. AADTs at new external centroid connectors were also imported to support the modeling of external travel.

For Massachusetts, the updated statewide road inventory GIS with AADTs through 2014 was obtained from the Massachusetts DOT at http://www.massdot.state.ma.us/planning/Main/MapsDataandReports/Data/GISData/RoadInventory.aspx. Unfortunately, AADTs for 2010 were not available, so AADTs for 2011 were used instead. For New Hampshire, a GIS of all public roads is available from its Geographically Referenced Analysis and Information Transfer System (GRANIT) at http://www.granit.unh.edu/data/search. This GIS includes AADTs for a specifically requested year. To obtain AADTs for 2010, a special request was made to GRANIT to access archived data.

To support an improvement to the medium- and heavy-truck travel sub-module of the Model, truck counts from individual automatic traffic recorders for 2014-2015 were needed, both inside Vermont and for the internal TAZs in Massachusetts and New Hampshire. Specific truck counts for New Hampshire could not be found, after a thorough review of both the GRANIT system and the traffic volume reports at https://www.nh.gov/dot/org/operations/traffic/tvr/locations/index.htm. Massachusetts truck traffic counts were available by specific automatic traffic recorder (ATR) location on their online tool for accessing all traffic data at http://mhd.ms2soft.com/tcds/tsearch.asp?loc=Mhd&mod=.

5 Improvements Methodology and Results

Model improvements undertaken in Year 8 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 Improved the TRUCK travel sub-module to allow growth

2 Calibrated and validated the expanded Model

3 Completed the analysis to support development of an external-travel sub-module

5.1 Improved the TRUCK Travel Sub-Module to Allow Growth

The TRUCK travel sub-module previously was an ODME that came from counts, and made use of external counts at external TAZs. However, those methods do not allow growth in truck travel in Vermont to be modeled consistently with the way growth is modeled in passenger car travel. This omission was creating problems when the Model was used in a forecast, because the Model was showing stable truck volumes in parts of the state where the forecast would otherwise have called for a decrease, due to a reduction in manufacturing employment. Recent Model runs in support of VTrans efforts to understand future highway flow volumes have suffered from poor estimation of future-year truck traffic. Therefore, a new sub-module for truck travel modeling was needed.

The goal of this effort was to improve the sub-module for estimating truck traffic volumes so it is based on one or more forecast-able attributes of TAZs. The procedure followed to generate a new regression-based truck travel sub-module was taken from a procedure implemented for the Connecticut Travel Demand Model in 2004 (Aultman-Hall et. al., 2004). First truck counts throughout the state were gathered for the years including 2009-2013. Truck counts beyond the base year of the Model had to be included to provide enough counts to perform reliable regression estimations. These nearly 1,400 counts were then all represented as daily 2-way truck traffic flows and regressed against existing TAZ characteristics of population and employment for the 2009-2010 base year. One of the findings of the regression analysis was that truck trips were most strongly correlated with retail employment and households. The regression also showed a strong disincentive for truck trips to be produced in TAZs with educational employment, possibly due to restrictions in truck travel around schools. The regression coefficients in

Table 5 were determined for production and attraction of truck trips in the Model.

Table 5 Regression Coefficients for Truck Trip Generation

Variable	P	A
Households	0.187	0.176
Retail Jobs		
Manufacturing Jobs	0.088	0.226
Non-Manufacturing Jobs	0.140	0.117
Government Jobs		0.144
Primary School Jobs		-0.307
University Jobs	0.187	0.176

Truck trip productions will be estimated from manufacturing and non-manufacturing employment, university employment, and households. Truck trip attractions will be estimated from each non-retail employment category and households, including a negative relationship to educational (primary school) employment. These estimations will be made for the base year, and growth/change in these categories will be used to forecast growth in truck trip generation.

Model-Year	Sum	Min	Max	Mean	Std Dev.
Previous Truck Trip-Generation Sub-Module					
Base (2010) Productions	240,342	0	1,763	269	197
2030 Productions	240,342	0	1,763	269	197
Base (2010) Attractions	240,342	0	3,314	256	388
2030 Attractions	240,342	0	3,314	256	388
Updated Truck Trip Generation Sub-Module					
Base (2010) Productions	102,750	0.0	1,990	109	136
2030 Productions	108,277	0.0	2,298	114	141
Base (2010) Attractions	102,750	0.0	1,497	111	123
2030 Attractions	108,277	0.0	1,267	117	120

Without a growth-oriented sub-module, the previous truck trip-generations remained constant. The updated sub-module allows the trip productions and attractions to grow at a rate that is consistent with growth in employment and population predicted in economic forecasts. Additionally, it is clear from the trip sums that far fewer truck trips are estimated for the base-year when the regression method is used. This outcome is the result of a method that is not biased heavily to the locations where truck counts were available for the base year. So locations where truck counts are not available are now estimated based on their employment and population, not considered equivalent to the locations that were counted. This change is important because it removes the heavy reliance on truck counts in the base year. It is likely that these truck counts were more heavily focused on locations where truck traffic is expected, and avoided roadways with truck restrictions entirely. This practice creates a natural bias toward higher truck trip totals. In the previous sub-module, truck trips accounted for 10.7% of all travel demand, but now only account for 4.3%. This level of demand is more realistic because it does not assume that roadways with truck counts are as likely to carry truck traffic as those without. Therefore, the regression-based sum is a more accurate base-year value, and forecasts growth between 2010 and 2030 that is consistent with the growth expected in employment and households.

5.2 Calibrated and Validated the Expanded Model

One of the short-term recommendations that came from the TMIP peer review of the Vermont Travel Model in Year 5 was to expand the spatial boundary of the Model as necessary to include important "halo" populations. This analysis consisted of the identification of urban areas and highways to consider for inclusion in the Model boundary, and then the addition of important contiguous UAs as internal TAZs and critical nearby roadways as links in the Model road network. Extensive discussion of the roadways and urban areas identified for inclusion in the Model boundary is provided in the 2014-2015 Model report (Sullivan and Sentoff, 2015).

As a result of the “halo” analysis, ten (10) new internal TAZs were created in the Model. All of these TAZs are entirely beyond Vermont’s border, in the neighboring states of New Hampshire and Massachusetts. New TAZs were drawn with careful consideration of UC & town boundaries, major highways, and prevailing travel patterns expected in each of the regions. These new TAZs are illustrated in Figure 2.

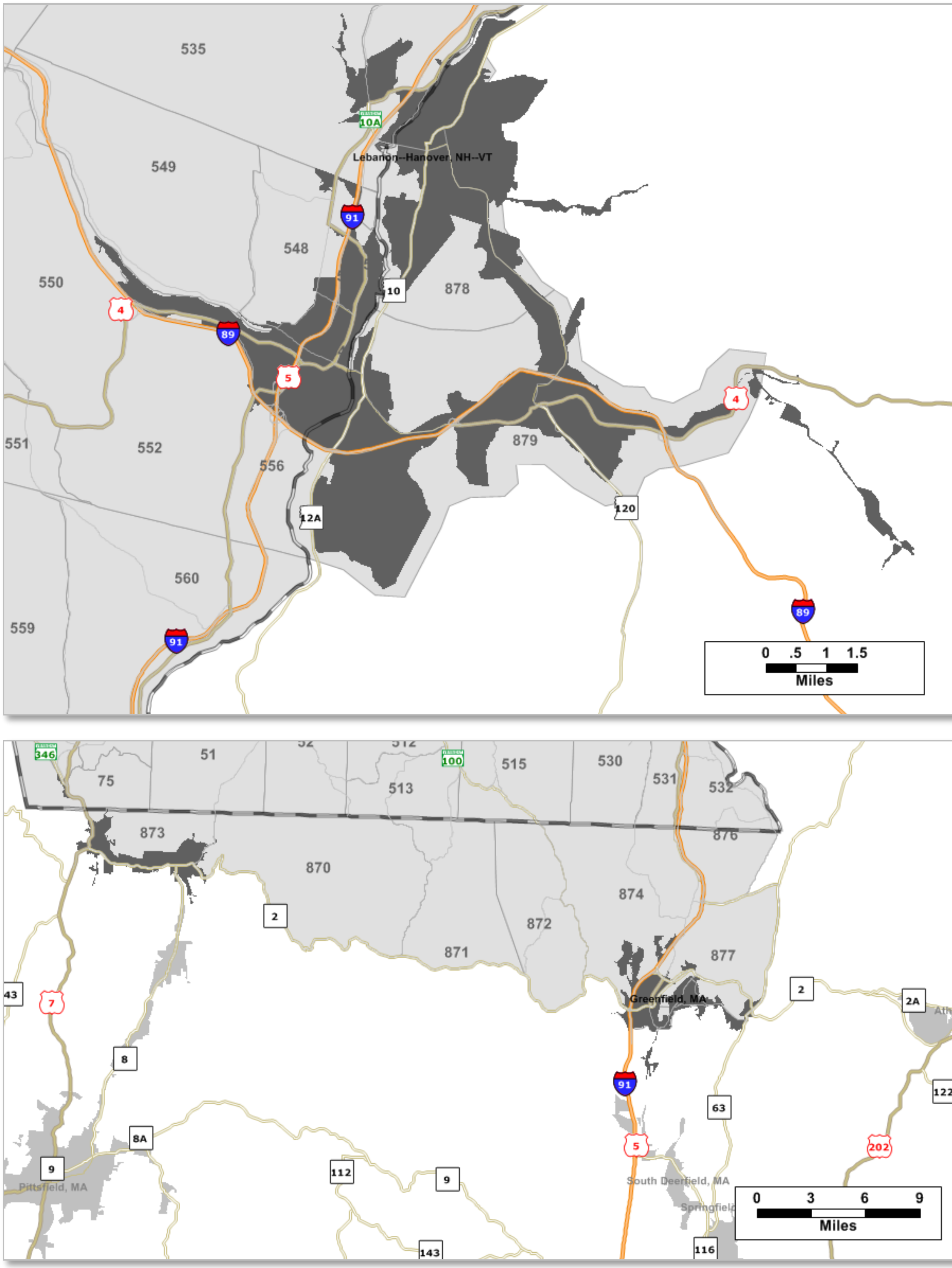

Figure 2 New TAZs Resulting from the "Halo" Analysis

Once the new TAZs had been drawn and travel patterns were established from preliminary Model runs, it was determined that aggregating all of the Greenfield UA into a single TAZ was not feasible. So TAZ 875 was divided into three TAZs to represent the Greenfield UA, creating new TAZ IDs 880 and 881, with the final configuration shown in Figure 3.

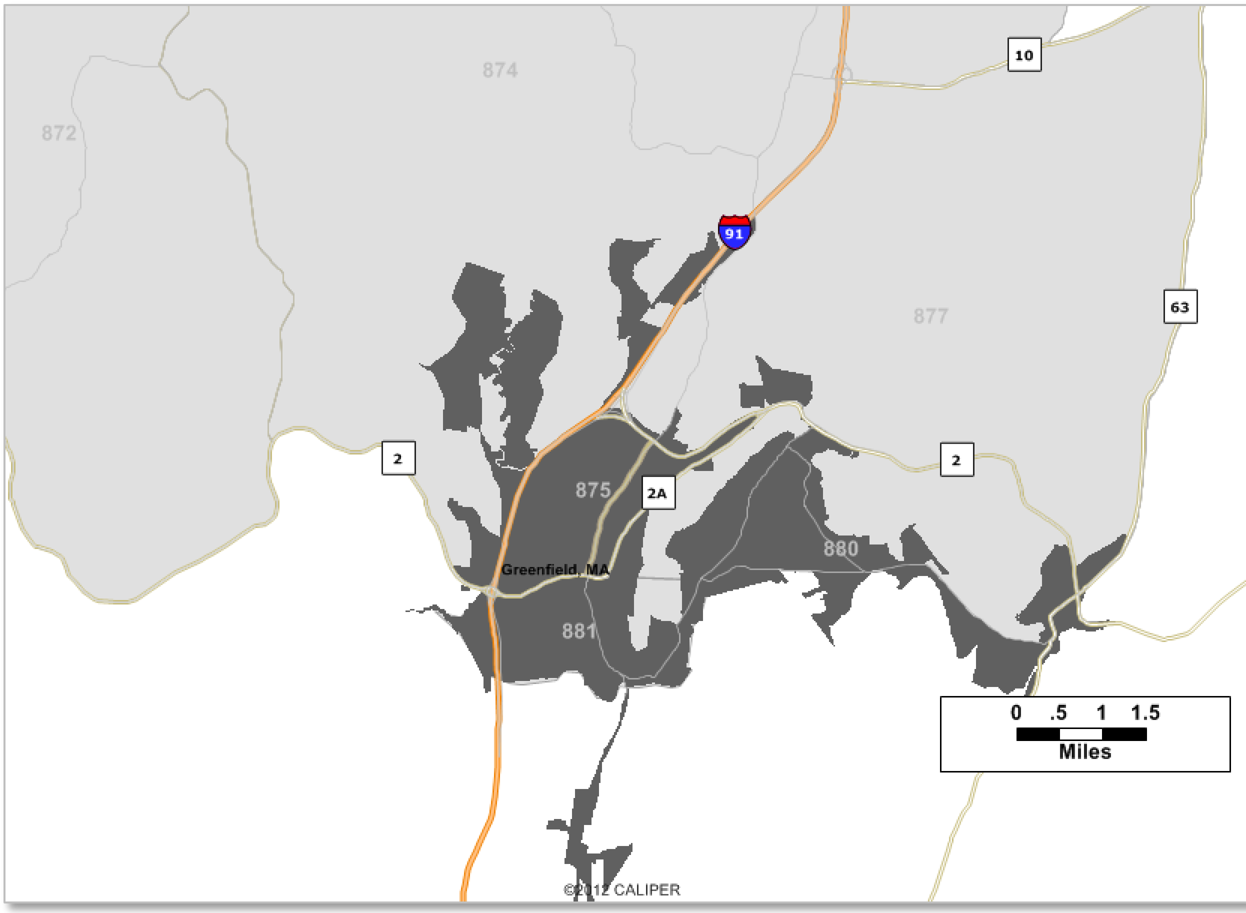

Figure 3 Final TAZ Configuration in Greenfield, Massachusetts

The final list of new TAZs created in the Model is provided in Table 6.

Table 6 New Internal TAZs Added from the "Halo" Analysis

New TAZ ID	Town or City	State
870	Rowe	Massachusetts
871	Heath	Massachusetts
872	Colrain	Massachusetts
873	North Adams	Massachusetts
874	Leyden	Massachusetts
875	Greenfield	Massachusetts

New TAZ ID	Town or City	State
876	Bernardston	Massachusetts
877	Gill	Massachusetts
878	Hanover	New Hampshire
879	Lebanon	New Hampshire
880	Greenfield	Massachusetts
881	Greenfield	Massachusetts

The benefit in expanding the Model boundary can be assessed by evaluating the change in traffic flows over the boundary after the expansion. Before the boundary was expanded, it coincided precisely with Vermont's political boundary, which created a relatively high-volume external link into the Lebanon/Hanover UA, at 47,941 vehicles per day (vpd). This daily volume is higher than any of the daily volumes that were internal to the Model. One of the most highly traveled corridors in the state was relatively under-defined in the Model, since it crossed the external boundary. Before the expansion, the average traffic flow across all of the Model external links was 4,291 vpd.

Following the expansion of the Model boundary to include, amongst others, the Lebanon/Hanover UA, the highest daily volume on any of the Model's external links is 29,939 vpd, and the average traffic flow across all of the external links in the Model is 4,071 vpd. Therefore, more of the regional travel is now captured by the Model than had been previously.

The Model is validated by comparing assigned traffic volumes to traffic counts where AADTs are available throughout the state. This comparison is calculated using the root-mean-square percent error:

$$RMSPE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\frac{Y_n^S - Y_n^O}{Y_n^O}\right)^2}$$

Where N is the number of observations, or traffic counts Y^o and Y^s is the corresponding model traffic volume. The goal of the Model improvement task is to maintain an RMSPE under 50%. The current RMSPE of the expanded model after the traffic assignment module is 43.9%. This value represents a slight change in the accuracy of the Model from the best RMPSE of 42.5%. This slight decrease in accuracy was expected since the new TAZs outside of Vermont are not as highly resolved as those inside the state's political boundary, making the trip-generation step less precise. In addition, the NHTS data, upon which the travel behaviors in the Model are built, did not include respondents from outside of Vermont, so it would be expected that the travel behavior of drivers in Massachusetts and New Hampshire differ from those in Vermont slightly.

5.3 Completed Analysis to Support Development of an External-Travel Sub-Module

In concert with the halo analysis that has been completed and resulted in an expansion of the Model boundary, improvements in the way that external travel (external-internal, internal-external, and external-external) is modeled and forecasted are desperately needed. Since the base-year sub-module for estimating external (E-I, I-E, and E-E) flows is based entirely on AADTs at the Model boundary, growth cannot be forecasted accurately. The goal of this effort is to improve the sub-module for estimating external volumes so it is based on one or more forecast-able attributes of regional urban areas that represent likely origins and destinations of external travel in the Model. More detailed information on the origins and destinations of external travel in the Model will also allow these trips to be more accurately distributed within Vermont.

The primary constraint of the effort is to make use of data that is already available for other Model procedures. Therefore, the development of this sub-module focused on the use of ACS data from the surrounding Census UAs and UCs and comparable Census and NHS data for CMAs and CAs in Canada. Each of these data sets is easily accessible and is expected to be available in the foreseeable future. The ACS data is used extensively in the Model for a variety of other trip generation processes.

Before assembling the final data set of regional external destinations for the Model, the likely destinations represented by external TAZs were adjusted so that all external TAZs mapped to one or more UAs or UCs. Previously, some of the external TAZs in extremely rural areas in NY, NH, and QC were mapped to very small towns that did not qualify as UAs or UCs. A summary of these adjustments is provided in Table 7.

Table 7 Summary of External TAZ Re-Mapping

TAZ	Previously Mapped to…	Was Re-Mapped to UAs and UCs…
962	Cambridge, NY	Greenwich, NY
953	Warren, NH; Haverhill, NH	Plymouth, NH
936	Pittsburg, NH	Saint-Georges, QC; Thetford Mines, QC
988	Mansonville, QC	Sherbrooke, QC; Cowansville, QC; Granby, QC

For these very small towns, ACS data is not available at the same level of quality that it exists for UAs and UCs. In addition, we would not expect external travel in the Model to be destined for a very small external town. A primary assumption of this effort is that as trip length increases for I-E, E-I, and E-E trips, the likely destination size increases.

With all of the external TAZs mapped to likely external regional UAs and UCs, a final dataset was assembled which consisted of the AADT at each external link and a variety of the demographic characteristics associated with its destinations. The final data set contains the following critical attributes for each of the UAs and UCs in the Vermont region for 2010:

- Total population
- Median age of population
- Population 16 and under
- Population 65 and over
- Male population
- Female population
- Total no. of workers (16 years and over)
- No. of workers who drive car, truck, or van to work
- Aggregate drive to work (in minutes)
- Average drive to work (minutes)
- No. of workers in households with no vehicle available
- No. of workers in households with 1 vehicle available
- No. of workers in households with 2 vehicle available
- No. of workers in households with 3 vehicle available
- No. of workers in households with 4 vehicle available
- No. of workers in households with 5+ vehicle available
- No. of passenger vehicles (car, truck, or van) used in commuting
- No. of workers who drove alone to work
- No. of workers who carpooled to work
- No. of workers who took public transportation to work
- No. of workers who walked to work
- No. of workers who took other to work

- No. of workers who worked at home
- Median age of workers
- Median 12-month earnings of workers ($)
- Total no. of households
- Total no. of family households
- No. of households with no vehicle available
- No. of households with 1 vehicle available
- No. of households with 2 vehicle available
- No. of households with 3 vehicle available
- No. of households with 4+ vehicle available
- Family households with children
- Non-family households
- Households with one person living alone
- Households with children
- Households with individuals 65 and over
- Average household size
- Aggregate household income in the past 12 months (4)
- Husband-wife families
- Husband-wife families with children
- Average family size

Urbanized areas in the Vermont region in New England include UAs as large as the New York City metropolitan area, with 18.4 million people in New York, New Jersey, and Connecticut, and as small as the urban cluster of Charlestown, New Hampshire, with only 2,280 people.

The following critical attributes for each of the CMAs and CAs in the Vermont region of Canada for 2011:

- Total population

- Total private dwellings
- Population density per square kilometer
- Median age of population
- No. of workers
- No. of workers who worked outside Canada
- No. of workers who drove a car, truck or van to work
- No. of workers who rode in a car, truck or van to work
- No. of workers who took public transit to work
- No. of workers who walked to work
- No. of workers who biked to work
- No. of workers who took other modes to work
- Median commuting duration (minutes)
- Median worker income ($)
- Average worker income ($)
- Median employment income in 2010 ($)
- Average employment income in 2010 ($)
- Family income in 2010
- Median family income ($)
- Average family income ($)
- Average family size
- Average household size
- Median household total income ($)
- Average household total income ($)

Urbanized areas in the Vermont region in Quebec and Ontario, Canada range from Quebec's largest city of Montreal, with 3.8 million to Hawkesbury, Ontario with only 10,551 people.

In Year 9, the AADTs at the Vermont border will be used to narrow these lists to a smaller set of attributes that best correlate with travel into or through Vermont. Regression will be used to narrow the lists, using the AADTs at the Vermont border as the dependent variable. From this smaller set of attributes, a gravity-model distribution will be used to distribute trips from Vermont's borders to/from the urbanized areas in Table 1 and Table 2.

6 Summary and Recommendations

The Model improvements conducted in Year 8 included the development and implementation of a new truck sub-module for truck trip generation, the calibration and validation of the Model with its new expanded boundary, and the completion of the initial analysis of external regions to support development of an external-travel sub-module in Year 9.

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 9 based on the short-term recommendations from the peer review and the accomplishments in Year 8:

- Complete the external travel sub-module;
- Calibrate the Model to 2015 as a “forecast year”, using actual 2015 traffic counts, 2015 population and employment estimates, and 2015 cross-class tables from the American Community Survey;
- Consider the use of seasonal trip tables in the Vermont Travel Model and analyze all supporting Model data by season to see if a bi-annual Model is feasible;
- Identify metrics for emergency scenario comparison to guide model development;
- Update all Model elements and modules to the most current version of Caliper’s TransCAD in order to utilize new software functionality.

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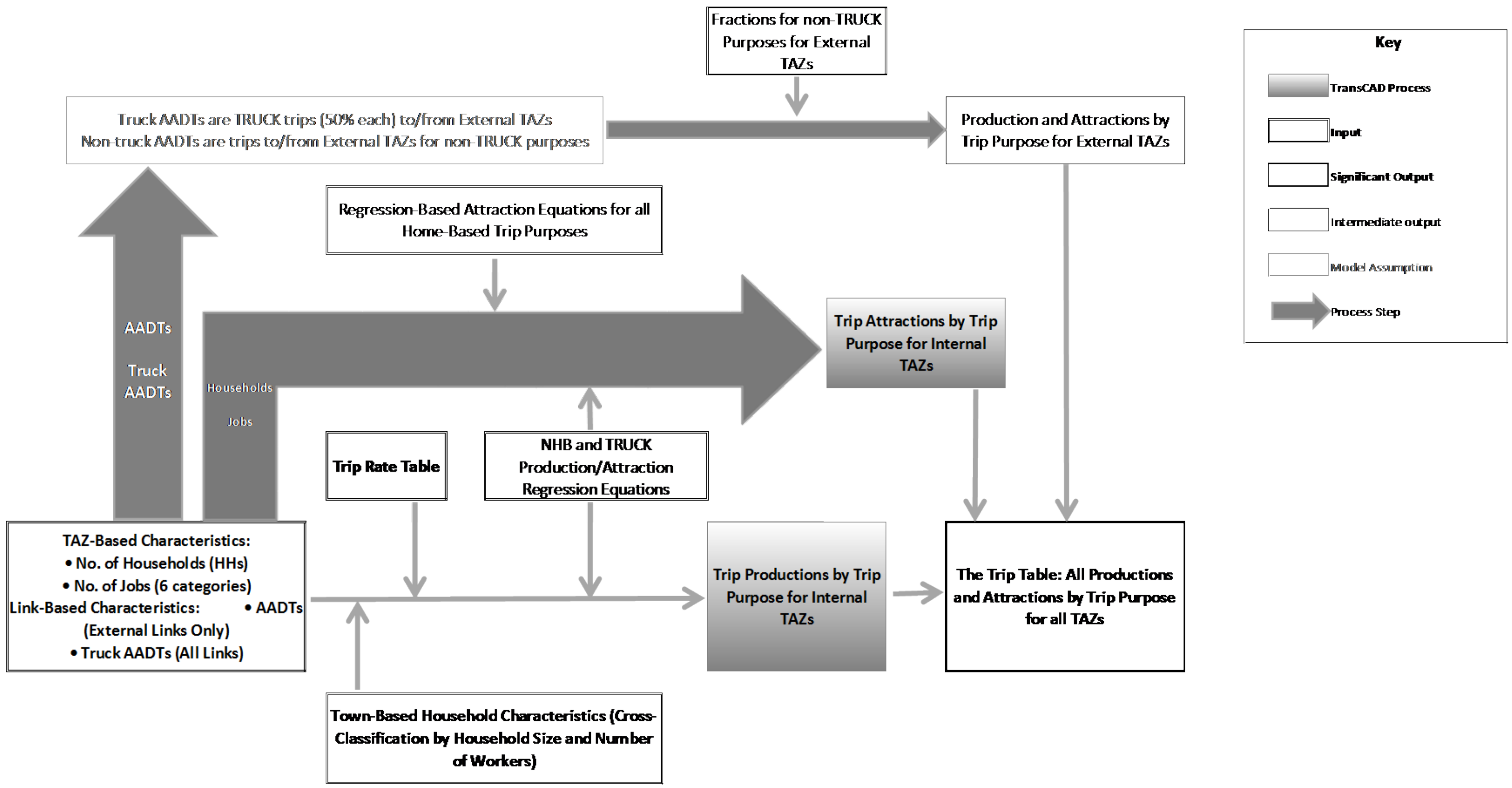
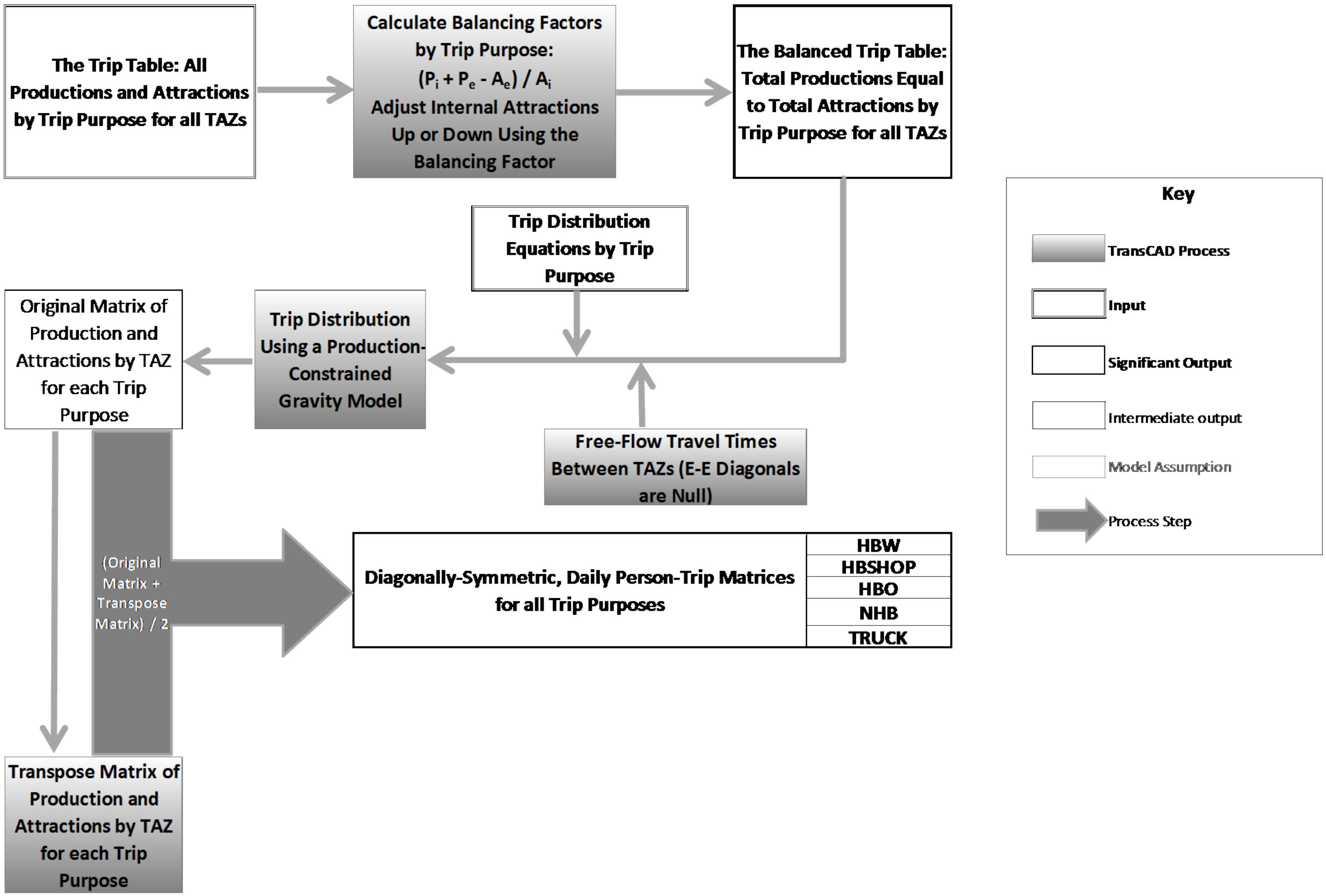
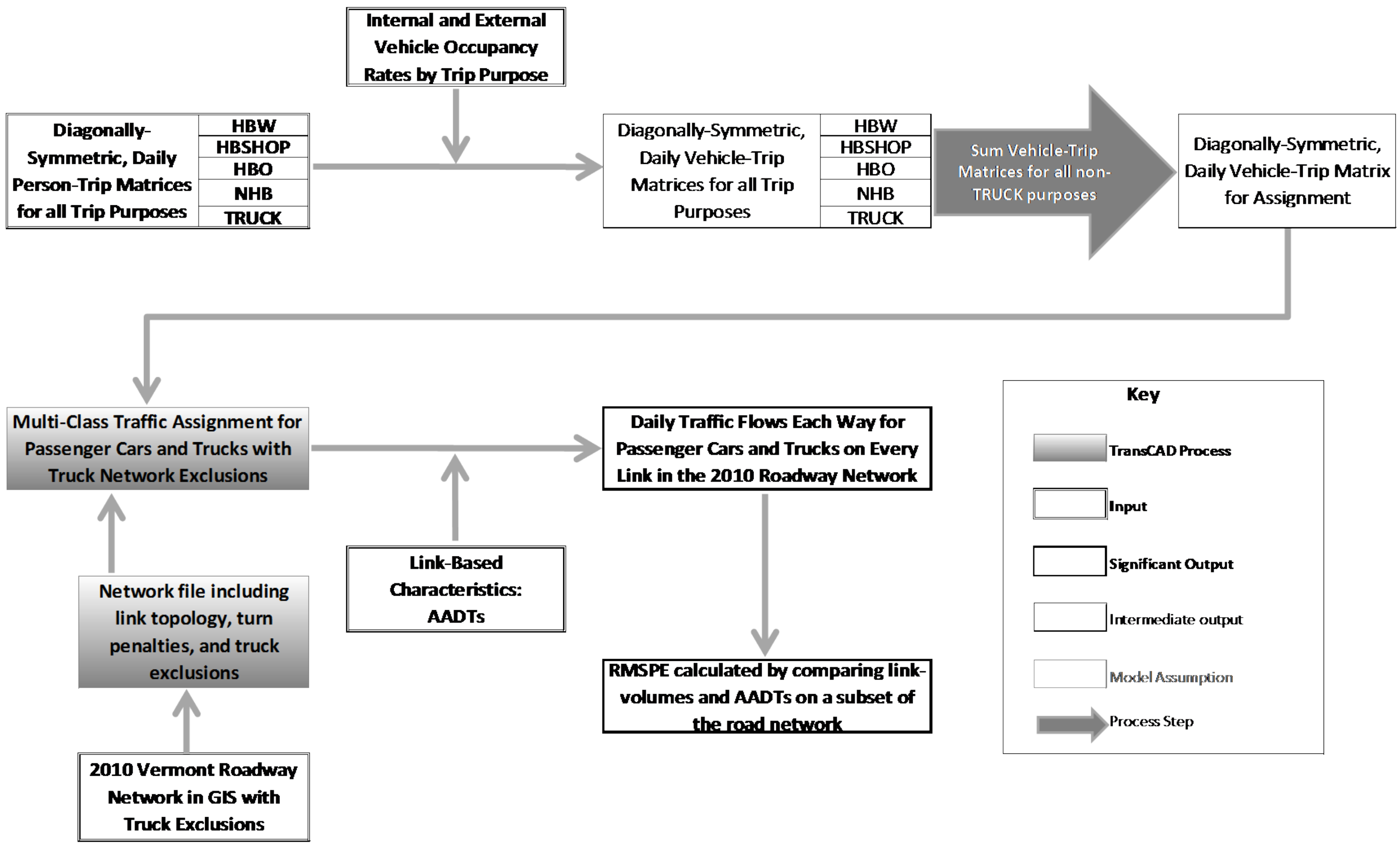
Appendix A – Description of the Model


Fractions for non-TRUCK Purposes for External TAZs
Key
TransCAD Process
Input
Significant Output
Intermediate output
Model Assumption
Process Step
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
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
NHB and TRUCK Production/Attraction Regression Equations
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 by Trip Purpose for Internal TAZs
The Trip Table: All Productions and Attractions by Trip Purpose for all TAZs
Town-Based Household Characteristics (Cross-Classification by Household Size and Number of Workers)



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
Link-Based Characteristics: AADTs
Network file including link topology, turn penalties, and truck exclusions
2010 Vermont Roadway Network in GIS with Truck Exclusions
RMSPE calculated by comparing link-volumes and AADTs on a subset of the road network
Key
TransCAD Process
Input
Significant Output
Intermediate output
Model Assumption
Process Step

Summary

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; and two distance classifications: long-distance and short-distance. Trip generation estimations are based on the 2010 US Census, the 2009 National Household Travel Survey (NHTS), the 2006-2010 American Community Survey (ACS), 2009 data from the Department of Employment and Training of the Vermont Department of Labor (VDOL), and 2009 data from the Bureau of Economic Analysis (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 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 are not passable for heavy trucks. Therefore, the multi-class assignment is used to allow passenger cars to use the entire network while preventing trucks from using links where they are prohibited.

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.

The Model can also be used to run a forecast, run a scenario, and calculate the Network Robustness Indices (NRIs) of links in the forecast-year. The forecast process is initiated by selecting a number of years from 2010 for the forecast to run. The Model then uses default growth rates to increase population and employment in each TAZ to represent the forecast-year growth. Then the Model processes are repeated using the forecasted population and employment. The scenario run implements a select-link analysis (SLA) for a prescribed set of links in the typical traffic assignment step for the forecast-year, outputting a set of towns that utilize the scenario links on a typical day. Then, adjusted capacities and/or travel-times for the scenario links are used in a second traffic assignment step for the forecast-year, to output the effects that the adjustments will have on traffic flows in the region. If the NRI run is selected for the forecast-year, the NRI is calculated for a prescribed set of links.

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 for both long- and short-distance classifications. 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 for both long- and short-distance classifications, each of which utilizes a different set of employment and/or population field(s) from the TAZ characteristics table.

<table>
<tr><th rowspan="2">Variable</th><th colspan="4">Long-Distance</th><th colspan="4">Short-Distance</th><th colspan="2">Truck</th></tr>
<tr><th>NHB (P/A)</th><th>HBW (A)</th><th>HB SHOP (A)</th><th>HBO (A)</th><th>NHB (P/A)</th><th>HBW (A)</th><th>HB SHOP (A)</th><th>HBO (A)</th><th>P</th><th>A</th></tr>
<tr><td>No. of Households</td><td></td><td></td><td></td><td></td><td>0.98</td><td></td><td></td><td>2.24</td><td>0.19</td><td>0.18</td></tr>
<tr><td>Retail Jobs</td><td>0.37</td><td rowspan="6">0.03</td><td>0.25</td><td></td><td>2.84</td><td rowspan="6">0.50</td><td>3.58</td><td></td><td></td><td></td></tr>
<tr><td>Manufacturing Jobs</td><td></td><td></td><td></td><td></td><td></td><td></td><td>0.09</td><td>0.23</td></tr>
<tr><td>Non-Manufact. Jobs</td><td></td><td></td><td>0.08</td><td>0.41</td><td></td><td>0.13</td><td>0.14</td><td>0.12</td></tr>
<tr><td>Government Jobs</td><td></td><td></td><td></td><td>0.25</td><td></td><td></td><td></td><td>0.14</td></tr>
<tr><td>Primary Sch. Jobs</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-0.31</td></tr>
<tr><td>University Jobs</td><td></td><td></td><td></td><td>0.98</td><td></td><td></td><td>0.19</td><td>0.18</td></tr>
</table>

For example, the equations for home-based work (HBW) trips attracted are based on all of the employment fields in the TAZ characteristics table, but the equations for home-based shopping (HBSHOP) trips are based solely on the retail employment field. Truck (TRUCK) productions and attractions are calculated from regression equations which utilize a different set of employment and/or population field(s) from the TAZ characteristics table. The distance classification is not applied to the estimation of truck trips in the Model, since our expectation is that the exponential distribution function handles all distances well.

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 8 trip purposes (4 main purposes x 2 distance classifications) using the following fractions:

- HBW – short-distance: 10%
- HBW – long-distance: 2%

- HBSHOP – short-distance: 19%
- HBSHOP – long-distance: 3%
- HBO – short-distance: 26%
- HBO – long-distance: 6%
- NHB – short-distance: 28%
- NHB – long-distance: 6%

Ultimately, this process outputs a table of productions and attractions for each of the ten trip purposes in the Model for each of the 943 internal and external zones. However, since the production and attraction estimates for the internal TAZs came from different sources, 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 by 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 ten trip purposes in the Model for each zone. Summary statistics of the balanced trip production/attraction table are provided in the following table:

Trip Purpose	Class	Sum	Min	Max	Mean	Std Dev.
HBW-SD	No. of Trips Produced	317,467	0.4	6,991	352	405
HBW-LD		17,781	0.0	347	20	25
HBSHOP-SD		507,387	0.6	9,493	560	627
HBSHOP-LD		27,600	0.0	1,374	30	78
HBO-SD		728,577	0.8	13,010	804	896
HBO-LD		52,716	0.0	1,751	58	103
NHB-SD		600,044	0.0	16,608	634	888
NHB-LD		34,983	0.0	1,742	37	108
TRUCK		102,750	0.0	1,990	109	136
HBW-SD	No. of Trips Attracted	317,467	0.0	12,670	336	662
HBW-LD		17,781	0.0	614	19	36
HBSHOP-SD		507,387	0.0	26,338	536	1,325
HBSHOP-LD		27,600	0.0	1,374	29	85
HBO-SD		728,577	0.0	14,848	770	922

Trip Purpose	Class	Sum	Min	Max	Mean	Std Dev.
HBO-LD		52,716	0.0	1,751	56	115
NHB-SD		600,044	0.0	16,608	634	888
NHB-LD		34,983	0.0	1,742	37	108
TRUCK		102,750	0.0	1,497	111	123

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 or friction factors to develop a matrix of trips between all zones. For short-distance trips, impedance functions are used but for long-distance trips the estimated impedance functions have been turned into a table of friction factors for HBO and NHB trips, so long-distance trips are prevented from being distributed to TAZs closer than 40 miles. The set of impedance functions used to distribute short-distance trips is:

Trip Purpose	Impedance Function		a	b	c
HBW-SD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.07	0.86	0.095
HBSHOP-SD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.099	1.15	0.128
HBO-SD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.029	1.2	0.126
NHB-SD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.11	0.75	0.116
TRUCK	Exponential	$f(t_{ij}) = e^{-c(t_{ij})}$			0.065

The impedance functions used to calculate friction-factors for long-distance trips are:

Trip Purpose	Impedance Function		a	b	c
HBW-LD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.07	0.86	0.095
HBSHOP-LD	Gamma	$f(t_{ij}) = a \cdot t_{ij}^{-b} \cdot e^{-c(t_{ij})}$	0.099	1.15	0.128
HBO-LD	Exponential	$f(t_{ij}) = e^{-c(t_{ij})}$			0.012
NHB-LD	Exponential	$f(t_{ij}) = e^{-c(t_{ij})}$			0.011
TRUCK	Exponential	$f(t_{ij}) = e^{-c(t_{ij})}$			0.065

The Model was found to perform better when the distance-classification threshold was not applied to the distribution of HBW or HBSHOP trips. Therefore, the impedance functions for long- and short-distance trips for these purposes are identical.

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, so no defensible data source for transit demand exists, 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:

Trip Purpose	Internal Trips	Internal to External & External to Internal Trips
Home-Based Work – SD	1.12	1.05
Home-Based Shopping – SD	1.48	1.79
Home-Based Other – SD	1.75	2.00
Non-Home-Based - SD	1.53	1.52
Home-Based Work – LD	1.38	1.16
Home-Based Shopping – LD	1.71	3.06
Home-Based Other – LD	1.57	1.95
Non-Home-Based – LD	1.43	1.94
Truck	1.00	1.00

Traffic Assignment

The final matrix, including all passenger vehicle-trips (all of the non-TRUCK matrices summed) and truck trips (all TRUCK trips), is assigned to the road network in the traffic assignment sub-module. Free-flow travel speed on each link is assumed to be 5 miles per hour over the speed limit, and the user-equilibrium multi-class traffic assignment is used. The multi-class assignment allows trucks and passenger vehicles to be assigned to a separate road network, with the truck network incorporating exclusions wherever trucks are prohibited on the road network. The assignment results in daily traffic flows in each direction for passenger vehicles and trucks on every link in the 2010 road network, as well as the RMSPE calculated by comparing these link volumes with AADTs on a subset (2,240 of 5,670) of the links in the network. Links excluded from the calculation include:

- Centroid connectors
- Links representing roadways for which an AADT was not determined
- Links with high variations in directional flow (the AADT is not distinguished by direction of flow)

The current RMSPE of the Model run for its base-year of 2010 is 43.9%.

Forecasting, Scenario Modeling, and Critical Link Analysis

Forecasting for scenario modeling in the Vermont Travel Model is accomplished using fixed growth rates derived from statewide and local economic forecasts for employment and population. Employment growth by sector & county and population growth by county are:

County	Retail	Manufacturing	Non-Manufacturing	Government	Education	Population
Addison	0.009	-0.011	0.008	0.002	0.003	0.003
Bennington	0.007	-0.012	0.006	0.000	0.003	-0.001
Caledonia	0.009	-0.007	0.008	0.002	0.003	0.003
Chittenden	0.009	0.000	0.009	0.002	0.004	0.006
Essex	0.007	-0.012	0.004	0.000	0.003	0.001
Franklin	0.009	0.000	0.008	0.002	0.003	0.006
Grand Isle	0.01	0.000	0.012	0.002	0.003	0.01
Lamoille	0.011	0.000	0.014	0.002	0.003	0.008
Orange	0.009	-0.006	0.008	0.002	0.003	0.003
Orleans	0.009	0.000	0.009	0.002	0.003	0.004
Rutland	0.007	-0.012	0.006	0.002	0.003	0.000
Washington	0.007	-0.006	0.007	0.002	0.003	0.002
Windham	0.006	-0.012	0.005	-0.003	0.003	-0.001
Windsor	0.007	-0.012	0.005	-0.002	0.003	0.000

Using these annual growth rates, any forecast-year can be selected and run. When a forecast-year is selected, the Model simply recalculates TAZ-level employment and households for the forecast year by applying the growth rate by county, and runs the Model using the updated TAZ characteristics. For forecasts beyond 2025, a modified road network is used for the traffic assignment which includes new roadways expected to be completed by then. For forecasts beyond 2035, additional projects are added to the 2025 network for the forecast-year run. Any Model outputs available for the base-year are available for the forecast-year, and the Model automatically calculates the change in traffic flows on each link between the base-year and the forecast-year.

The Model can also be used run a scenario for a selected set of scenario-links in the forecast-year. For a scenario run, the link layer is modified with a "1" in the "Scenario?" field for any links that will be modified as part of the scenario. Scenario-specific capacity and travel-time fields are also provided to enter the adjusted values that will be used to simulate the scenario. Then, if the "Run a forecast scenario" checkbox is checked, the scenario run first implements a SLA in the assignment step for the forecast-year, outputting a set of towns that utilize the scenario link(s) on a typical day. Then the assignment step is repeated using the adjusted capacities and/or travel-times for the scenario link(s) for the forecast-year. The traffic flow outputs of the scenario assignment can then be compared to the outputs of the standard assignment for the forecast year, indicating the effects that the adjustments arte expected to have on traffic flows in the region.

If the "Run the forecast NRI" checkbox is checked, the NRI is calculated for a prescribed set of links. A selection tool is opened for the user to specify the capacity reduction to apply, and the subset of links to apply it to, and an output file is created with the NRI values for each link specified. For additional information on the NRI process for determining link criticality, refer to Sullivan et. al., (2010).

Appendix B - Users' Guide

Model Platform and Files

The Vermont Travel Model is a GISDK scripted “macro” in the TransCAD software platform that invokes many of TransCAD’s built-in menu-driven processes to simulate a typical day of travel in Vermont:

- Trip Production / Cross-Classification…
- Trip Attraction / Apply a Model…
- Trip Distribution / Gravity Application… & Gravity Calibration…
- Static Traffic Assignment / Multi-Modal, Multi-Class Assignment…

The Model consists of the geographic layers representing the road network and the TAZ layer saved in TransCAD’s native “map” (*.map) file format, along with TransCAD’s native “network” (*.net) file representing the road network topology, and its complementary “turn penalty” table representing prohibited turns in the network topology. Binary-format input tables (“*.bin”) used by the Model include:

- Cross-classification of household types by number of workers and number of household members for each Vermont town
- Trip-rate table by number of workers and number of household members
- Forecast annual growth-rates for employment and population by County
- Coefficients of the regression equations by trip purpose for trip-attraction calculations
- Constants for the gamma and exponential trip-distribution equations by trip purpose
- Friction-factors for long-distance classifications by trip purpose

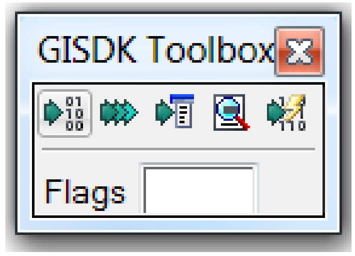
Future road-network configurations are provided for 2105, 2025 and 2035 in TransCAD’s network (*.net) file format to enforce the future topology for forecast-year simulations.

The names of each of these files are provided in the following table:

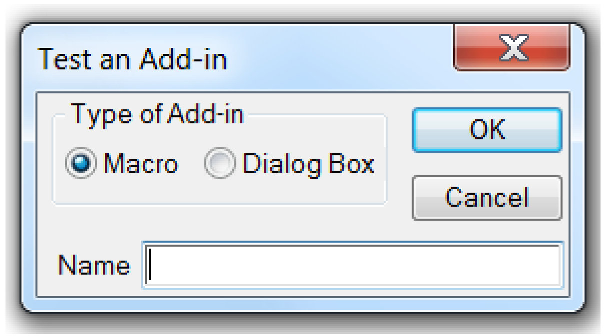
File Description	Name	Type
Native map file which opens the road network, the TAZ layer, and the network topology	Vermont Travel Model	TransCAD map (.map)

File Description	**Name**	**Type**
Road network geographic file	2010 Model Links	TransCAD standard geographic file (.dbd)
TAZ layer geographic file	2010 Vermont TAZs	.dbd
Network topology file representing the road network in the base year	2010ModelNet	TransCAD network (.net)
Complementary "turn penalty" table representing prohibited turns in the network topology	TurnPenalties	Binary table (.bin)
Cross-classification of household types by number of workers and number of household members for each Vermont town	HHTypeByTown_2009	.bin
Trip-rate table by number of workers and number of household members	VTM Trip Rate Table	.bin
Forecast annual growth rates for employment and population by County	Growth Rates	.bin
Coefficients of the regression equations by trip purpose for trip attraction calculations	RegressionCoefficients	.bin
Constants for the gamma and exponential trip distribution equations by trip purpose	TripDistImpedanceSpecs	.bin
Friction factors for long-distance classifications by trip purpose	LDFrictionFactors	.bin
Network file representing the topology of the road network in 2015	fymodelnet (distinguished by its location, in the *2015 Forecast Year* folder)	.net
Network file representing the topology of the road network in 2025	fymodelnet (distinguished by its location, in the *2025 Forecast Year* folder)	.net
Network file representing the topology of the road network in 2035	fymodelnet (distinguished by its location, in the *2035 Forecast Year* folder)	.net

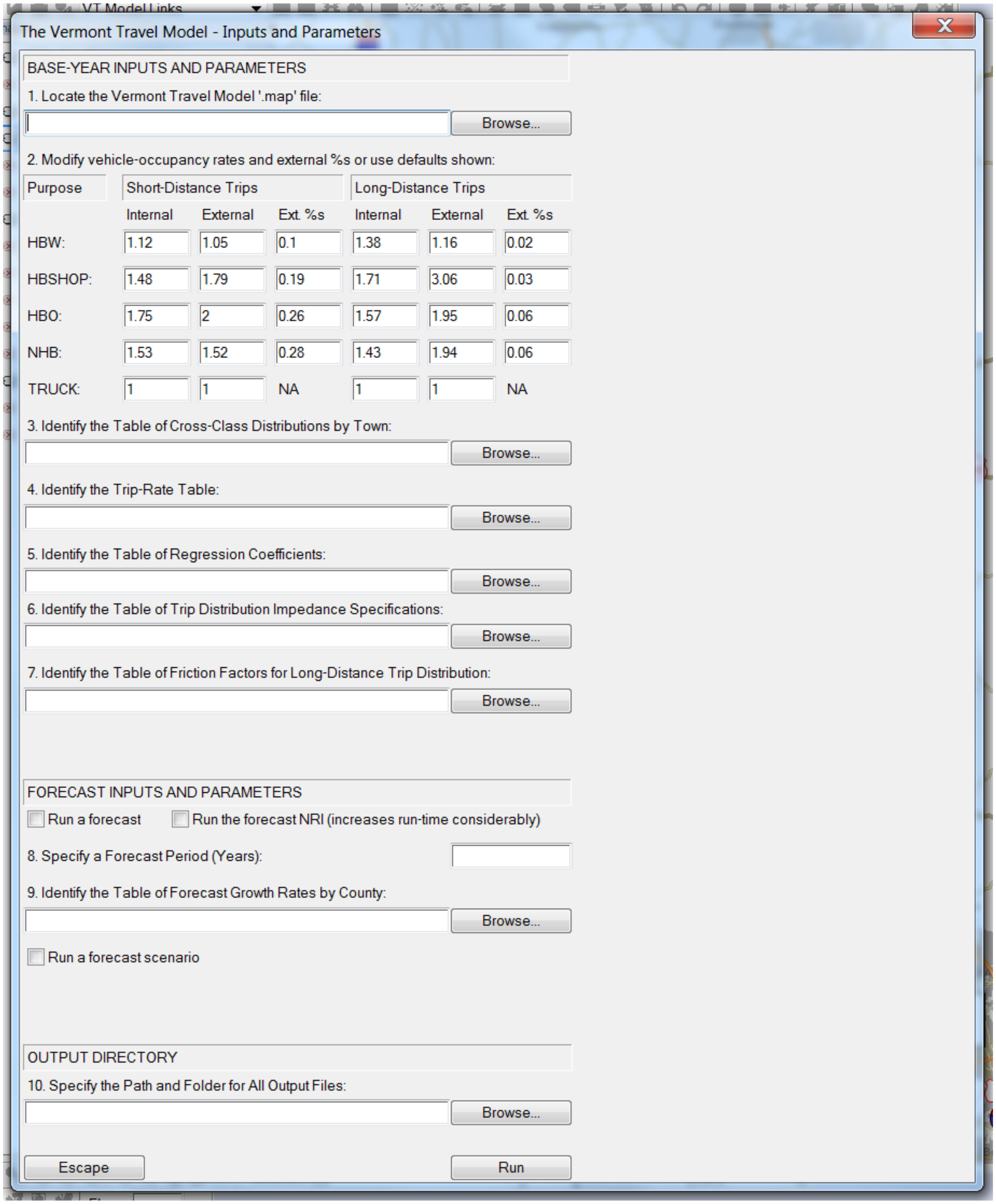
The new menu interface is called up by activating the GISDK Toolbox:



Selecting the button on the far left (a single arrow pointing to 0s and 1s) 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



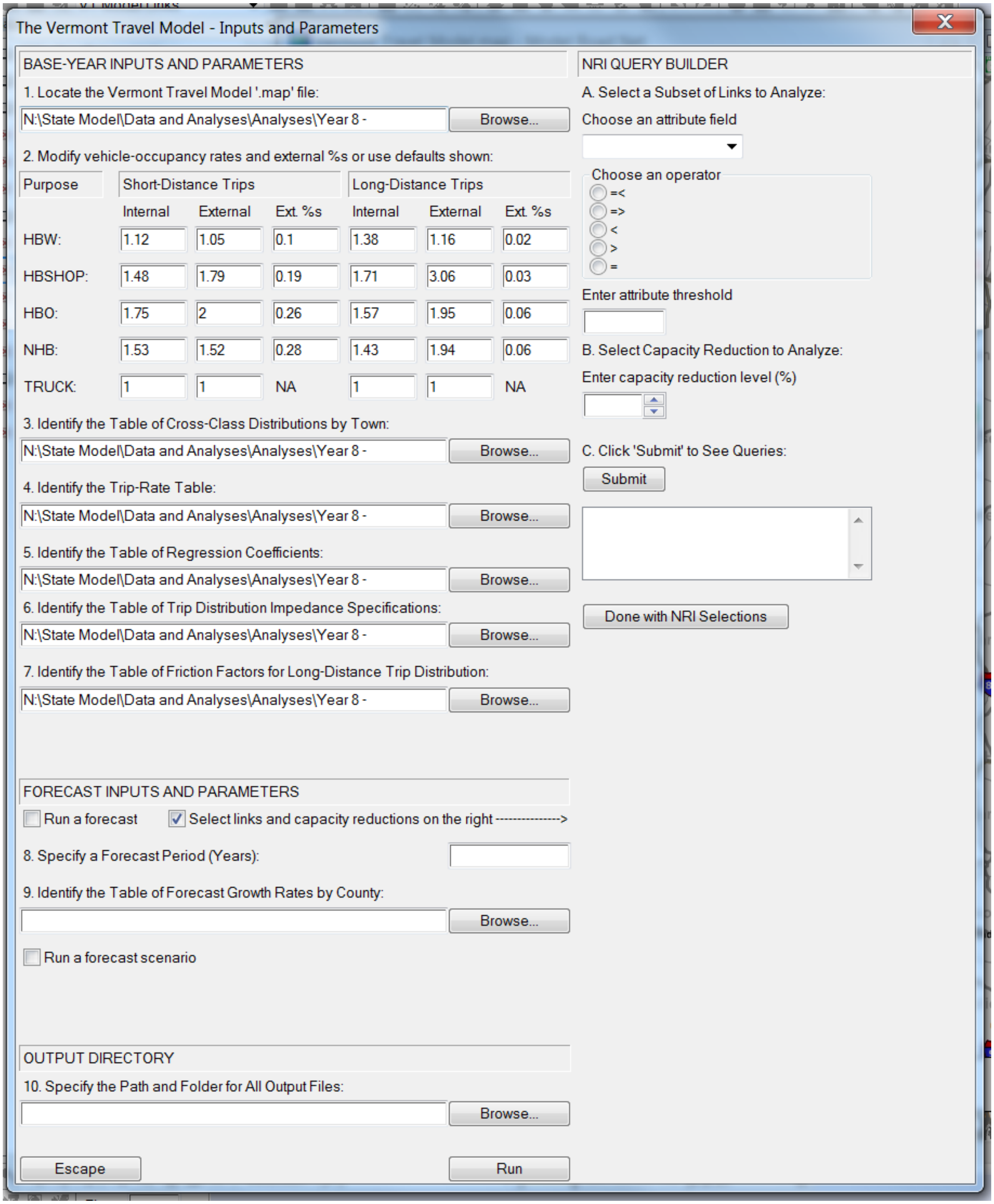
To open the initial Model menu, the user enters “The Vermont Travel Model” (leaving the “Macro” radio button selected) and clicks OK. Once this is done, the initial Model menu appears:



The menu contains ten (10) items and three (3) checkboxes 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 "TripDistImpedanceSpecs.bin" and contains the coefficients to be used in the impedance functions for short-distance trip distribution to determine the destinations of trips from each TAZ
7. Table of Friction-Factors for Long-Distance Trip Distribution – currently called "LDFrictionFactors.bin" and contains the friction factors corresponding to the impedance functions for long-distance trip distribution
8. Forecast Period – user-specified number of years to forecast travel to, assuming a base year of 2010 (any integer)
    a. "Run a forecast" checkbox – check to run the forecast
    b. "Run the forecast NRI" checkbox – check to open the NRI specification dialog box and run the NRI for the forecast year:



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

   a. “Run a forecast scenario” checkbox – check to implement the scenario run steps for the forecast year

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 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 that 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.

Once all of the items are populated, the Model is initiated by clicking the “Run” button at the bottom right corner of the Initial Model Menu.

Output Files

All Model output files are placed in the folder identified on the initial menu by the user. An example of a full set of output files from a Model run includes:

Name	Date modified	Type	Size
Forecast_Year_2040	4/24/2015 2:23 PM	File folder	
Gravity_Raw.mtx	4/24/2015 2:21 PM	TransCAD Matrix	64,250 KB
MMA_LinkFlow.bin	4/24/2015 2:21 PM	BIN File	1,184 KB
MMA_LinkFlow.dcb	4/24/2015 2:21 PM	DCB File	2 KB
ODME_TRUCK_OD.mtx	4/24/2015 2:19 PM	TransCAD Matrix	3,407 KB
ODMETruckLinkFlow.bin	4/24/2015 2:19 PM	BIN File	888 KB
ODMETruckLinkFlow.dcb	4/24/2015 2:19 PM	DCB File	2 KB
RMSPE_Out.bin	4/24/2015 2:21 PM	BIN File	183 KB
RMSPE_Out.BX	4/24/2015 2:21 PM	BX File	21 KB
RMSPE_Out.DCB	4/24/2015 2:21 PM	DCB File	1 KB
SPMAT.mtx	4/24/2015 2:18 PM	TransCAD Matrix	6,491 KB
Transpose.mtx	4/24/2015 2:20 PM	TransCAD Matrix	27,119 KB
trip_table.bin	4/24/2015 2:18 PM	BIN File	611 KB
trip_table.DCB	4/24/2015 2:18 PM	DCB File	4 KB
TripGenCross.bin	4/24/2015 2:18 PM	BIN File	45 KB
TripGenCross.dcb	4/24/2015 2:18 PM	DCB File	1 KB

In this example, the “Run a forecast” checkbox was checked and a 30-year forecast was run, so the forecast-year output folder is automatically named “Forecast_Year_2040”. Clicking on the forecast-year folder reveals the additional output files:

Name	Date modified	Type	Size
2040_trip_table.bin	4/24/2015 2:21 PM	BIN File	611 KB
2040_trip_table.DCB	4/24/2015 2:21 PM	DCB File	4 KB
Gravity_RawFY.mtx	4/24/2015 2:23 PM	TransCAD Matrix	57,430 KB
MMA_LinkFlowFY.bin	4/24/2015 2:24 PM	BIN File	1,184 KB
MMA_LinkFlowFY.dcb	4/24/2015 2:23 PM	DCB File	2 KB
SPMATFY.mtx	4/24/2015 2:21 PM	TransCAD Matrix	6,492 KB
TransposeFY.mtx	4/24/2015 2:23 PM	TransCAD Matrix	23,725 KB
TripGenCrossFY.bin	4/24/2015 2:21 PM	BIN File	45 KB
TripGenCrossFY.dcb	4/24/2015 2:21 PM	DCB File	1 KB

The following table provides descriptions of each of the output files generated by a typical Model run.

File Name	File Description
TripGenCross.bin (and matching *.dcb)	A fixed-format binary table of trip productions by TAZ for the 6 home-based trip purposes
trip_table.bin (and matching *.dcb)	A fixed-format binary table of trip productions and attractions by TAZ for the 8 non-TRUCK trip purposes
SPMAT.mtx	A TransCAD matrix file consisting of the shortest travel-time paths between all TAZs in the Model
ODME_Truck_OD.mtx	A TransCAD matrix file consisting of the final O-D matrix core of TRUCK trips resulting from the O-D Matrix Estimation step
ODMETruckLinkFlow.bin (and matching *.dcb)	A fixed-format binary table of link TRUCK flows resulting from the O-D Matrix Estimation step for every link in the Model network
Gravity_Raw.mtx	A TransCAD matrix file consisting of 19 matrix cores with the output of the trip distribution step for each of the 9 trip purposes in person-trips and vehicle-trips, concluding with a core of the diagonally-symmetric total vehicle-trips for the traffic assignment
Transpose.mtx	A TransCAD matrix file which is the transpose of the assymetric total vehicle-trip matrix, used to make the diagonally-symmetric matrix of total vehicle trips
MMA_LinkFlow.bin (and matching *.dcb)	A fixed-format binary table of link flows resulting from the multi-class traffic assignment for every link in the Model network
RMSPE_Out.bin (and matching *.dcb)	A fixed-format binary table of squared errors between the link flows and AADTs every link in the Model network that has an AADT, and the RMSPE of the Model run
TripGenCrossFY.bin (and matching *.dcb)	A fixed-format binary table of **forecast-year** trip productions by TAZ for the 6 home-based trip purposes
YYYY_trip_table.bin (and matching *.dcb)	A fixed-format binary table of **forecast-year** trip productions and attractions by TAZ for the 8 non-TRUCK trip purposes
SPMATFY.mtx	A TransCAD matrix file consisting of the shortest travel-time paths between all TAZs in the Model for the **forecast-year network**

File Name	File Description
Gravity_RawFY.mtx	A TransCAD matrix file consisting of 19 matrix cores with the output of the trip distribution stepfor the **forecast-year** for each of the 9 trip purposes in person-trips and vehicle-trips, concluding with a core of the diagonally-symmetric total vehicle-trips for the traffic assignment
TransposeFY.mtx	A TransCAD matrix file which is the transpose of the assymetric total vehicle-trip matrix for the **forecast-year**, used to make the diagonally-symmetric matrix of total vehicle trips
MMA_LinkFlowFY.bin (and matching *.dcb)	A fixed-format binary table of link flows resulting from the multi-class traffic assignment in the **forecast-year** for every link in the Model network

The RMSPE 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 allows the Model to be re-estimated and/or updated more efficiently.

When the “Run a forecast scenario” and “Run the forecast NRI” checkboxes are checked, additional output files can be expected in the forecast-year output folder. A list and description of the additional output files are provided in the following table:

File Name	File Description
SLA_Output.mtx	A TransCAD matrix file with the SLA output for the scenario links in the **forecast-year**, used to make SLA_OutputAgg.mtx
SLA_OutputAgg.mtx (and its transpose SLA_OutputAggTrans.mtx)	A TransCAD matrix file (and its transpose) with the SLA output for the scenario links in the **forecast-year**, aggregated to towns (instead of TAZs) using the “Aggregate Matrix” macro, used to make SLA_Output_Table.bin
SLA_Output_Table.bin (and SLA_Output_Table.dcb)	A fixed-format binary table of link flows for all towns that use the scenario-links on a typical day resulting from the multi-class traffic assignment in the **forecast-year**
MMA_LinkFlowSC.bin (and MMA_LinkFlowSC.dcb)	A fixed-format binary table of link flows resulting from the multi-class traffic assignment in the **forecast-year** for every link in the Model network with scenario-specific capacities and travel times
FYNRI_Output.bin (and FYNRI_Output.dcb)	A fixed-format binary table of NRIs resulting from the NRI calculation in the **forecast-year** for every link specified in the NRI Specification Dialog Box

Model outputs in the output folder get over-written each time the Model is run, so this information should be saved to a new folder each time the Model is run. If a different forecast-year is used, the old forecast-year outputs will remain in the old forecast-year output folder, so in that case there is no need to save the outputs separately to a new folder.