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Vermont Travel Model 2012-2013 (Year 5) Report

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Vermont Travel Model 2012-2013 (Year 5) 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 2012-2013 year (Year 5) 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 toward this goal in the 2012-2013 (Year 5) year of the contract. Other activities undertaken in Year 5 of the contract 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 936 traffic analysis zones (TAZs) and 5,327 miles of highway-network links (Figure 1).

In Year 3, the TRC updated the Model with data from the 2009 National Household Travel Survey (NHTS) and the Vermont Department of Labor (VDOL). In Year 4, land-use characteristics in the Model were updated with new residential information from the 2006-2010 American Community Survey (ACS) and the 2010 US Census, and new employment information for 2009 from the Bureau of Economic Analysis (BEA). Land-use characteristics updated included using the cross-classification of number of household members and number of household workers by town, the number of households by Census block, and the number of jobs by industry by County. Road network characteristics were also updated, reflecting modifications or improvements to the network since 2000. The characteristics of roadways that were updated included speed limits, alignments, and daily capacities.

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 update (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 with recommendations for Year 6 (Section 5).

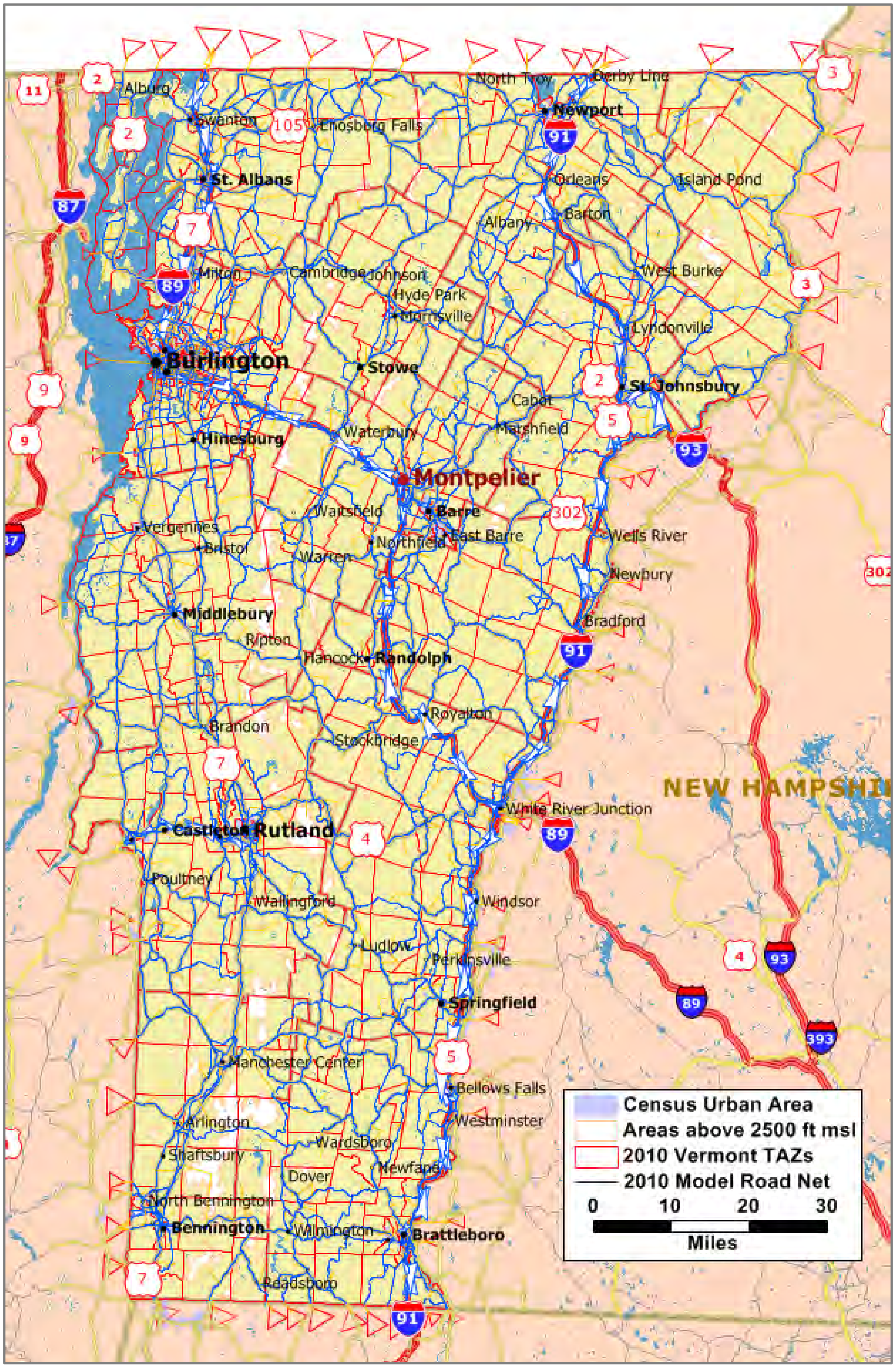

Figure 1 Zones and Road Network in the Vermont Travel Model

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.

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.

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. The parameters inside the block arrows are used in the process represented by the arrow.

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 ADT for the external zones listed in the TAZ characteristics table (taken from traffic counts) multiplied by the truck percentages from the TAZ characteristics table - these are split evenly as productions and attractions. The total for other passenger-car external vehicle-trips (VTs) is taken as the non-truck ADT for each external zone listed in the TAZ characteristics table. 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 by the other 5 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 936 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	SD
HBW	No. of Trips Produced	240,276	0	1,729	257	202
HBSHOP		396,125	0	5,175	423	357
HBO		710,555	0	7,353	759	613
NHB		611,586	0	18,237	653	986
TRUCK		143,224	0	2,658	153	170
HBW	No. of Trips Attracted	240,276	0	4,071	257	397
HBSHOP		396,125	0	9,478	423	855
HBO		710,555	0	8,356	759	897
NHB		611,586	0	18,237	653	986
TRUCK		143,224	0	2,658	153	170

2.2.1 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
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

2.2.2 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 all data sources used in this Model update, and how they were pre-processed for use in the update.

3.1 k-Factors

VTrans' Traffic Research Section publishes annually a Continuous Traffic Counter Grouping Study and Regression Analysis, also known as "The Red Book" (VTrans, 2011). The annual publication contains:

- Introduction and CTC Annual Summary Report
- Monthly factors to adjust short-term counts to annual average daily traffic (AADT) and annual average weekday traffic (AAWDT)
- Daily factors to adjust short-term counts to monthly average daily traffic (MADT)
- Growth factors to project AADTs to a future year and tables and charts to estimate design hour volumes (DHV) from AADTs

Within this study, the Traffic Research section also calculates k-factors, which represent the relationship between the design (peak) hourly volume and the AADT, expressed as a percent. The k-factor is used in the Model to calculate a daily capacity from the hourly capacity for each road-network link. However, the roadways in the Red Book are grouped according to the seasonality of their traffic patterns, as established by FHWA guidelines (FHWA, 2001). The results reveal six (6) generally "definable" groupings for Vermont. These groups (both with and without weekend influence) are shown in Table 4, with their corresponding k-factors from the Red Book.

Table 4 Roadway Grouping and k-Factors from the Red Book

Seasonal Adjustment Factor Group	Description	k-factor
Interstate Rural	Interstate highways not within an urban area in Vermont.	0.1233
Other Rural	Other rural Vermont federal-aid highways	0.1126
Urban	Urban roadways with a more stable year-round traffic pattern, primarily due to the large portion of commuter travel and typical daily urban activities.	0.1059
Summer Recreational	Roadways with a distinct summer recreational influence, presumably due to proximity to camping, lake/beach resorts, historical and sight-seeing areas.	0.1326

Summer/Winter Recreational (US and VT Routes)	US/VT routes with a distinct summer & winter recreational influence, presumably due to proximity to camping, lake/beach resorts, ski resorts, historical and sight-seeing areas.	0.1398
Summer/Winter Recreational (Town Highways)	Town highways with a distinct summer & winter recreational influence, presumably due to proximity to camping, lake/beach resorts, ski resorts, historical and sight-seeing areas.	0.2425

3.2 Recreational Features

Recreational features used to update the Model road network came from the E911 GIS. The E911 GIS consists of the location and classification of each habitable structure in the state. The Vermont E911 data includes residential locations (single-family, multi-family, seasonal, and mobile homes) and non-residential locations (commercial, industrial, educational, governmental, health-care and public gathering). Vermont is unique in that this E911 database is publicly available to support emergency-response personnel statewide via the Vermont Center for Geographic Information (VCGI). The following feature-types were selected from the Vermont E911 GIS to represent the Summer Recreational category:

- Auditorium / Concert Hall / Theater / Opera House
- Boat Ramp / Dock
- Campground
- Community / Recreation Facility
- Cultural
- Historic Site / Point of Interest
- Race Track / Dragstrip
- Sports Arena / Stadium
- Trailhead
- Youth Camp

The "Ski Area / Alpine Resort" and "Ice Arena" feature-types were added to the Winter Recreational selection.

3.3 Roadway Characteristics

Roadway characteristics used in support of functional-class and capacity updates to the Model road network were taken from the Vermont Highway Performance

Monitoring System (HPMS) GIS maintained by VTrans. The HPMS itself is a spreadsheet which contains references to starting and ending milemarkers for each section of federal-aid highway in Vermont. The HPMS data is submitted to FHWA annually for their use in the national HPMS and the publication of Our Nation's Highways every two years (FHWA, 2010). The national HPMS is a national-level highway information system that includes data on the extent, condition, performance, use and operating characteristics of the nation's highways. The linear reference points in the HPMS are mapped to the Vermont HPMS GIS using VTrans' Linear Reference System layer, which is updated every two years. The database was queried and mapped to a GIS for selected attributes for use in this project.

In selected situations, Google Maps Street View was also used to confirm anomalous roadway characteristics and roadway signs.

3.4 Forecast Growth Rates

To generate forecast-year travel estimates for the Model, base-year employment and household totals are extrapolated to the forecast years with annual growth rates.

3.4.1 Sources

A variety of sources were consulted for use in forecasting employment and population growth in Vermont. Two statewide sources were considered, one from the Vermont Department of Labor's (VDOL) Economic and Labor Market Information (see Appendix B), and the other from Moody's Analytics, purchased for the Vermont Freight Plan (VTrans, 2012). Other regional sources were also considered from regional planning commissions (RPCs) who conducted forecasts specific to their region. The following region-specific sources were considered:

- Addison County Regional Plan (Adopted December 14, 2011): includes economic and demographic forecasts for 2000 to 2025
- Economic and Demographic Forecast, Central Vermont Planning Region, 2000 to 2020 (November 2001)
- Economic and Demographic Forecast, Demographic Forecast Update for Chittenden County, 2000 to 2035 (June 2001)
- 2035 Metropolitan Transportation Plan, Chittenden County Regional Planning Commission, Draft Chapter 3 (undated): includes employment, population, and household growth between 2010 and 2035

Each of these sources provides projected economic and demographic growth rates specific to their region. The growth forecasts are typically purchased from a private company specializing in long-term regional economic and demographic projections. However, neither the sources, the coverage (employment sectors and demographic dynamics), nor the time periods of these are consistent. In addition, several RPCs in the state either do not have forecasts available. Therefore, the use of region-specific forecasts to provide statewide projections of growth is infeasible. In addition, due to the inconsistencies between the region-specific forecasts and the statewide sources, it is also methodologically incorrect to use both together. Using region-specific forecasts for regions where they are available and statewide forecasts for other regions would result in a data set that lacks a consistent baseline, making the models built from it inaccurate. Based on these considerations, only the two statewide sources were used for the Model forecast (VDOL, 2012; VTrans, 2012).

3.4.2 Employment Growth Rates

Two sources were used to derive sector- and County-specific growth rates for employment. First, sector-specific growth-rates published by the Vermont Department of Labor (VDOL) for the entire state from 2010 to 2020 were used. These growth rates are shown in Table 5.

Table 5 2010 – 2020 Employment Growth Rates from VDOL

Employment Sector	Annual Growth, 2010 - 2020
Retail	0.9%
Manufacturing	0.0%
Non-Manufacturing	0.8%
Government	-0.2%
School / University	0.3%
Health Services	0.9%

Second, employment growth rates from 2009 – 2039 provided separately by major industry and County in the Vermont Freight Plan (VTrans, 2012) were used. These growth rates are shown in Table 6.

Table 6 Forecasted Growth Rates for Employment by Industry and County in Vermont

Industry	Annual Growth, 2009 - 2039	County	Annual Growth, 2009 - 2039
Educ. & Health Srvcs	1.3%	Chittenden	0.6%
Retail	0.7%	Rutland	0.3%
Government	0.2%	Washington	0.6%
Leisure	1.1%	Franklin	0.7%
Prof. & Business Srvcs	1.2%	Windsor	0.3%
Manufacturing	-1.2%	Windham	0.6%
Construction	1.3%	Addison	1.0%
Financial	0.8%	Bennington	1.1%
Other	0.4%	Caledonia	0.6%
Wholesale	0.2%	Lamoille	0.7%
Transportation & Util.	-0.4%	Orange	0.4%
Information	1.0%	Orleans	0.5%
Farming	-0.7%	Grand	0.2%
Nat. Resource & Mining	-0.7%	Essex	0.3%
Total	**0.6%**	Vermont	**0.6%**

In order to use these growth rates in a travel forecast for the Model, the industries needed to be consolidated into the 5 employment sectors used by the Model (Retail, Manufacturing, Non-Manufacturing, Government, and Education), then cross-classified to provide sector-specific growth rates by County, as opposed to separate sector-specific and County-specific growth rates.

First, the industries shown in Table 6 were mapped to the 5 employment sectors in the Model by matching Retail to Retail, Manufacturing to Manufacturing, Government to Government, Education and Health Services to Education, and the rest of the industries to Non-Manufacturing (as an average weighted by 2009 employment totals).

Next, the VDOL employment sectors in Table 5 were mapped to the 5 employment sectors in the Model by matching "Health Services" and "Non-Manufacturing" to Non-Manufacturing (as an average weighted by 2009 employment totals), and matching the remaining sectors directly to their counterparts. Once the sector-matching was completed, the growth rates from each source were combined into a single sector-specific growth rate to be used for the Model forecast, as shown in Table 7.

Table 7 Summary of Growth Rates by Sector

<table>
<tr><th>Employment Sector</th><th>2009 Employment</th><th>Annual Growth, 2009 - 2039</th><th>Annual Growth, 2010 - 2020</th><th>Final Growth Rate for the Model Forecast</th></tr>
<tr><td>Retail</td><td>54,600</td><td>0.7%</td><td>0.9%</td><td>0.8%</td></tr>
<tr><td>Manufacturing</td><td>30,500</td><td>-1.2%</td><td>0.0%</td><td>-0.6%</td></tr>
<tr><td>Non-Manufacturing</td><td>107,400</td><td>0.6%</td><td>0.8%</td><td>0.8%</td></tr>
<tr><td>Government</td><td>54,200</td><td>0.2%</td><td>-0.2%</td><td>0.1%</td></tr>
<tr><td>Education</td><td rowspan="2">60,400</td><td rowspan="2">1.3%</td><td>0.3%</td><td>0.3%</td></tr>
<tr><td>Health Services</td><td>0.9%</td><td>Non-Manufacturing</td></tr>
<tr><td>**Total**</td><td>**307,100**</td><td>**0.6%**</td><td></td><td></td></tr>
</table>

For the Retail and Manufacturing sectors, the final growth rates are simply the mean of the rates from the two sources. For the Non-Manufacturing growth rate, the mean of the growth rates from the two sources (0.6% and 0.8%) and the rate for Health Services from the VDOL (0.9%) were taken as the final growth rate (0.8%). For the Government growth rate, the mean of the rates from the two sources was augmented by 0.1% to reflect the likely positive influence of the Health Services sector growth. For the Education sector, the rate from the VDOL was used directly because the Freight Plan rate did not specifically separate Education from Health Services.

A goal-programming step was then performed to allocate growth rates by sector across each of the 14 counties in Vermont. The goal-programming process used the final growth rates shown in Table 7 and the County-specific growth rates shown in Table 6 as constraints, and found County/sector-specific rates which satisfied both constraints, and approximated a weighted average based on 2009 employment totals. The results of this step are shown in Table 8.

Table 8 Goal-Programming Results for County/Sector-Specific Growth Rates

County	Retail		Manu-facturing		Non-Manu-facturing		Government		Education		✓
	n	Rate	n	Rate	n	Rate	n	Rate	n	Rate	
Addison	2,725	0.9%	2,086	-1.1%	15,045	0.8%	2,172	0.2%	1,319	0.3%	0.6%
Bennington	3,697	0.7%	2,780	-1.2%	15,500	0.6%	2,455	0.0%	1,447	0.3%	0.3%
Caledonia	2,133	0.9%	1,796	-0.7%	11,278	0.8%	2,320	0.2%	1,449	0.3%	0.6%
Chittenden	13,379	0.9%	10,021	0.0%	55,402	0.9%	11,527	0.2%	11,064	0.4%	0.7%
Essex	186	0.7%	21	-1.2%	1,430	0.4%	462	0.0%	190	0.3%	0.3%
Franklin	2,643	0.9%	3,031	0.0%	14,305	0.8%	4,346	0.2%	2,064	0.3%	0.6%
Grand Isle	301	1.0%	6	0.0%	1,742	1.2%	364	0.2%	206	0.3%	1.0%
Lamoille	1,745	1.1%	692	0.0%	11,474	1.4%	1,835	0.2%	1,448	0.3%	1.1%
Orange	1,336	0.9%	727	-0.6%	9,883	0.8%	2,139	0.2%	1,005	0.3%	0.6%
Orleans	1,777	0.9%	1,360	0.0%	9,827	0.9%	2,286	0.2%	1,215	0.3%	0.7%
Rutland	5,071	0.7%	3,273	-1.2%	24,364	0.6%	5,061	0.2%	3,201	0.3%	0.4%
Washington	4,922	0.7%	2,783	-0.6%	26,623	0.7%	8,279	0.2%	2,070	0.3%	0.5%
Windham	3,244	0.6%	2,121	-1.2%	21,657	0.5%	3,250	-0.3%	2,129	0.3%	0.3%
Windsor	3,237	0.7%	2,253	-1.2%	23,717	0.5%	5,409	-0.2%	2,091	0.3%	0.3%
✓		0.8%	✓	-0.6%	✓	0.8%	✓	0.1%	✓	0.3%	✓

Notes:
n – number of jobs in this County/sector in 2009
✓ - weighted averages programmed to match Table 6 and Table 7

Note the match between the weighted averages shown in Table 8 and the growth rates by County in Table 6 and by sector in Table 7.

3.4.3 Household Growth Rates

To derive County-specific growth rates for households, the population-growth estimates from the Freight Plan (VTrans, 2012) were used to represent household growth directly. These growth rates are shown in Table 9.

Table 9 Population Growth Rates

County	Annual Population Growth, 2009 – 2039	County	Annual Population Growth, 2009 – 2039
Chittenden	0.6%	**Bennington**	-0.1%
Rutland	0.0%	**Caledonia**	0.3%
Washington	0.2%	**Lamoille**	0.8%
Franklin	0.6%	**Orange**	0.3%
Windsor	0.0%	**Orleans**	0.4%
Windham	-0.1%	**Grand Isle**	1.0%
Addison	0.3%	**Essex**	0.1%

Note: Weighted-average growth rate for the entire state from 2009 to 2039 is 0.3%.

4 Improvements Methodology and Results

4.1 Model Process Improvements

The Model processes used in the CUBE application were validated by replicating these processes in the TransCAD platform. At each Model step, Model outputs were compared from each application to identify inconsistencies that might point to problems with Model processes. The balanced trip tables which come out of the trip generation modules compared well. However, when the initial trip matrices coming out of the trip-distribution module were compared, inconsistencies with the distributions of external-external (E-E) trips were identified. Figure 2 provides a schematic representation of a trip matrix to illustrate these inconsistencies.

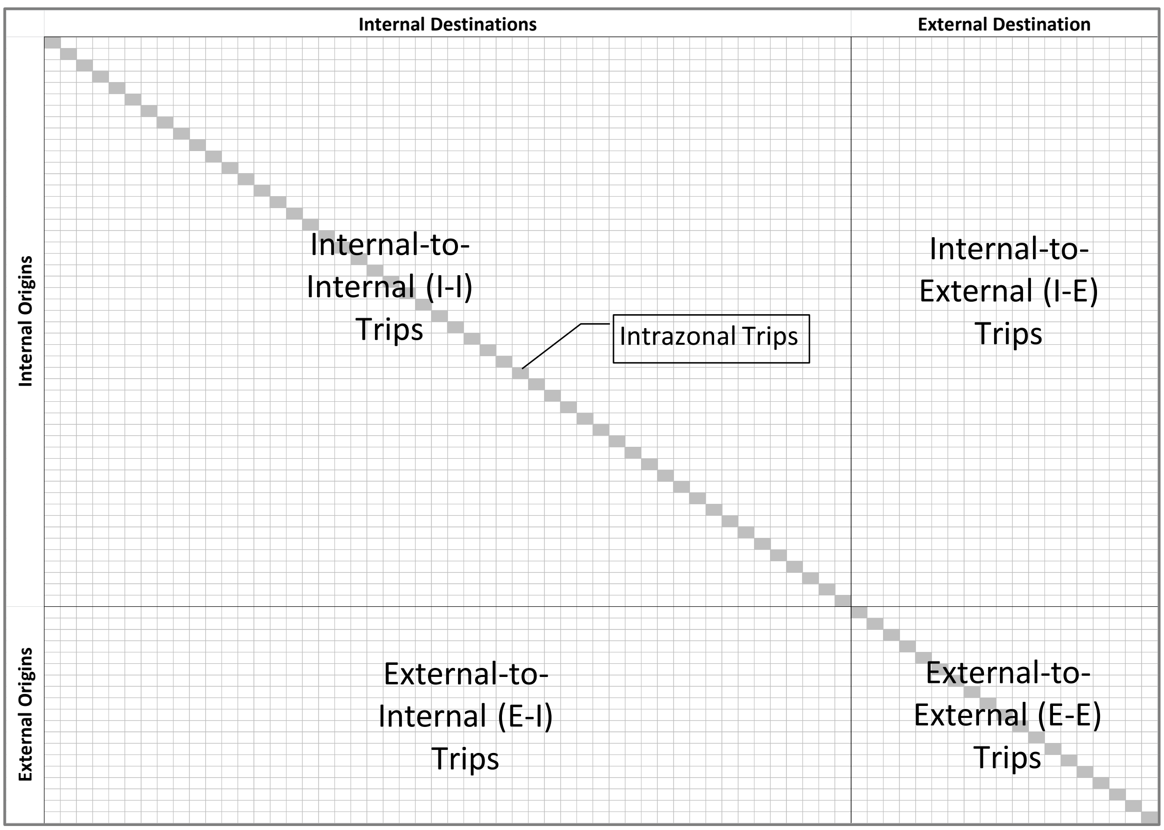

Figure 2 Schematic Example Matrix Output from the Trip Distribution Module

In the figure, the locations of I-I, I-E, E-I, and E-E cells in the matrix are identified, along with intrazonal trip cells along the diagonal of the matrix. I-I and I-E non-truck trips are consistently estimated using the NHTS travel behavior data for Vermonters. The E-I and E-E trips are estimated using primarily daily traffic counts at roadways entering/leaving the state, which are assumed to be roughly 50% entering and 50% leaving on a typical day. These daily traffic counts are broken down by non-truck trip purpose using the general tendencies exhibited by the I-E trips in the NHTS (which does not include trucks). The assumption that non-truck E-I and E-E trips exhibit the same general tendencies for trip purpose as I-E trips significantly weakens the Model's ability to estimate these types of trips. Therefore, the Model estimation of non-truck trips in the I-I and I-E sections of the matrix is considerably better than its estimation of non-truck trips in the E-I and E-E sections.

For truck trips, the Model uses daily truck traffic counts as the primary source of calibration data. Therefore, the Model's ability to estimate truck travel behavior in Vermont is consistent across all sections of the matrix.

It became clear when the matrices from each of the Model runs were compared, that the CUBE application was not distributing trips to the E-E section of the matrix. Trips were prevented from being distributed to this section of the matrix because the free-flow travel-time matrix is filled with 0s for all of the E-E cells within the "Network Processing" script. Based on the input data used to calibrate the new base-year update of the Model, the lack of E-E trips is logically inconsistent. Calibrating the Model with cross-border traffic counts means that it is impossible to exclude E-E trips from the Model, so excluding them at the trip distribution step results in an overestimation of I-E and E-I trips.

Based on this finding, the "Network Processing" script was revised to allow travel between external TAZs. This revision was sensitive to the exclusion of intrazonal trips in the E-E section of the matrix. Intrazonal trips in the E-E section of the matrix are not included in the Model, as they represent travel completely outside of Vermont. To accomplish this exclusion, the free-flow travel time matrix is filled with 0s along the diagonal of the E-E section for the updated CUBE application. The TransCAD application requires a null value in the diagonal of the E-E section to prevent trips from being distributed to those cells.

4.2 Road Network Improvements

Roadway characteristics in the Model were refined to improve the accuracy and performance of the Model processes, particularly the trip distribution and traffic assignment Modules. Link speed limits, from which travel times are calculated, were revised and improved. Validity of the existing speed limits in the Model is unknown.

Physical characteristics used to improve the representations of capacities were also refined and added. Capacities are critical to the traffic assignment Module. Currently, only the number of lanes, the FHWA functional class, and a "Divided" status for each link is provided, with a functional capacity whose origin could not be ascertained. The validity and origin of the number of lanes information is unknown, and no documentation of the method used to calculate hourly capacities for FHWA functional classes is available. Hourly capacities are translated to daily capacities through the use of a k-factor, which normally relates the peak-hour volume to the AADT. However, the validity and origin of the k-factors used in the Model is also unknown.

4.2.1 Refined Speed Limits and Travel Times

The initial validation of speed limit for links in the Model was achieved using a line layer from VCGI which identifies “speed zones” in downtown areas of Vermont. Speed limit reductions in downtown areas were assigned to Model links if they represented more than ½ of the link length, otherwise they were ignored.

Other speed limits were revised using the Google Maps Street View to verify posted speed limits from roadside signs. This verification was performed wherever categorical or statistical anomalies in the speed limit data were identified. The revised field name was changed from “Speed” to “Speed_Limit”. These revisions resulted in the new distribution of speeds shown in Table 10.

Table 10 Speed Limits Re-Coding Summary

Code (mph)	Link Counts	
	Speed	Speed_Limit
15	5	4
20	7	2
25	131	135
30	1,263	1,271
35	380	399
40	1,596	1,578
45	248	245
50	96	90
55	151	143
60	3	3
65	175	185

Free-flow travel times were re-calculated using the revised speed limits. Free-flow travel times were assumed to be the time taken to traverse each link when traveling at 5 mph faster than the speed limit.

4.2.2 Refined Number of Lanes Each Way

To refine the field which provides the number of travel lanes in each directions for roadways in the Model, all links were first separated by functional class. Within each class, anomalies were found using selection sets. These anomalies were spot-checked using Google Maps Street View to confirm that the number of lanes in each direction. The largest number of lane assignment errors was found on lower-capacity roadway classes. Many links previously coded as having 2 lanes in each direction were re-coded to show that they actually have 1 lane of travel in each direction. Several links which had been coded as having 2 lanes in each direction were re-coded to show that they actually have 3 lanes of travel in each direction. In addition, the coding of the 1,300 centroid connectors for this field was changed from 0 to 1. Finally, the revised field name was changed from “Lanes_One-Way” to “Lanes_Each-Way”. A summary of the link-counts for this field is provided in Table 11.

Table 11 Number of Lanes Each Way Re-Coding Summary

Code & Description		Link Counts	
		Lanes_One-Way	Lanes_Each-Way
0	?	1,441	no longer used
1	One lane each direction	3,072	4,627
2	Two lanes each direction	831	707
3	Three lanes each direction	17	21

4.2.3 Refined Divided Status

The "Divided" field in the road network is presumably used to identify roads that are represented by two links, one for each direction of travel. This field is used to clarify the calculation of capacities, and to support the validation of network flows against AADTs. However, it was not clear if this field is also expected to represent links which feature a physical median. Therefore, spot-checks were performed and revisions were made to define this field in the former way.

An initial check was performed to ensure that all links identified as "divided" were one-way, and featured a "partner" link which mirrored its trajectory and geography. Not all one-way links are "divided", though, since ramps and urban one-way streets are not represented in mirrored pairs. In addition, some links which were found to be physically divided by a median are not represented as mirrored pairs and therefore should not have been identified as divided.

The coding of the 1,300 centroid connectors in this field was changed from null to "Not Divided" to avoid errors during calculations. In addition, new coding was added for 160 roadways added to the network in Year 4, most within Chittenden County. A total of 17 other links in the network were found to be incorrectly coded as "Divided" when in fact they were not. These errors may have been due to confusion about the intent of the field. Finally, the revised field name was changed from "Divided" to "Net_Divided" to clarify its use in the Model. These revisions resulted in the new distributions shown in Table 12.

Table 12 Divided Status Re-Coding Summary

Code & Description		Link Counts	
		Divided	Net_Divided
0	?	1,460	no longer used
1	Divided	395	378
2	Not Divided	3,506	4,983

4.2.4 Refined k-Factors

The first three groupings in Table 4 can be related easily to functional classes in the Model. In order to relate the recreational groupings to the roadways used in the Model, selections were made based on proximity to recreational features in the Vermont. Town highways and US/VT highways within 0.5 miles of the Summer Recreational features and not within an urban area were put in the Summer Recreational grouping. Highways within 3 miles of the Winter Recreational features were added to the highways already in the Summer Recreational grouping to create the Summer/Winter Recreational grouping. From these groupings, the k-factors from Table 4 were assigned to all non-centroid-connector links in the Model road network. In addition, all of the links directly represented in the Red Book were coded with the Factor Group that is used in the Red Book. Finally, the links in each category were checked for continuity, and additional links were added/removed from each group to ensure continuity of recreational routes. This coding resulted in the new distribution of k-factors shown in Table 13.

Table 13 Distribution of k-Factor Groupings in the Model

Seasonal Adjustment Factor Group	k-Factor	Link Count
Interstate Rural	0.12	340
Other Rural	0.11	1,940
Urban	0.11	1,490
Summer Recreational	0.13	142
Summer/Winter Recreational (US and VT Routes)	0.14	106
Summer/Winter Recreational (Town Highways)	0.24	37
Centroid Connectors	0.10	1,300

The distribution of these factor groups across the state is shown in Figure 3.

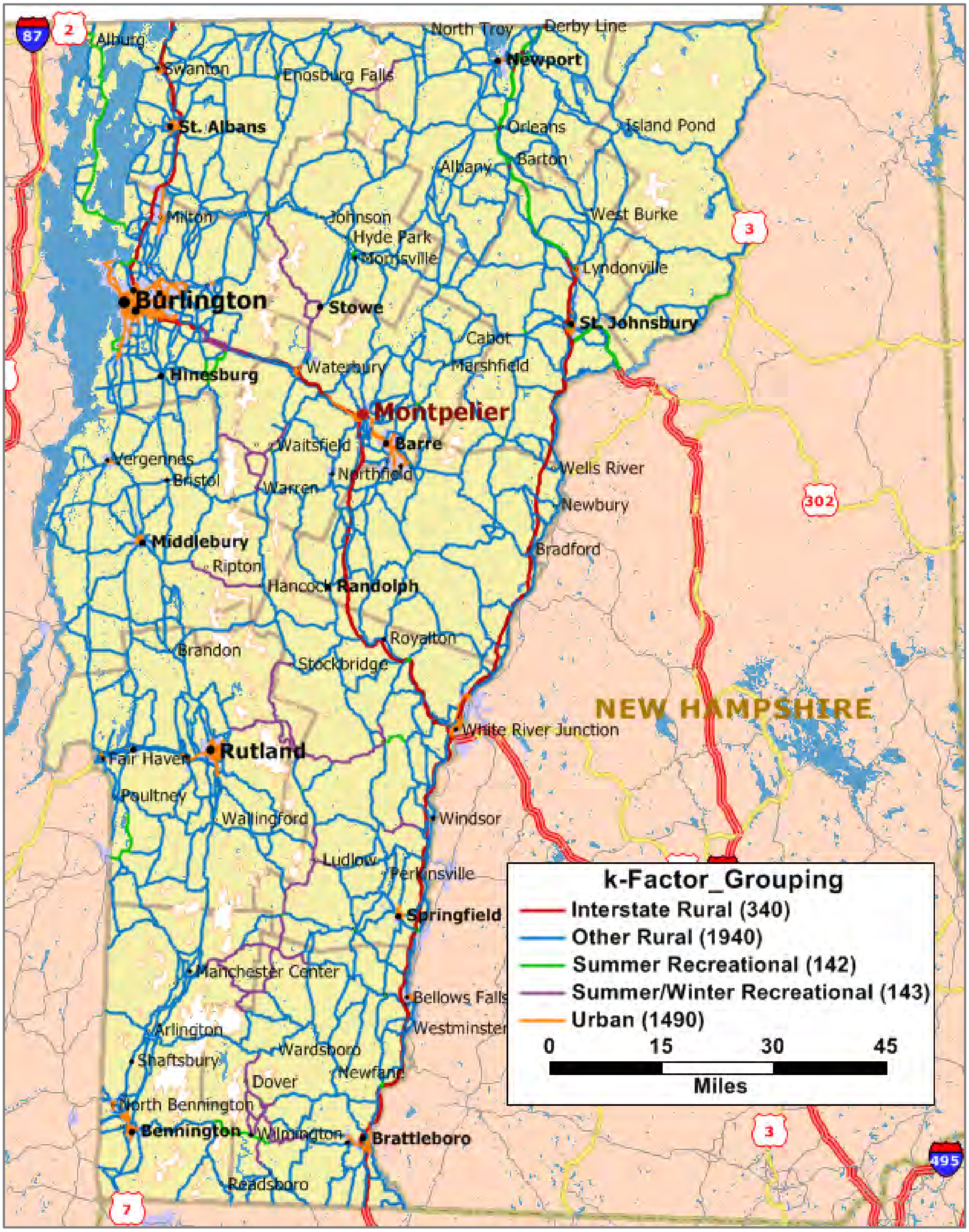

Figure 3 Distribution of k-Factor Grouping in Vermont

As shown in the figure, the Summer/Winter Recreational roads are generally aligned with the Green Mountain range and the downhill ski resorts along the center axis of the state. Summer Recreational roads are on the Lake Champlain

Islands, in the Northeast Kingdom, and scattered around other summer destination in the state.

4.2.5 Added Median, Shoulder and Lane Widths

The current Model road network does not include any physical cross-sectional dimensions of the road system. In order to support refined capacity calculations, the median width, shoulder widths, and lane widths were needed. The HPMS GIS contains a single measurement of lane width, left and right shoulder widths and median width (if present) along a significant, but not exhaustive, set of roadways in the Model. Therefore, the HPMS GIS was spatially joined, wherever possible, to each non-centroid-connector link in the Model and tagged with the lane, shoulder and median widths. Approximately 85% of the 4,055 non-centroid-connector links were matched to a corresponding link in the HPMS GIS, using the "Select by Location..." tool in TransCAD.

All interstates and access-controlled roadways were matched to the HPMS and shown to have a median. Other than these links, very few roads in the Model network contain medians. Therefore, the presence and width of a median on these other roads was verified exhaustively using Google Maps' Street View tool.

For those links which could not be matched to the HPMS GIS, a lane width of 10 feet, a right shoulder width of 2 feet, and no median were assumed, based upon the mean or mode values for the rest of the Model network.

4.2.6 Added Urban/Rural Designation

Though not necessarily an important descriptor of actual travel behavior, an urban/rural designation for links in the Model road network is essential to the effective calculation of capacities. Using the TransCAD "Select by Location..." tool, each link was designated as "Urban" if it fell entirely within an urban area or served as the boundary for an urban area. The rest of the links in the network were designated as "Rural".

4.2.7 Added Terrain Descriptor

Most of the roads in Vermont are low-volume rural roads located in hilly terrain. Therefore, in order to better describe the physical attributes of the road network and support refinement of roadway capacities, a terrain descriptor was developed and added to the Model road network. TRB recommends three classes of terrain in the HCM methodology to quantify the effects of heavy duty vehicles upon free flow speed and lane capacity – level, rolling and mountainous, mountainous terrain defining those links with over 6% in grade (TRB, 2010). For this project, two steps were taken to derive this attribute. The Model road network, as it exists, is composed of links with multiple grade changes of variable length. The data describing these grade changes is not currently available in digital form. The first step, therefore, in the derivation of a terrain descriptor was to ascertain the degree or extent of elevation change experienced along each link. This was achieved using the USGS 20-ft contour layer and the TransCAD Fill/Tag functionality. Each link was tagged using the Fill/Tag... tool in TransCAD 20-foot contours from a statewide coverage from USGS, providing the minimum, maximum and total number of 20-foot contours crossed by the link. For each link, a contour variation parameter was computed, measured as the total relative elevation change (number of contours crossed multiplied by 20 feet) divided by the link length (in feet). This unitless parameter provides the best estimate of terrain using a proxy for grade change. The countour variation parameter was then classified as one of the three terrain descriptors, whose definitions and resulting distributions are shown in Table 14.

Table 14 Terrain Descriptor Classification and Distribution

Terrain Descriptor	Contour Variation	Link Count
Level	< 0.02	2,671
Rolling	>= 0.02 and <= 0.06	1,185
Mountainous	> 0.06	199

The distribution of these terrain descriptors across the state is shown in Figure 4. From the figure, it is evident that Vermont's roadways have significant contour variation, with many rolling and mountainous links in the network. In fact, the link count shown in Table 14 may be a misleading representation of terrain in the Model road network. When road mileage is considered, the "Rolling" and "Mountainous" categories are shown to constitute 53% of the Model road network.

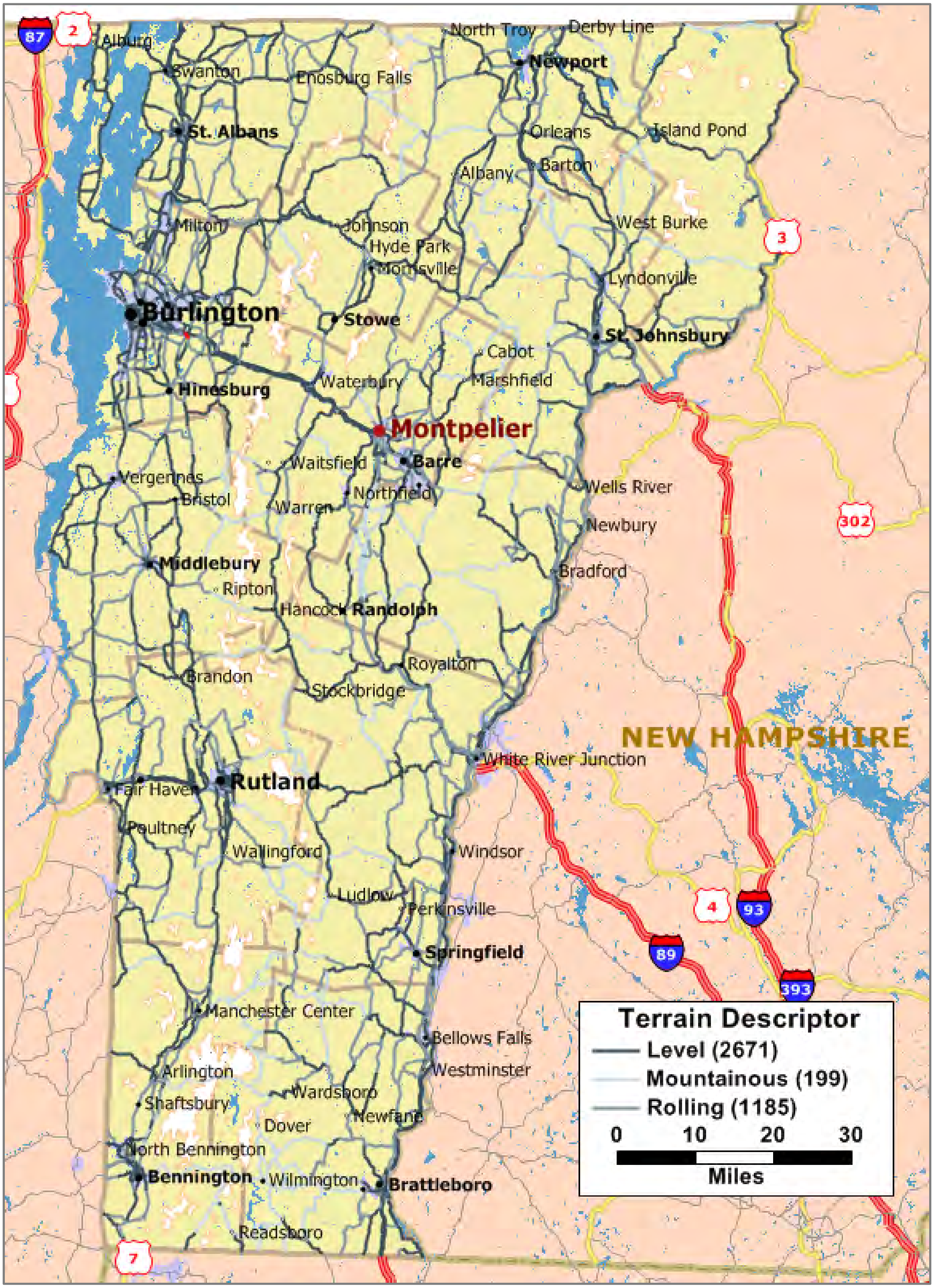

Figure 4 Distribution of Terrain Descriptors in Vermont

4.2.8 Refined Functional Class, Hourly Capacity, and Daily Capacity

The roadway capacity used in the traffic assignment module of the Model is a daily, two-way capacity. The daily capacity is calculated from the hourly capacity and the k-factor. Therefore, in order to have accurate daily capacities, accurate hourly capacities are required. More accurate hourly capacities will also strengthen the Model if a peak-hour assignment module is developed. The first step in the refinement of the hourly capacities in the Model is to classify each of the roadways according to the alternative functional classes in the 2010 HCM and the FHWA HPMS Field Manual. Methodology for capacity calculation is provided for each of the following types of uninterrupted flow facilities:

- Freeways (Urban and Rural)
- Multilane Highways (Urban and Rural)
- Rural Two-Lane Highways
- Rural One-Lane, One-Way Highways
- Rural Three-Lane Highways
- Urban One/Two/Three-Lane Highways

Using the defining characteristics for each of these facility-types, the existing links in the Model were re-classified. Table 15 provides a cross-classification of link counts for these facility types and the former FHWA functional classes.

Table 15 Cross-Classification of Link Counts for HCM Facility Types and FHWA Functional Classes

FHWA Func. Class		HCM Facility Types				
ID	Description	Freeway (Urban or Rural)	Multilane Highway (Urban or Rural)	Rural Highway (2 or 3 Lane)	Urban 1, 2, or 3 Lane	Total No. of Links
1	Rural Interstate	357				357
2	Rural Principal Arterial	61	20	191	10	282
6	Rural Minor Arterial	2	18	394	18	432
7	Rural Major Collector			889	49	938
8	Rural Minor Collector			267	3	270
9	Rural Local Road			57		57
11	Urban Interstate	126				126
12	Urban Freeway	49	22	2	6	79

FHWA Func. Class		HCM Facility Types				
ID	Description	Freeway (Urban or Rural)	Multilane Highway (Urban or Rural)	Rural Highway (2 or 3 Lane)	Urban 1, 2, or 3 Lane	Total No. of Links
14	Urban Principal Arterial		13	52	413	478
16	Urban Minor Arterial		4	131	329	464
17	Urban Collector			135	310	445
19	Urban Local Road			18	109	127
	Total	**595**	**77**	**2,136**	**1,247**	**4,055**

The 1,300 centroid connectors in the network are not included in the table, and there are no known rural one-lane highways in Vermont.

Hourly capacity for each facility type is defined by the HCM as the flow expected at a Level of Service of "E". Using the methodologies described in the FHWA HPMS Field Manual and the roadway characteristics described previously, hourly single-lane capacities were re-calculated for all of the links in the network. The products of these single-lane capacities and the number of lanes in each direction provide refined peak hourly capacities for all links. Finally, the revised field name was changed from "Hourly_Cap" to "Hourly_Cap_EachWay" to clarify its use in the Model. These revisions resulted in the new distribution shown in Table 16.

Table 16 Hourly Capacities Refinement Summary

Capacity Range (vph)		Link Counts	
		Hourly_Cap	Hourly_Cap_EachWay
0	**500**	369	10
501	**1000**	1,107	782
1001	**1500**	1,557	2,192
1501	**2000**	508	370
2001	**2500**	205	96
2501	**3000**	16	100
3001	**3500**	26	199
3501	**4000**	258	18
4001	**4500**	0	55
4501	**5000**	9	232
5001	**5500**	0	0
5501	**6000**	0	0
6001	**6500**	0	0
6501	**7000**	0	1
	Total	**4,055**	**4,055**

With unadjusted single-lane capacities of between 500 and 2,400 vehicles per hour (vph) for most uninterrupted facilities in the HCM, most single-lane facilities have a capacity of between 1001 and 1,500 vph and that many two-lane facilities fall into the range of 4,501 – 5,000 vph. The highest capacity link is a segment of I-89 in South Burlington which has 3 lanes of travel in each direction, with a one-way capacity of 6,900 vph.

The increase in the number of higher-capacity facilities in the revised distribution (Hourly_Cap_EachWay) is more likely due to an improved application of the number of lanes in each direction in the calculation of the value than to the actual discovery of more higher-capacity facilities. In particular, newer links in Chittenden County that are now part of the network may not have been coded correctly in the past, but are now accurately represented as roadways with a lower single-lane hourly capacity, but a higher overall capacity (due to the presence of multiple lanes of travel each way).

These new directional hourly capacities were then divided by the refined k-factors to refine the daily capacities to be used in the assignment module of the Model. The revised field name was changed from "Daily_Cap" to "Daily_Cap_EachWay" to clarify its use in the Model. These revisions resulted in the new distribution shown in Table 17.

Table 17 Daily Capacities Refinement Summary

Capacity Range (vpd)		Link Counts	
		Daily_Cap	Daily_Cap_EachWay
0	5000	457	32
5001	10000	2,352	1,227
10001	15000	337	2,085
15001	20000	173	32
20001	25000	27	159
25001	30000	153	144
30001	35000	45	92
35001	40000	181	204
40001	45000	21	79
45001	50000	18	0
50001	55000	4	0
55001	60000	55	0
60001	65000	55	1
65001	70000	5	0
70001	75000	2	0
75001	80000	170	0
	Total	**4,055**	**4,055**

Contrary to the higher trend indicated in Table 16, the refined daily capacities are not consistently higher than the previous values. At the lower end of the spectrum, many more links moved from the 5,001 – 10,000 vpd range up to the 10,001 – 15,000 vpd range. This change is likely due to the corresponding increase in single-lane capacities shown in Table 16. However, at the upper end of the spectrum, most links moved down into the 20,000 to 45,000 vpd ranges from ranges greater than 45,000 vpd. This trend is likely due to a corresponding increase in the refined k-factors and a more precise application of the number of lanes each way to the capacity calculation, both of which would result in a reduction.

4.3 Base-Year Traffic Assignment

Trips are assigned to the road network as passenger vehicles, using the MMA Static Traffic Assignment function in TransCAD 6.0. The four non-truck vehicle-trip matrices are summed and the resulting matrix is assigned to the base-year road network, while the truck vehicle-trip matrix is assigned to the base-year road network excluding the links with truck restrictions, with a user-equilibrium minimization of travel-time.

After the user-equilibrium MMA traffic-assignment (100 iterations; relative gap of 0.0001), the overall root-mean-square-percent-error (RMSPE) is calculated for a subset of the links on the network using the link-specific flow and the corresponding link specific AADT. There are a total of 5,349 links in the entire Model road network, but centroid connectors, links without an AADT, and links with flows less than 1,000 vpd are not included in the calculation. Centroid connectors are not actual roads, so AADTs are not available for them, nor are they available for many rural and small urban roads. In addition, links with less than 1,000 vehicles per day (vpd) are excluded from the calculation even if they have an AADT available. Since the assignment method is not stochastic, smaller volumes are not routed on links unless they are on a shortest-path between two TAZs. In addition, the presence of centroid connectors, or dummy links, on the network can create 0-flow links that are necessary to balance the flows elsewhere in the network. The initial RMSPE calculation resulted in an overall value of 48%. However, after making a unilateral 10% reduction in flow volumes throughout the network, the agreement between the total AADTs and flows statewide improves. This improvement might indicate the effect of modes like walking, biking, and transit being omitted from the Model. Following this reduction, the overall RMSPE is at 45%. RMSPEs of the individual road types are shown in Table 18.

Table 18 RMSPE Summary by Functional Classification

Functional Classification		No. of Links:		Average:		
ID	Description	In the Model Network	Used to Calculate RMSPE	2009 AADT	Link Flow (vpd)	RMSPE (%)
1	Rural Interstate	357	77	6,134	5,113	32.3
2	Rural Principal Arterial	282	206	5,947	6,067	29.1
6	Rural Minor Arterial	432	359	4,867	4,218	44.0
7	Rural Major Collector	938	564	2,989	3,054	51.0
8	Rural Minor Collector	270	17	3,534	2,171	63.2
9	Rural Local Road	57	1	2,430	2,104	13.4
11	Urban Interstate	126	28	12,590	10,263	27.2
12	Urban Freeway (not Interstate)	79	37	6,209	6,089	30.6
14	Urban Principal Arterial	478	381	12,775	11,625	35.8
16	Urban Minor Arterial	464	343	7,754	5,973	48.3
17	Urban Collector	445	197	4,706	3,585	59.5
19	Urban Local Road	127				
20	Centroid Connector	1,300				

The RMSPE calculation is an aggregated comparison of the flow volumes from the Model and the AADTs for the corresponding roadways:

$$RMSPE = \frac{\sqrt{\frac{\sum_{i=1}^{N}[(x_i - y_i)^2]}{N}}}{\frac{\sum_{i=1}^{N} x_i}{N}}$$

Where x_i is the AADT and y_i the modeled volume, both on link i, for all of the N links used in the calculation.

AADTs are estimated from counts collected at different times during the year, so they may be biased seasonally if adequate annual representation is not present. Since the Model is aimed at representing an annual average day, it might be doing a better job of that than the AADTs. In addition, the counts themselves include error inherent to the counting process used and the data collection methodology. In some cases, this counting error has been estimated at as much as 20% (Wright et. al., 1997). AADTs also are not "balanced" at intersections, nor are they balanced to a complete trip. The flows in the Model result from the completion of complete trips – to and from a destination, and as such represent a simulation, so they would not be likely to match AADTs completely.

For these reasons, the sum of the AADTs on the set of links used for the RMSPE calculation is 14,229,515, but the sum of all link flows from the Model on the same set of links is 12,616,764. AADTs may be counting the same vehicle on the same trip more than once, but the Model flows account for each vehicle-trip only once. Therefore, it is not effective to overfit the Model volumes to the AADTs, but it makes more sense to use the AADTs to identify links in the Model which may be coded incorrectly, aligned incorrectly, or missing from the Model. Using this approach, no obvious errors in the road network could be found, so the RMSPE of 45% was accepted.

4.4 Model Forecast

Forecast growth rates were used to pre-process the TAZ-based characteristics for households and employment to projected values for 2025 (15-year forecast) and 2035 (25-year forecast).

All parameters, rates, coefficients, and roadway characteristics in the Model were assumed to remain unchanged. However, for each forecast year, a set of new roadways was assumed to be constructed and added to the Model road network. These new roadways were determined by examining the long-term transportation planning documents of the individual RPCs in Vermont. Table 19 provides the assumed schedule for new roadways to be completed and added to the Model network.

Table 19 Schedule of Proposed Network-Connector Projects in Vermont

Project Description	Project Number	Phase	Assumed Year of Completion
Morrisville Truck Route	STP F 029-1(2)	Construction	2015
Market Street	STP 5200(17)	Construction	2015
Bennington By-Pass Northern Segment	NH F 019-1(5)	Project Design	2020
Full Interchange at Exit 13 in South Burlington	IM 089-3(35)	Scoping	2020
Segments A & B of Circumferential Highway	NH 033-1(24)	Conceptual Design (EIS)	2020
The Crescent Connector	STP 5300(13)	Project Design	2020
Airport Drive extension to Airport Parkway	NH 5200( )	Project Design	2020
Bennington By-Pass Southern Segment	NH F 019-1(4)	Scoping	2025
New Interchange (Exit 12B) at I-89 & VT 116	IM 089-3( )	Conceptual Design (EIS)	2025
Champlain Parkway / Southern Connector	MEGC M 5000(1)	Scoping	2035
I-89 Exit at West Milton Road	--	--	2035
Segments G & H of Circumferential Highway	--	--	2035
Segments I & J of Circumferential Highway	--	--	2035
O' Brien Connector from VT 116 to Marshall Ave	--	--	2035
Allen Martin Parkway	--	--	2035
Old Cross Rd Extension between Dorset St and VT 116	--	--	2035
Swift St Extension between Dorset Street and VT 116	--	--	2035
Mary Street between Dorset Street and Williston Road	--	--	2035

Notes:
Projects lacking a project number were discovered in planning documents or maps but could not be identified in any project development processes.

Most of the new roadways already have a project number in the project development process at VTrans. Projects that have not entered the development phases were assumed to be constructed by 2035, as shown in the Draft 2035 CCMPO Metropolitan Transportation Plan (CCRPC, 2013).

Using the forecasted TAZ characteristics and the assumed road network for each forecast-year, the Model was run through the assignment module to yield forecast trip tables, vehicle-trips matrices, and link-flow volumes. Figure 5 shows the changes in total employment (jobs), households, and trips (by purpose) over the full 26-year forecast period.

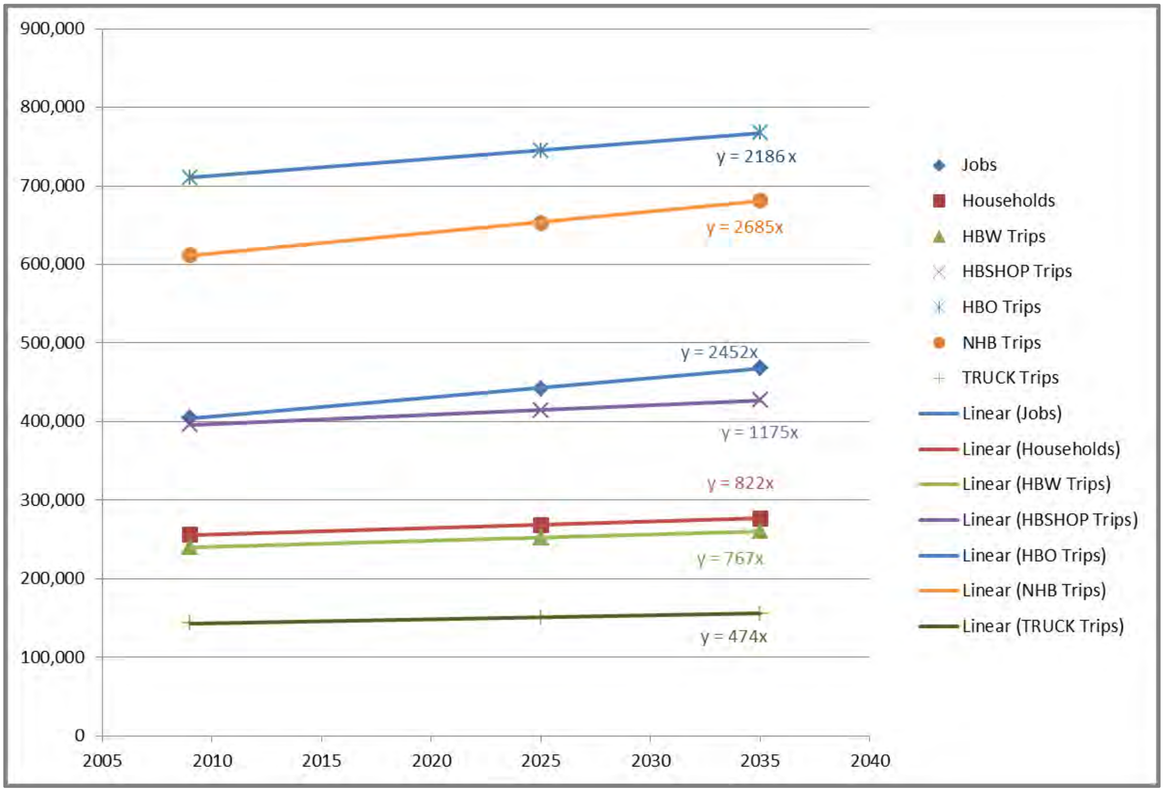

Figure 5 Changes Jobs, Households, and Trips, 2009 - 2035

Also provided in the chart are the rates of increase of each, expressed as a linear equation. Evident in the chart are the sharper rates of growth for jobs, home-based other (HBO) trips, and non-home-based (NHB) trips. More moderate growth is evident for home-based shopping (HBSHOP) trips and households. Milder growth is evident for home-based work (HBW, commuting) trips and truck trips. An increase of over 2,400 jobs per year across the forecast period results in increases of nearly 2,700 NHB trips per year, but only 474 commuting trips per year.

Figure 6 and Figure 7 show the change in traffic flows between the base-year (2010) and the 2035 forecast-year at critical locations throughout the state. The most significant flow changes occur around major new roadways in the state, where they serve to alleviate traffic flows on some redundant routes, and re-focus traffic flows on others. Other increases in flow occur because of the general growth in trips between 2010 and 2035, especially on links like I-89 where traffic volumes were already high.

Figure 6 Significant Changes in Traffic Flows Between 2010 – 2035 in the Burlington Urban Area

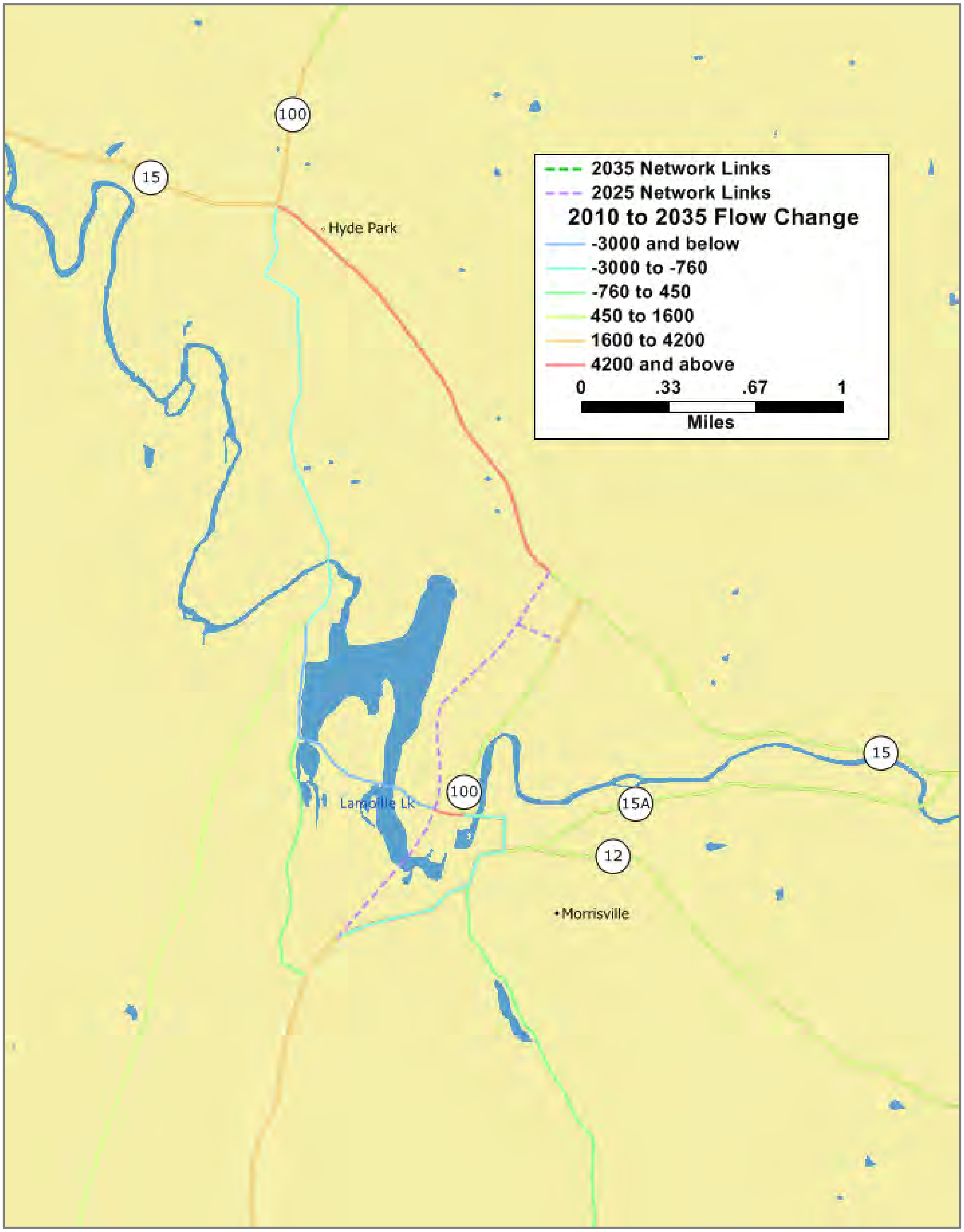

Figure 7 Significant Changes in Traffic Flows Between 2010 – 2035 in the Morristown Area

4.5 TMIP Process

A peer review of the Model was conducted under the Travel Model Improvement Program (TMIP) sponsored by FHWA. The TMIP peer review serves multiple purposes, including identification of model deficiencies, recommendations for model enhancements, and guidance on model applications. Given the increasing complexities of travel-demand forecasting practice and the growing demands by decision-makers for information about policy alternatives, it is essential that travel forecasting practitioners have the opportunity to share experiences and insights. The TMIP peer review program provides a forum for this knowledge exchange.

VTrans's overall goal for model improvement and its motivation for seeking a TMIP peer review was to continuously maintain and apply a model representative of the state of the practice in travel forecasting that equips the agency with the support needed for informed decision-making throughout the state. The peer review was conducted in four 2-hour phone/web meetings:

- Two technical background meetings including TMIP moderators, VTrans and associated staff, and peer review panelists
- One meeting between the panelists and TMIP moderators to discuss potential recommendations
- One final meeting involving all parties to present the recommendations to VTrans

The results of each of these discussions and the final recommendations from the panel are presented in a report (FHWA, 2013). Panel members included:

- Keith Killough, Director of Transportation Analysis at Arizona DOT
- Judy Raymond, Transportation Supervising Planner at Connecticut DOT
- Chad Baker, Statewide Model Branch Chief at Caltrans
- Becky Knudson, Senior Transportation Economist in the Transportation Planning Analysis Unit at the Oregon DOT
- Kevin Hooper , Principal at Kevin Hooper and Associates

4.5.1 General Comments and Recommendations

The panelists highly recommended that VTrans internally strengthen their agency's understanding of the Model, specifically with regard to its sensitivities and appropriate uses at the statewide level. The panel also noted it critical that VTrans staff are able to illustrate the value of the Model as a planning tool to gain financial support from agency management. The panel recommended that the Model developer, whether in-house or external, provide features in support of desired analyses by the agency. Furthermore, at least one VTrans staff person should have a strong understanding of the Model in order to conduct analyses.

Another overarching issue discussed in the peer review sessions was the need for VTrans to minimize dependence on the Model by developing other tools that have the ability to meet agency needs while managing resources and effort. Particularly, the panelists noted that one model cannot provide the analytical power required for different levels of spatial acuity. Therefore, VTrans would benefit from maintaining a variety of tools that are consistent and compatible with each other and use data collected by the agency in a streamlined and automated manner.

Finally, the panel underscored the importance of identifying project types and metrics desired for project prioritization prior to the redesign of Model features. Panelists lauded the ambitious nature of VTrans' Model enhancement goals. However, the panel also noted that it will be imperative to first achieve basic functionality and incorporate comments from FHWA before any mid- to long-term goals that require extensive model development efforts are realized. Therefore, specific recommendations are provided in a phased format below.

4.5.2 Phased Recommendations

The following subsections partition panelist recommendations by potential timeframe for implementation: short-, mid-, and long-term.

4.5.2.1 Recommended Short-Term Recommendations

The panel feels that VTrans should focus on the following priorities in the next year:

- Address the comments from FHWA's review of the current Model:
    - Undertake the list of fundamental Model development considerations from FHWA
    - Develop a users' guide and technical reference
    - Define short/mid/long term priorities based on the current Model to create a detailed Model development plan
- Include new tools or model metrics for resiliency planning in the Model:
    - Recognize that emergency contingency planning is associated with links damaged by an emergency event not general facility design; therefore, the consideration of dynamic traffic assignment to assess traffic patterns in emergency response may be a preferable method.
    - Identify metrics for emergency scenario comparison to guide Model development if the agency selects the Model as the tool for resiliency planning.
    - Develop an at-risk location inventory in the Model network via link attributes and automate their incorporation into the network if the agency selects the Model as the tool for resiliency planning.
- Incorporate various Model improvements to address network and structure deficiencies identified by the peer review panelists:

- Enlarge the external Model area by including a halo over the state line.
- Ensure that the roadway network includes all interstates, major arterials, and collectors with accurate speeds, lengths, and classifications.
- Reassess centroid connectors.
- Consider seasonal trip tables.
- Differentiate between short- and long-distance trips.
- Expand to a future year beyond 2030.
- Decide on one freight model component based on either commodity flows or truck/rail vehicles.

- Review the following references for additional ideas for statewide modeling best practices:
    - Special Report 288 "Metropolitan Travel Forecasting"
    - TCRP Report 95 " Traveler Response to Transportation System Changes Handbook"
    - NCHRP Project 836-B Task 91 "Final Report: Validation and Sensitivity Considerations for Statewide Models"
    - NCHRP Report 735 "Long-Distance and Rural Travel Transferable Parameters for Statewide Travel Forecasting Models"
    - NCHRP Synthesis 406 "Advanced Practices in Travel Forecasting"
    - A Transportation Modeling Primer, Edward A. Beimborn Center for Urban Transportation Studies University of Wisconsin-Milwaukee, May 1995, Updated June 2006

4.5.2.2 Recommended Mid-Term Improvements

Over the next two to three years, the panel recommended VTrans consider the following:

- Establish a methodology for evaluating system preservation and disinvestment:
    - Coordinate with pavement program staff to determine need for this type of effort.
    - Identify the performance measures desired for project prioritization prior to adjusting the Model.
    - Consider evaluating volumes and road wear for project prioritization.

- Review Oregon's use of HERS-ST as a working example of transportation investment optimization.

- Include model components for the evaluation of performance measures to address MAP-21 and asset management:
    - Identify and prioritize Model design features for each performance metric desired based on agency needs.
    - Apply economic assessment software to Model output to assess economic impacts of transportation features.
    - Develop post processing methodology to determine economic impact/GSP value of individual links.
    - Consider use of a separate project-specific benefit/cost model.
    - Implement the determined freight component based on either commodity flows or truck/rail vehicles

4.5.2.3 Recommended Longer-Term Improvements

The panel also identified potential improvements for VTrans to consider over the longer term (beyond the next three years):

- Apply the Model to incorporate the assessment of fair-share methodologies:
    - Develop VMT estimates for new development by land-use type and trip-purpose to determine change over time and assess impact fees.
    - Recognize that Model resolution is not adequate for a post-processing methodology to determine long-range growth rates for background traffic.
    - Consider a micro-simulation model, which applies future volumes and growth rates from a regional model.
    - Review off-model techniques that can be used as separate/compatible tools for development impact assessment, such as the ITE Trip Generation Manual.
- Develop methodologies to assess transit and non-motorized for corridor prioritization:
    - Recognize that the Model may not be at an appropriate resolution for evaluating non-motorized transportation improvements.
    - Develop separate/compatible tool for non-motorized transportation.
    - Consider micro-simulation models for local area analysis.
    - Consider survey efforts to understand current travel by mode.
    - Consider a tiered approach to activity-based model development for non-motorized travel as a long-term priority if the agency envisions

the Model as the preferred tool for non-motorized transportation assessment.

- Determine the best methodology for assessing energy use and emissions:
  - Include a mode choice component.
  - Use MOVES in conjunction with Model output once the Model includes a mode choice component to estimate emissions.
  - Identify and test sensitivities in energy/emission performance measures.
  - Recognize the difficulty in addressing performance measures given the scale and resolution of the Model.
  - Consider a separate aggregate model to apply data from both the statewide model and the MPO model to evaluate energy and emissions data.
  - Consider scenario testing in the long-term.

5 Summary and Recommendations

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 programs at the Agency, and much of the data was 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 in Year 5, resulting in a comprehensive set of recommendations for Model improvements for Year 6 and beyond. Selected subtasks are recommended based on the short-term recommendations from the peer review to achieve this goal:

- Break up HBO and NHB trips in the Model with sub-categories (personal-discretionary, personal non-discretionary, and business) and distance classes (long and short - 50 mile cut-off) as data supports in accordance with NCHRP guidance
- Test the validity of leaving the trip matrices asymmetrical, particularly for NHB travel, since NHB trips do not necessarily return to their origin daily
- 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
- Re-assess all centroid connectors locations and resolution of TAZs
- 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

Year 6 includes efforts to continue the improvement of the basic Model functionality, accuracy, and effectiveness, all within its new base-year of 2009-2010. Continued improvements will bring the Model closer to its goals for functionality and effectiveness.

6 References

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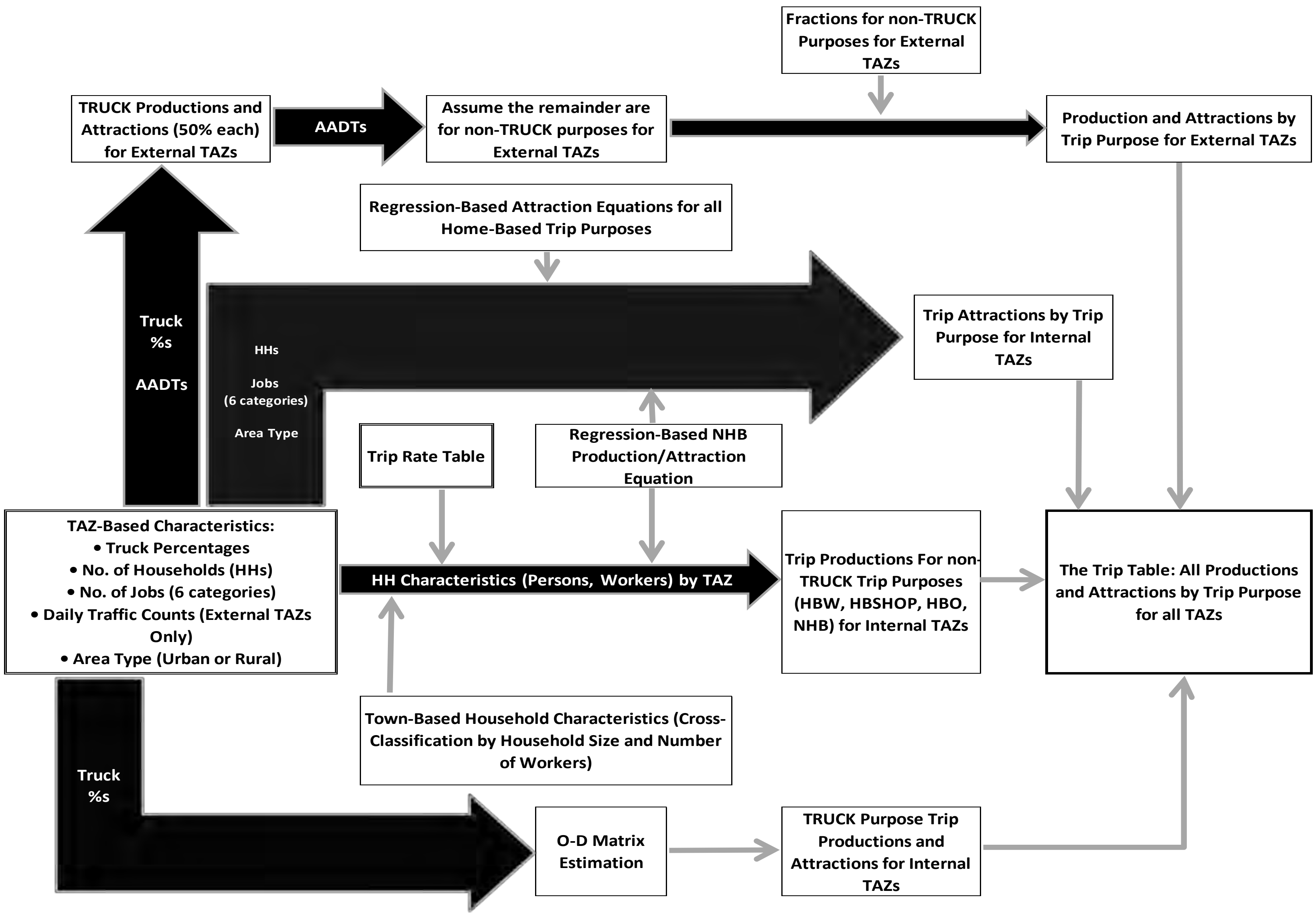
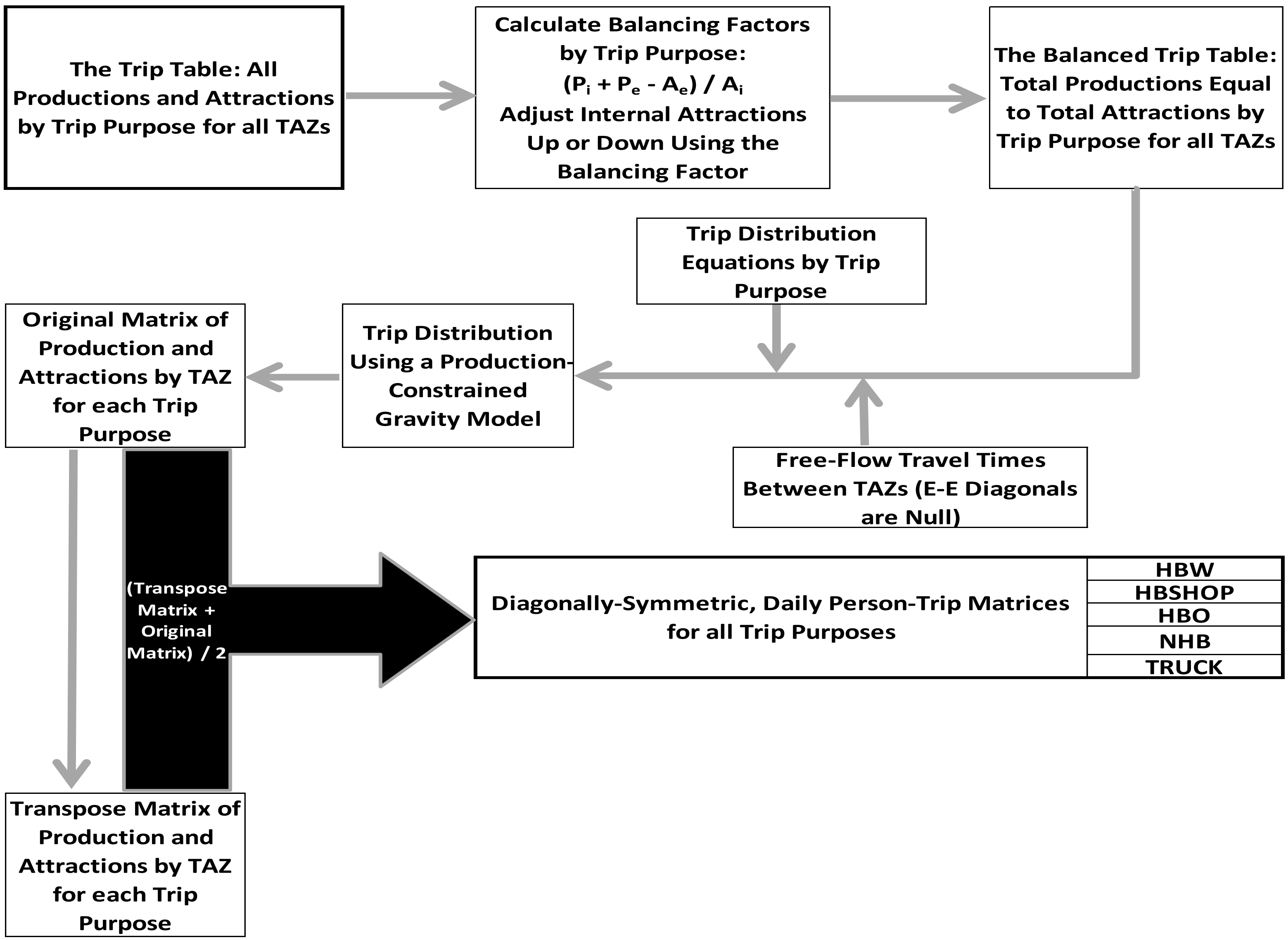
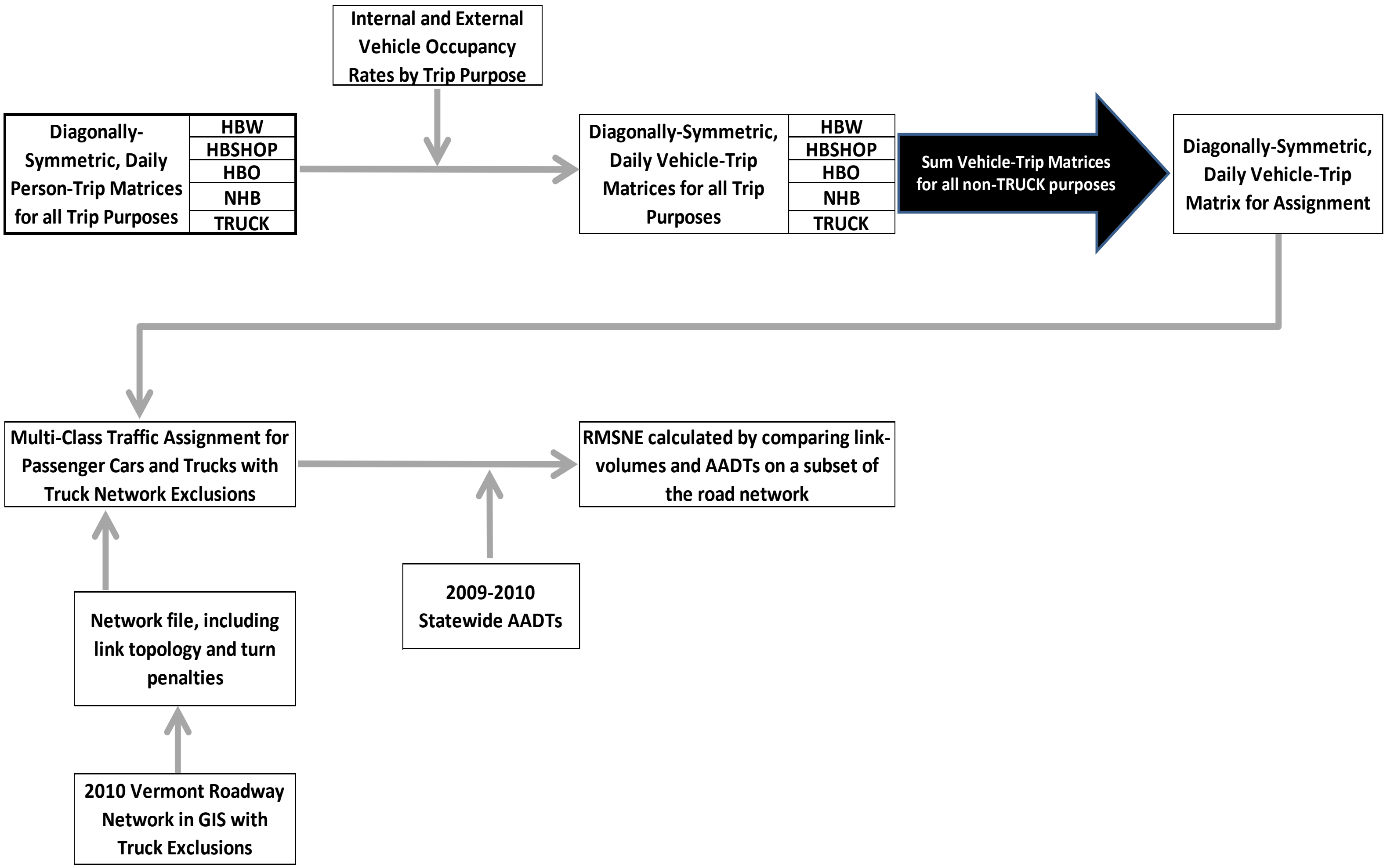
Appendix A


Fractions for non-TRUCK Purposes for External TAZs
TRUCK Productions and Attractions (50% each) for External TAZs
AADTs
Assume the remainder are for non-TRUCK purposes for External TAZs
Production and Attractions by Trip Purpose for External TAZs
Regression-Based Attraction Equations for all Home-Based Trip Purposes
Truck %s
AADTs
HHs
Jobs (6 categories)
Area Type
Trip Attractions by Trip Purpose for Internal TAZs
Trip Rate Table
Regression-Based NHB Production/Attraction Equation
TAZ-Based Characteristics:
• Truck Percentages
• No. of Households (HHs)
• No. of Jobs (6 categories)
• Daily Traffic Counts (External TAZs Only)
• Area Type (Urban or Rural)
HH Characteristics (Persons, Workers) by TAZ
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
Town-Based Household Characteristics (Cross-Classification by Household Size and Number of Workers)
Truck %s
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)
(Transpose Matrix + Original 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


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
RMSNE calculated by comparing link-volumes and AADTs on a subset of the road network
Network file, including link topology and turn penalties
2009-2010 Statewide AADTs
2010 Vermont Roadway Network in GIS with Truck Exclusions