A Report from the University of Vermont Transportation Research Center

Vermont Travel Model 2010 - 2011 (Year 3) Report

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Disclaimer

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1 Introduction

This report is being prepared under Task 1 of the "Maintenance, Operation and Evaluation of the VTrans Statewide Transportation Model" contract with the Vermont Agency of Transportation (VTrans) in the 2010-2011 year of the contract. The objective of this task is to update the VTrans Statewide Travel-Demand Model using new data and information. In December 2010, the TRC proposed that the model update be addressed in phases and that the updates based primarily on the National Household Travel Survey (NHTS) data for Trip Generation and Trip Distribution be completed in Year 3. The purpose of this report is to document the update activities which were completed in the 2010-2011 (Year 3) year of the contract.

The TRC updated the model in Year 3 with new information from the 2009 NHTS Data for Vermont, 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 volumes 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 updated 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 remainder of this report contains a thorough 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 the data for use in the Model (Section 4), and a summary of the results of the update (Section 5)

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. Daily travel demand is estimated by the model between traffic analysis zones (TAZs) by the purpose of a trip. From this travel demand, trips are routed and it is possible to estimate the flow of traffic that will occur in an average day on each link in the model road network. Attachment A provides a schematic representation of the model inputs (boxes) and model processes (block arrows).

It is important to note, though, that the Model can only estimate travel demand between TAZs, not between specific locations, and it can only estimate link flow on the roads that are included in the Model, which are interstate highways, federal highways, state highways, federal urban area routes and some major collectors. Many minor roads are not included, as shown in Figure 1.

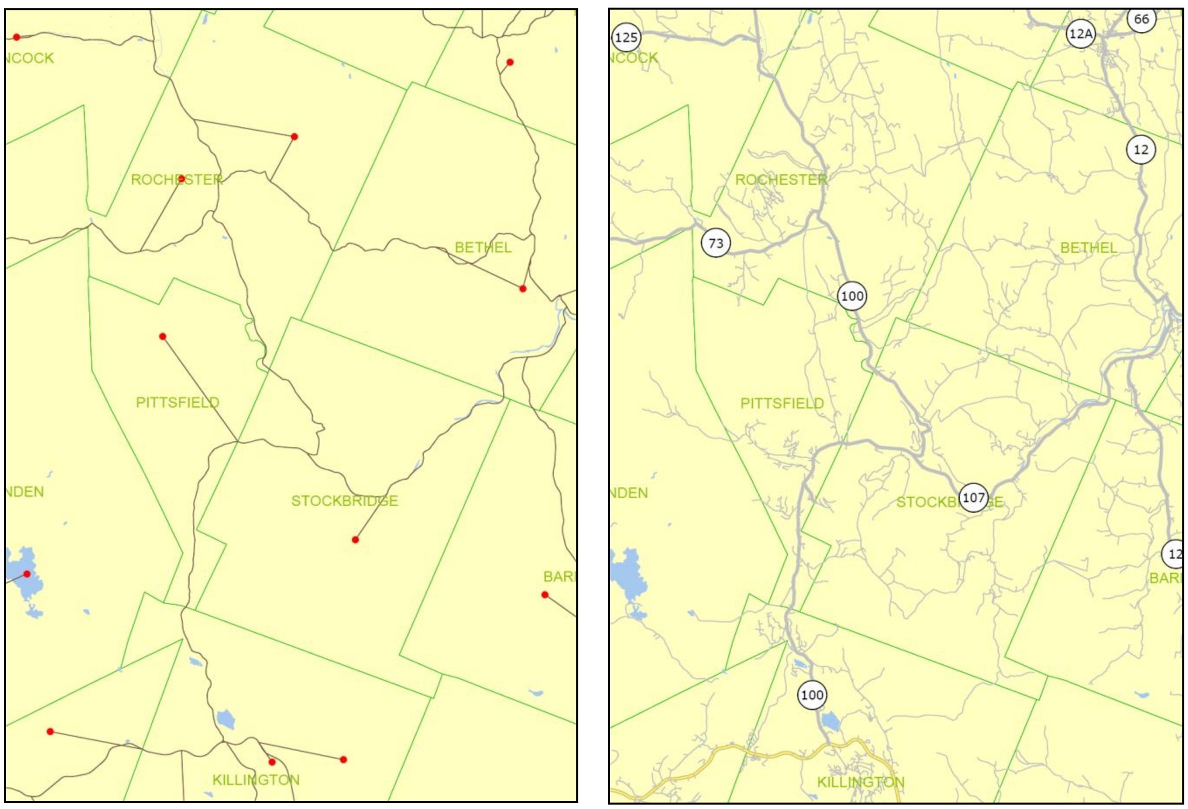

Figure 1 Roadway Representation Example in the Vermont Travel Model

Still 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 and the University of Vermont Transportation Research Center – all which from time to time may rely on the model for transportation planning and research activities.

The model is currently in the Cube/Voyager software platform. The model has a base year of 2000 and forecast years of 2020 and 2030. The model divides Vermont into 698 TAZs, of which 70 represent external zones in New Hampshire, Massachusetts, New York, and Quebec, as shown in Figure 2.

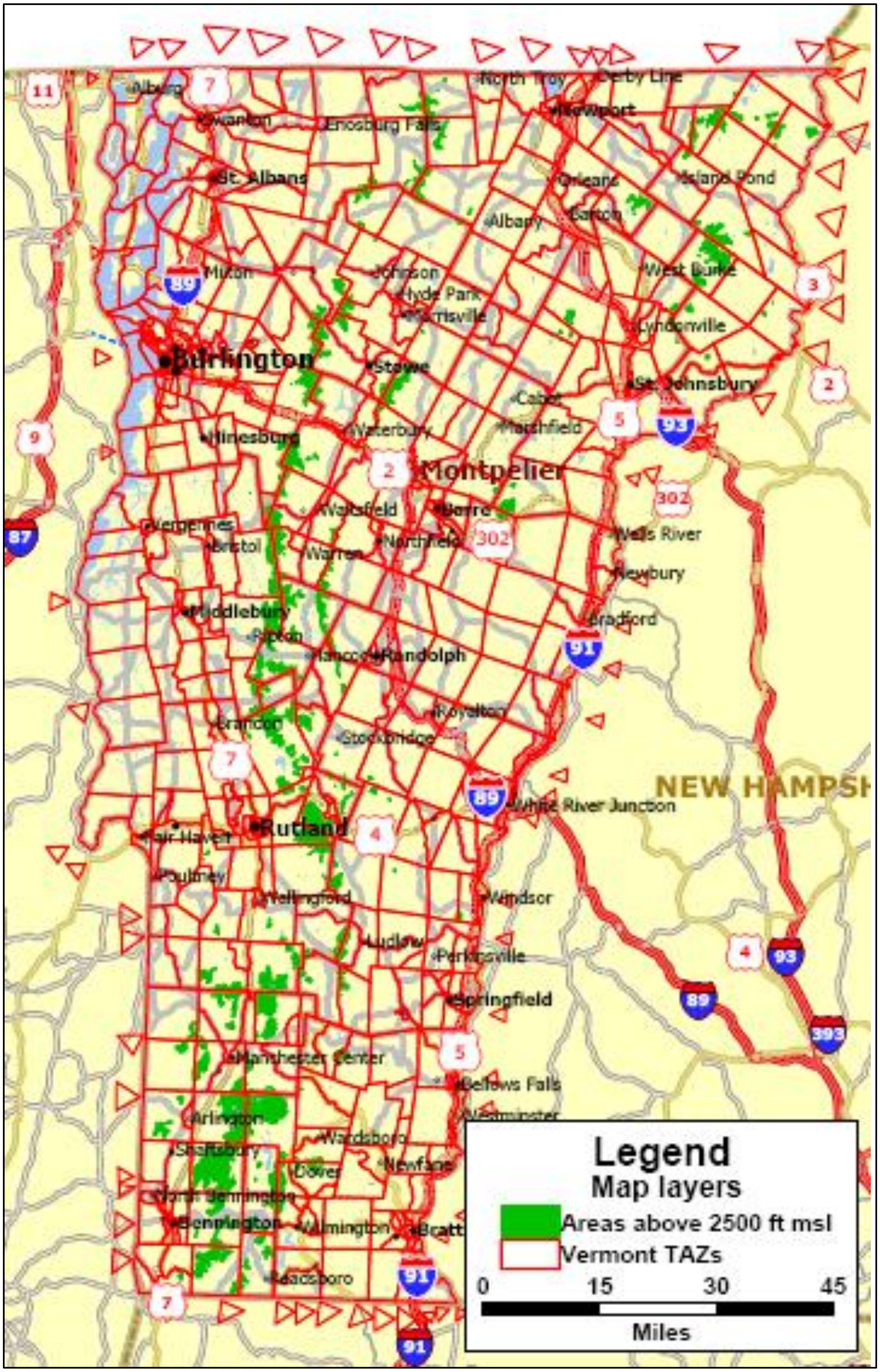

Figure 2 TAZs in the Vermont Travel Model

Small towns are typically divided into between 1 and 5 TAZs, while larger towns and cities have considerably finer zonal resolution. Trip generation information is estimated for each of six trip-purposes (home-based work, home-based shopping, home-based school, home-based other, non-home-based, and truck) based on the 2000 US Census, a 1994 statewide household survey, and March 2000 data from the Department of Employment and Training of the Vermont Department of Labor (VDOL). Trip distribution is accomplished using a gravity model. The traffic assignment phase of the model uses a user-equilibrium assignment process.

The passenger model described above includes truck traffic by incorporating "Truck" as a trip purpose. A limited freight model has been partially developed which breaks down truck travel into medium and heavy commercial trucks, but that portion of the model is incomplete and was never calibrated for inclusion in the general model. Rail transport and non-motorized travel are not currently part of the Model.

Passenger transit is also not included in the Model, although accommodation is made for the input of an externally-developed transit trip matrix. The sole purpose of this trip matrix is to remove these person-trips from the matrix of all travel before assigning the travelers to POVs.

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 model 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 Vermont Travel Model was moved to the Transportation Research Center at the University of Vermont. 2010 – 2011 was the 3rd year that the UVM TRC has hosted the Vermont Travel Model. For most of the 2008-2009 contract-year, the TRC conducted an evaluation of the Vermont Travel 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.

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 CMEM with eight drive cycles, two per route per direction. A report was completed in September of 2009 with details of the analysis and the findings (Weeks, 2009).

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 were documented in a technical memo, dated February 26, 2010, and delivered to VTrans on March 3, 2010.

A preliminary travel analysis was also conducted for the Route 22A Corridor near Fair Haven, Vermont in association with a VTrans contractor. The results of this travel analysis, which included queries of the model for link-specific data, was documented in a technical memo, dated and delivered to Stantec and VTrans on July 2, 2010.

As the data from the National Household Travel Survey (NHTS) began to roll in during the late summer of 2010, the UVM TRC prepared a work plan for the task of updating the Model with information from the 2009 NHTS and the US Census. The update was initiated by compiling statistics on auto-occupancy and trip generation rates from the NHTS.

2.2 Functionality of the Model

The figures in Attachment A illustrate the model processes which comprise the Trip Generation and Trip Distribution modules. In the figures, model inputs and outputs are shown as boxes, whereas model processes are indicated by block arrows. The parameters inside the block arrows are used in the process represented by the arrow. Capitalized names in parentheses represent actual input or process look-up tables used by the model. The Mode Choice and Traffic Assignment modules of the model are simpler processes and contain fewer parameters to be updated. Diagrammatic representation of these modules will be included in subsequent phases, but a narrative description of the Mode Choice module is included here.

2.2.1 Trip Generation

The trip-generation scripted CUBE application starts by combining the TAZ-based land-use data with the town-based fraction of household-size / vehicle-ownership cross-classifications to calculate home-based trips produced by each internal TAZ from the look-up rate table. It then calculates trip attractions for each internal TAZ by purpose and trip-productions for the non-home-based (NHB) purpose using a purpose-specific set of regression equations, each of which utilizes different 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 NHB trips. These truck percentages are classified by regional planning commission (RPC), presumably from traffic counts on roads within each RPC's region. These trips are then removed from the NHB purpose and transferred to the TRUCK purpose.

External productions and attractions are calculated differently. First, external TRUCK trips are taken to be the ADT for the external zones listed in the TAZ characteristics table (presumably 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 external vehicle-trips (VTs) is taken as the remaining fraction of the 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 six trip purposes in the model for each of the 698 internal and external zones. However, since the production and attraction estimates for the internal TAZs came from different procedures for each of the four home-based trip purposes, they do not match, as is typical of a model which estimates travel throughout the day. In other words, the model assumes that most home-based trips end the same day that they began, so the home-based productions and attractions must match. 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 applying the balancing factors to the internal trip attractions only, iteratively until 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 six trip purposes in the model for each zone.

2.2.2 Trip Distribution

The trip-distribution scripted CUBE application takes the balanced trip table, a matrix of free-flow travel times between TAZs and a table of friction factors by trip purpose to develop a matrix of productions and attractions between all zones. The table of friction factors actually contains the output of the impedance functions for a production-constrained gravity model, by free-flow travel time between zones, as shown in Table 1.

Table 1 Existing Impedance Functions in the Vermont Travel Model

Trip Purpose	Impedance Function		a	b	c
HBO	Gamma	$f(c_{ij}) = a * t_{ij}^{-b} * e^{-c(tij)}$	139,173	1.285	0.094
HBSCH	Gamma	$f(c_{ij}) = a * t_{ij}^{-b} * e^{-c(tij)}$	139,173	2.000	0.094
HBSHOP	Exponential	$f(c_{ij}) = e^{-c(tij)}$			0.150
HBW	Gamma	$f(c_{ij}) = a * t_{ij}^{-b} * e^{-c(tij)}$	28,507	0.020	0.123
NHB	Gamma	$f(c_{ij}) = a * t_{ij}^{-b} * e^{-c(tij)}$	219113	1.332	0.100
TRUCK	Exponential	$f(c_{ij}) = e^{-c(tij)}$			0.065

The gravity model is implemented with a built-in CUBE function for each trip purpose. As the function runs, it looks up the friction factor for each trip purpose which corresponds to the free-flow travel time between the two TAZs, and uses it to run the gravity model. The result of this step is a matrix of productions and attractions between all zones.

The final step in the trip-distribution application is to convert this matrix into a matrix of origin-destination (O-D)-based trips. Since the model is a daily model, all trips are expected 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 transposed, added to the original, and then all cells are halved. The result is a diagonally-symmetric O-D matrix of PTs.

2.2.3 Mode Choice

The full functionality of the scripted mode-choice application in CUBE is not currently enabled in the model. The full functionality could develop transit mode-shares by person-trip from a comparison of the highway travel times and the transit travel times between each O-D pair. In lieu of this functionality, the model currently requires an input matrix of internal person-trips for transit by trip purpose. For the current layout of the model, these matrices were developed externally by applying trip generation tools in TRANPLAN to the land-use characteristics in the TAZ characteristics table. The resulting matrices are simply subtracted from the diagonally-symmetric O-D matrix of PTs for each trip purpose for all internal zones in the matrix. The matrices resulting from this step are then divided by a vehicle-occupancy to convert them from person-trips by vehicle to vehicle-trips. The vehicle occupancies currently used in the base-year 2000 model are shown in Table 2.

Table 2 Vehicle Occupancy Rates in the Existing Vermont Travel Model

Trip Purpose	Internal Trips	Internal to External & External to Internal Trips
Home-Based Work	1.15	1.74
Home-Based Shopping	1.37	1.74
Home-Based School	10.0	1.74
Home-Based Other	1.56	1.74
Non-Home-Based	1.39	1.74
Truck	1.00	1.00

The final matrix, including all external vehicle-trips, is assigned to the road network in the traffic assignment module.

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 The 2009 National Household Travel Survey in Vermont

3.1.1 Summary of the Release

The Full National Data of the 2009 National Household Travel Survey (NHTS) became available in early January 2010. The NHTS Vermont Add-On Data became available in pieces in early March 2010. The TRC began securing institutional review board (IRB) approval to use the data immediately, receiving final mission to use the Add-On data, including the home and work addresses of participants, on April 26, 2010.

The TRC began with the task of evaluating the quality of the Add-On data set so that it could be defensibly used for a variety of research endeavors. The Data Quality Analysis was substantially completed in late June 2010, and a large number of potential errors, inconsistencies, anomalies, and missing information were discovered. The FHWA notified the Add-On recipients in a May 20, 2010 email communication that

> *A discrepancy between the numbers of nationwide transit trips reported by the NHTS and by FTA's National Transit Database (NTD) was brought to our attention. While we do not expect that these two sources match exactly given somewhat different trip definitions, data collection techniques, and data collection limitations, we do expect them to be statistically similar once adjustments are made for such differences. What we have found is that the transit estimates from the NHTS data are higher than those made using the NTD data, which motivated us to look into the data processing methods.*
>
> *While examining the data processing procedures, we paid particular attention to how we treated outliers. The results of this review led us to the decision to enhance the weights by adding more precise geographic dimensions to the raking and weight trimming steps, which should particularly reduce the effect of outliers on estimated travel. We expect that the revised weights will provide enhanced estimates for transit and potentially other estimates of travel by low-income households. The enhancement will also allow us the opportunity to use the newly released 2008 American Community Survey (ACS), which was not available at the time when the original data was collected.*

In July of 2010, the use of the 2009 NHTS data was postponed until the updated version of the data could be used. In early November 2010, the updated version

(Version 2.0) of the 2009 NHTS Add-On for Vermont was received and the TRC completed its initial evaluation of the data.

3.1.2 General Data Description

The 2009 NHTS is a public data set which provides information to assist transportation researchers, planners and policy makers who need comprehensive information on travel and transportation patterns in the United States. It contains travel-diary survey information regarding the participant's trips, modes of travel, and distances of travel throughout a typical day. The TRC, together with the Chittenden County Metropolitan Transportation Organization (CCMPO), and the Vermont Agency of Transportation (VTrans), funded an "add-on" to the nation-wide NHTS, with the goal of providing enough Vermont-specific data to allow comprehensive research focused on our state. The agreement for Vermont included 1,500 households, with Chittenden County oversampled with 500 households, rural Chittenden County towns oversampled from that 500, and rural Vermont Counties oversampled from the remaining 1,000. These sample results were received and compiled into a cleaned geo-coded database of 1,690 households. As part of the "add-on" program, the partners also received a private data set with the geographic locations of the origins (typically home) and destinations (work, shopping, etc.) of all recorded trips.

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

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

The five tables delivered in the 2009 NHTS Vermont Add-On were converted into a database, linked by the HOUSEID field and new key fields for the Persons Table (PERSONKEY, which concatenates HOUSEID and PERSONID) and the Vehicles Table (VEHICLEKEY, which concatenates HOUSEID and ID). The database relationships amongst the four tables are illustrated in Figure 3.

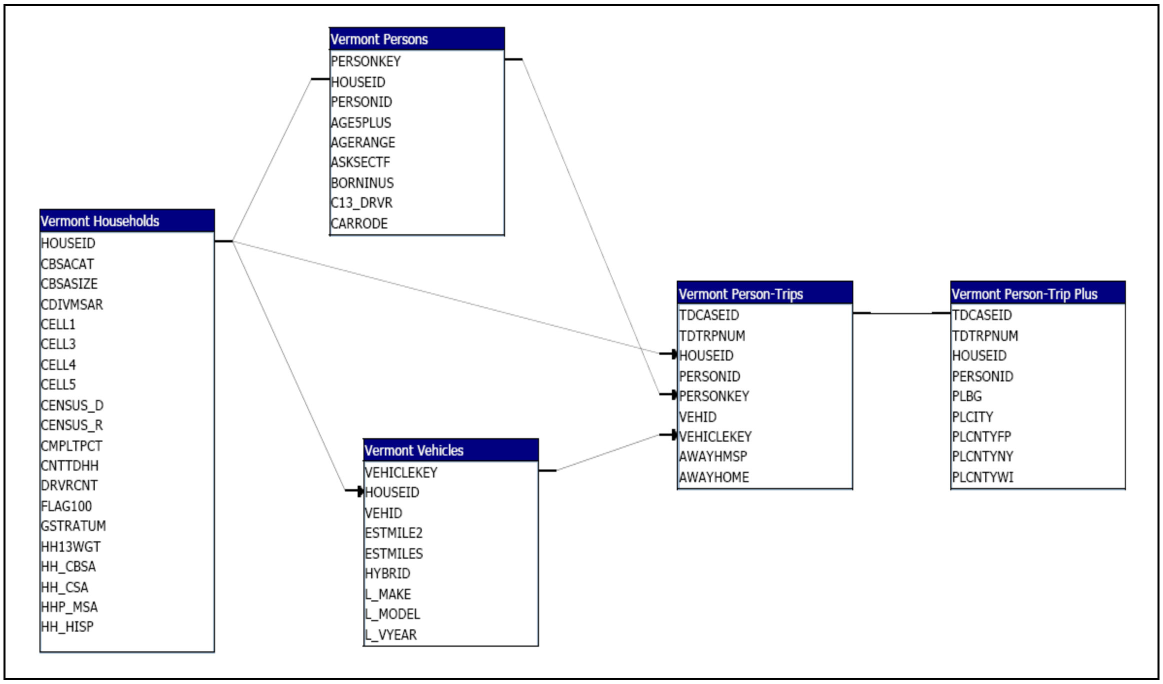

Figure 3 2009 NHTS Vermont Database Structure

Negative variables in the NHTS data have special meanings:

- "-1" indicates an appropriate or legitimate skip, meaning that the question leading to that variable was not asked of this respondent.
- "-7" indicates that respondent refused to answer
- "-8" indicates that the respondent didn't know the answer
- "-9" indicates that a coded response could not be ascertained from the information given by the respondent

These negative variables are removed when calculating statistics, like means or averages, with the data.

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

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

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

3.1.3 Vermont Households Table

This data table contains 1,690 independent 8-digit identification numbers one for each household sampled. Households are defined as "completed" (and included in the data set) if at least 50% of the adults in the household complete the extended interview. 1,491 of the 1,690 VT households completed the survey for every member of the household. All 14 Vermont counties are represented and all 365 days of the year are represented. We had an unusually high number of travel-days sampled in November of 2008, and an unusually low number in March of 2008. However, we have very even representation of the seven days of the week. We had the best income representation by far at the highest income level (> $100,000). Table 3 contains a summary of the continuous (numerical) variables in the Vermont Households Table.

Table 3 Summary of Continuous Variables in the Vermont NHTS Households Table

Variable Description	Sum	Mean	Count	St. Dev.	Variance
Number of drivers in the household	3,044	2	1,690	1	1
Count of household members	3,814	2.26	1,690	1.13	1.28
Count of household vehicles	3,512	2	1,690	1	1
Count of household members 18 years and older	3,115	1.84	1,690	0.64	0.41
Count of responding persons in the household	3,434	2.03	1,690	1.04	1.08
Number of workers in the household	1,840	1.09	1,690	0.89	0.8
Household weight	252,580	149	1,690	132	17,404

3.1.4 Vermont Persons Table

This data table identifies 3,550 person-records from the 1,690 Vermont households. There are responses in the Person Table related to general travel habits which are in some ways duplicative of travel-diary information which ended up in the Person-Trip Table. The other information in the Person Table consists of general demographic information. Many of the "Travel to Work" variables in the Person Table have a relatively low response, since these questions were not asked unless the response to the question about the primary activity on the travel day was "Working".

Therefore, response rates for variables in the Person Table are strongly related to conditions of the interview. General travel habits questions, like number of walk or bike trips taken last week, have good response rates since these questions were asked of almost everyone, except those not capable of independent trips (respondents aged 0 to 4). "Travel to School" questions were only asked of a selected subset of the respondents involved in school-related travel. So response rates were highest for the General Travel questions (over 3,400), then for Internet Usage questions (about 3,000), then for Travel to Work questions (about 1,750), then for Travel to School questions (about 260). Table 4 contains a summary of the continuous (numerical) variables in the Vermont Persons Table.

Table 4 Summary of the Continuous Variables in the NHTS Vermont Persons Table

Variable Description	Sum	Mean	Count	St. Dev.	Variance
One-way distance to workplace	21,250	13.82	1,538	20.06	402.34
Euclidean distance from home to work	16,421	9.32	1,761	35.73	1,276.83
Final travel-to-school weight	79,991	22.53	3,550	110.03	12,105.51
Final person weight	616,571	173.68	3,550	177.05	31,346.82
Miles driven during past 12 months (mi.)	29,733,367	12,756	2,331	10,783	116,274,186

3.1.5 Vermont Vehicles Table

This data table identifies 3,520 vehicle-records from the 1,690 Vermont households. There are responses in the Vehicle Table related to general characteristics of household vehicles and to the amount that the vehicle(s) is driven. Table 5 contains a summary of the continuous (numerical) variables in the Vermont vehicles Table.

Table 5 Summary of the Continuous Variables in the NHTS Vermont Vehicle Table

Variable Description	Sum	Mean	Count	St. Dev.	Variance
Miles vehicle driven since respondent purchased (mi.)	2,448,379	5,603	437	6,777	45,921,484
Odometer reading (mi.)	211,355,393	76,384	2,767	63,725	4,060,863,991
Age of the vehicle (yr.)	28,954	8.5	3,389	7.5	56.2
Miles vehicle driven last 12 months (mi.)	26,503,400	10,139	2,614	8,535	72,839,483
How long vehicle owned (mo.)	176,339	52.9	3,335	51.6	2,663

3.1.6 Vermont Person-Trips Table

This data table identifies 13,119 person-trip records (from 3,550 person-records). All of the information in this data table comes from the travel-diary responses. The Person-Trip Table contains unique records for each person on a trip. If two persons took the same trip together, there is a separate record for each of them. There is currently no unique trip field in the Person-Trip Table. The creation of a new field which concatenates HOUSEID, STRTTIME (trip start time), ENDTIME (trip end time), and TRPTRANS (travel mode) reveals 10,949 unique trips in the data set. Table 6 contains a summary of the continuous (numerical) variables in the Vermont Person-Trips Table.

Table 6 Summary of the Continuous Variables in the NHTS Vermont Person-Trips Table

Variable Description	Sum	Mean	Count	St. Dev.	Variance
Time spent at destination of trip – minutes	1,130,794	111.53	10,139	153.49	23,559

Variable Description	Sum	Mean	Count	St. Dev.	Variance
Trip distance in miles	144,818	11.13	13,006	49.5	2,451
Derived trip time – minutes	264,764	20.21	13,101	31.1	967
Calculated travel time – minutes	267,298	20.41	13,099	32.02	1,025.40
Trip time – minutes	201,311	15.39	13,080	11.68	136
Final trip weight	8.01E+08	61,069	13,119	61,824	3.82E+09

3.1.7 Geocoded Locations

A full assessment of the quality of the geographic data was conducted to determine the usefulness of the geographic data for travel modeling. The key variables related to the geo-coding quality (HOMEGEO, WORKGEO, and TRPEDGEO) share the same coding: system, as described in Table 7.

Table 7 Coding System for Geocoded Variables in the NHTS

Code	Description
01	Matched to street address
02	Matched to nearest intersection
03	Matched to the nearest landmark's street address or nearest intersection
04	Matched to geographic ZIP code centroid
05	Matched to Census "Designated Place" centroid
06	Matched to state
07	Left unmatched

Coordinates were provided for records with a geo-coding quality of 01 to 05.

3.1.7.1 Individual Home and Work Locations

Geo-coding quality of household locations was very good. 82% of the household locations were matched to the address, with the rest matched to either the nearest intersection or a zip code centroid. As a further check on the quality of the geo-coding results for household locations, a minimum error for every point was determined as the distance from each point to the nearest residential structure in the E911 habitable-structures GIS for Vermont. Summary statistics on this minimum-error value are provided in the Table 8.

Table 8 Summary of the Minimum-Error Values in Geocoding of Household Locations

		Minimum Error Dist. (miles)	No. of Values Greater Than 0.31 miles
All Points	Minimum	0.00	9*
	Maximum	1.68	
	Mean	0.04	
Matched to street address	Minimum	0.00	6
	Maximum	1.68	
	Mean	0.04	
Matched to nearest	Minimum	0.00	0
	Maximum	0.14	

		Minimum Error Dist. (miles)	No. of Values Greater Than 0.31 miles
intersection	Mean	0.04	
Matched to geographic ZIP code centroid	Minimum	0.01	3
	Maximum	1.25	
	Mean	0.07	
* All of these were rural households			

Generally, the home locations that had been matched only to the nearest zip code (HOMEGEO = "04") had a higher mean minimum-error than those which had been matched to a street address or the nearest intersection. Interestingly, the mean minimum-error of households which were matched to a street address or an intersection were identical. All 9 locations which exceeded 0.31 miles were in rural areas. Perhaps differences would be revealed if the true error in these geo-codings could be identified. Very few of the geo-coding matches (only 9 of 1,690) exceed ½ the theoretical maximum walking distance, but certainly a geo-coding location which could only match to the nearest zip code ("04") or worse is questionable for use in modeling non-motorized travel.

Geo-coding quality of work locations was also very good, with 85% of the persons identified as workers (49% of all persons in the table) having their work locations geo-coded to the nearest address. Another 12% had their work locations geocoded to the nearest intersection. 18 of the remaining persons could not be matched to any geocoding. The 51% of the respondents in the Person Table who are not identified as workers (including young, retired, and unemployed persons), did not have work locations geocoded.

Geo-coding quality of all other trip-destinations is recorded in the Person-Trip+ Table. 63% of the trip-destinations were geo-coded to the nearest address, indicating a low degree of quality in the geo-coding effort. Another 25% of the trip-destinations, however, were geocoded to the nearest intersection, which could be miles from a residence in many rural Vermont towns.

3.1.7.2 Origin-Destination Pairs

The quality of trip origin-destination pairs was assessed by cross-classifying the trip-destinations according to the quality of the trip-destination geocoding and the household-location geocoding. This cross-classification is represented in Table 9.

Table 9 Cross-Classification for Geocoding of Origin-Destination Pairs in the NHTS

	TREDGEO	01	02	03	04	05	06	07	-9
HOMEGEO	01	7,575	2,391	152	433	45	84	74	147
	02	347	660	20	65	12	11	5	21
	04	359	263	6	413	1	14	10	11

58% of the trip origin-destination pairs were geo-coded to the nearest address, indicating a low degree of quality in the geo-coding effort. 85% of the trip origin-destination pairs (highlighted area) were geo-coded to the nearest address, intersection or landmark, indicating a high portion of trips that are potentially acceptable for non-motorized travel modeling. However, 66% of those pairs are in rural areas of the state, where the possibility of mismatched geo-coding is higher.

3.2 The 2005 – 2009 American Community Survey

The American Community Survey (ACS) is an ongoing survey by the U.S. Census Bureau that provides data every year, giving communities the current information they need to plan investments and services. Information from the survey generates data that help determine how more than $400 billion in federal and state funds are distributed each year. The ACS is conducted every year on a smaller scale than the decennial census to provide up-to-date (but less reliable) information about the social and economic needs of American communities.

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. For the Model update, household counts by town in Vermont for the pooled years 2005-2009 were used.

3.3 The 2009 Vermont Annual Average Covered Employment and Wages

The Covered Employment and Wages Data is a product of the Quarterly Census of Employment and Wages (QCEW) program in Vermont, and is accessible by town at the Vermont Department of Labor website, with annual and quarterly data from 1978 for employment by state, county, and town areas. The QCEW is a cooperative program involving the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor and the State Employment Security Agencies (SESAs). The program produces a comprehensive tabulation of employment and wage information for workers covered by state unemployment insurance laws and federal workers covered by the Unemployment Compensation for Federal Employees (UCFE) program. Employment data under the QCEW program represent the number of covered workers who worked during, or received pay for, the pay period including the 12th of the month. For the Model update, employment data by town in Vermont for 2009 were used.

3.4 The 2009 Average Annual Daily Traffic Volumes

AADT for 2009 in Vermont were obtained from a GIS developed and maintained by VTrans. This data layer includes data collected from 1990 through 2009 for interstate highways, federal highways, state highways, federal urban area routes and major collectors. Not all of the roadways in the model are represented with AADT counts or estimates. Procedures for estimating AADT are well established and rely on automated counting methods to collect continuous count data at a relatively small number of sites (Cambridge Systematics 1994; Wright, Hu et al. 1997; FHWA 2001). VTrans had a total of 170 permanent, continuous traffic counters available in 2009, in the locations shown in Figure 4.

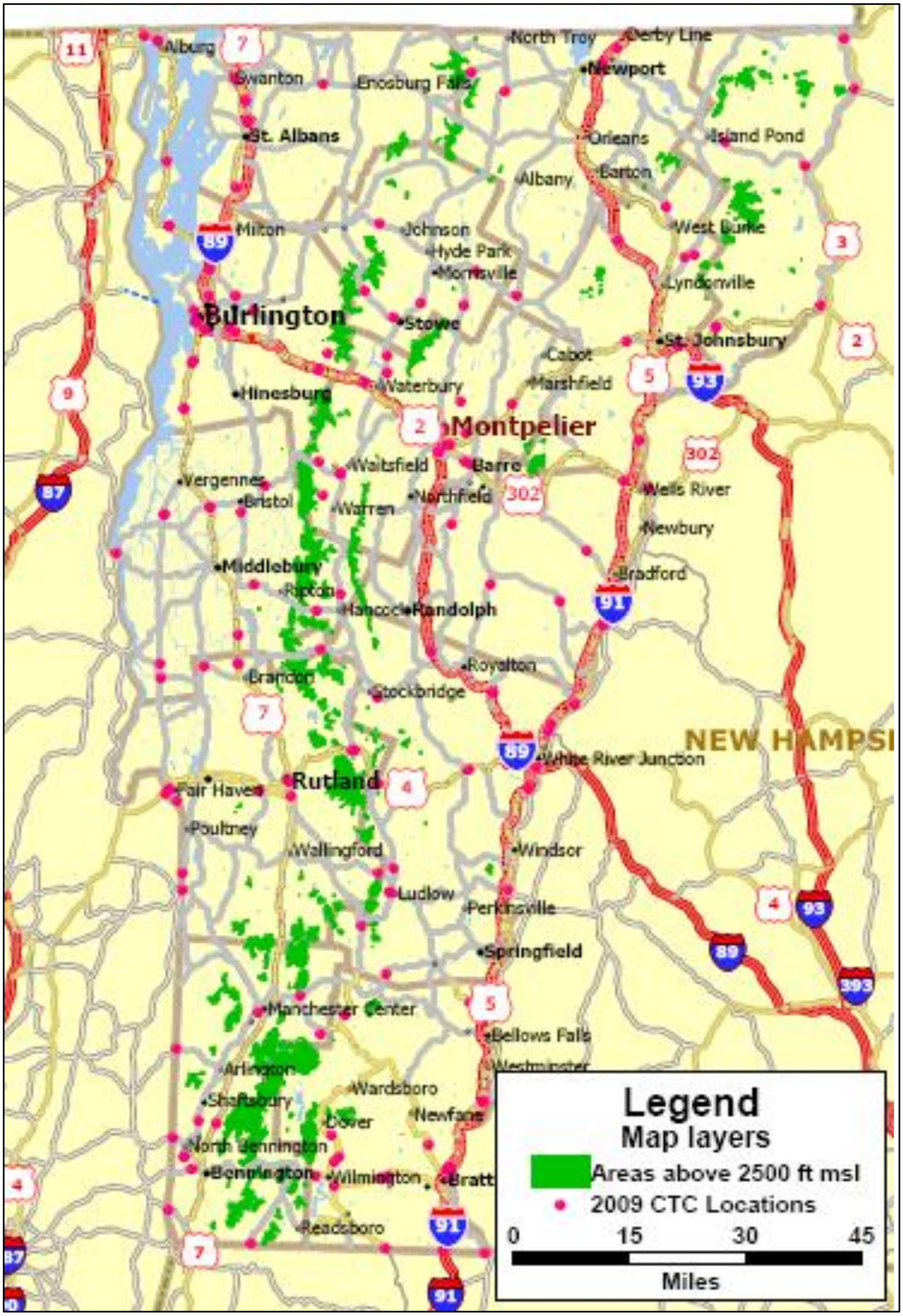

Figure 4 Continuous Traffic Counter Locations in Vermont

Based on these continuous counts, a series of adjustment factors are calculated to account for variations in traffic levels at different hours of the day, days of the week and months of the year. These adjustment factors are then applied to more numerous, short-duration counts taken at roadways with similar traffic patterns, creating comprehensive estimates of annual average daily traffic (AADT) on all road links within a given study area. The total data set of traffic counts available for AADT estimates statewide in 2009 was over 6,000.

4 Methodology and Results

4.1 Land-Use Characteristics Update

4.1.1 Employment Update

Employment data from the QCEW is stratified by ownership type (private, federal, state, and local) and by North American Industry Classification System (NAICS) code. These industries were mapped to the employment categories used by the model as shown in Table 10.

Table 10 NAICS Classification Mapping to Model Categories

<table>
<tr><th colspan="3">NAICS Industries</th><th rowspan="2">Mapped to Model Category..</th></tr>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td rowspan="3">Goods Producing</td><td colspan="2">Manufacturing</td><td>MANUFACTURING</td></tr>
<tr><td colspan="2">Construction</td><td rowspan="3">NON-MANUFACTURING</td></tr>
<tr><td colspan="2">Natural Resources and Mining</td></tr>
<tr><td rowspan="12">Service Providing</td><td rowspan="4">Trade, Transportation, and Utilities</td><td>Wholesale trade</td></tr>
<tr><td>Retail trade</td><td>RETAIL</td></tr>
<tr><td>Transportation / Warehousing</td><td rowspan="5">NON-MANUFACTURING</td></tr>
<tr><td>Utilities</td></tr>
<tr><td colspan="2">Information</td></tr>
<tr><td colspan="2">Financial Activities</td></tr>
<tr><td colspan="2">Professional and Business Services</td></tr>
<tr><td rowspan="3">Education and Health Services</td><td>Elementary and Secondary Schools</td><td>PRIMARY SCHOOL</td></tr>
<tr><td>Colleges and Universities</td><td>UNIVERSITY</td></tr>
<tr><td>Government Not Public Education</td><td>GOVERNMENT</td></tr>
<tr><td colspan="2">Leisure and Hospitality</td><td rowspan="2">NON-MANUFACTURING</td></tr>
<tr><td colspan="2">Other Services Except Public Administration</td></tr>
</table>

Having data at the town level, though, is not directly useful, since the model relies on a geographic level, the TAZ, that is usually smaller than its town. Figure 5 shows the boundaries of a few TAZs and towns in southwestern Vermont, illustrating this relationship. The triangles represent external TAZs. For example, the town of Dorset includes TAZs 39 and 40, and the town of Manchester includes at least 4 different TAZs. Therefore, the job numbers by town must be allocated down to the individual TAZs within the town. Jobs by town, (J) were allocated to job totals for individual TAZs (j) for each job class in the same proportion as the existing allocations (k) as follows:

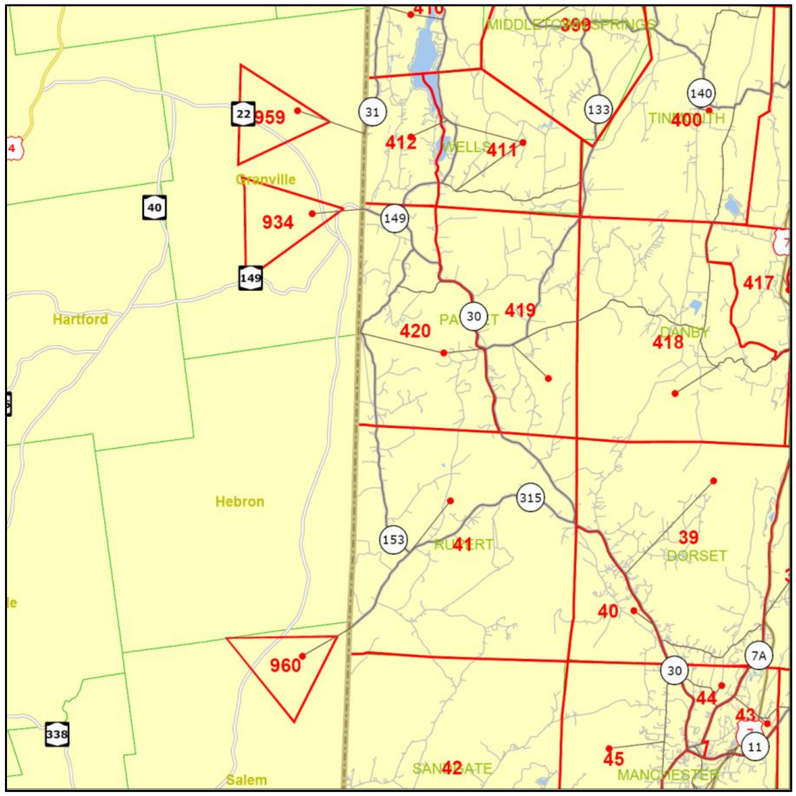

Figure 5 Model TAZ-to-Town Relationship Example

$j_n = J_N \left(k_N / \sum_n k_n\right)$ for all TAZs *n* in town *N*

Such that $J_N = \sum_n j_n$ for all TAZs *n* in town *N*

4.1.2 Number of Households Update

The release of the 2005-2009 ACS 5-year estimate coincided with the release of the 2009 NHTS. Therefore, the ACS data for households by town in Vermont was used to update the model. Similar to the employment update, households were allocated from towns to TAZs as follows. Households by town, (H) were allocated to households for individual TAZs (h) in the same proportion as the existing allocations (i) as follows:

$h_n = H_N \left(i_N / \sum_n i_n\right)$ for all TAZs *n* in town *N*

Such that $H_N = \sum_n h_n$ for all TAZs *n* in town *N*

4.2 Trip Rate Table Update

The model currently uses a trip-rate table to estimate the number of home-based trips produced by each household in the state. Recognizing that households with different characteristics tend to produce different numbers of trips, the existing rate table uses a cross-categorization of the number of people in the household, or household size, and the number of vehicles owned by the household as the most significant. As shown in the existing trip rate table (Table 11), larger households and households with more vehicles tend to make more trips per day.

Table 11 Existing Model Trip-Rate Table

Category		Existing Home-Based Trip Rates for...				
No. of People in Household	No. of Vehicles	Work	Other	School	Shopping	Total
1	0	0.864	1.08	0	0.45	2.394
1	1	1.08	1.44	0	0.63	3.15
1	2	1.08	1.62	0	0.63	3.33
1	3	1.08	1.62	0	0.63	3.33
1	4 or more	1.08	1.62	0	0.63	3.33
2	0	1.08	1.62	0	0.72	3.42
2	1	1.512	2.25	0.09	1.08	4.932
2	2	1.944	2.43	0.09	1.17	5.634
2	3	2.16	2.52	0.09	1.26	6.03
2	4 or more	2.16	2.61	0.27	1.62	6.66
3	0	2.16	2.07	0.27	0.9	5.4
3	1	2.268	2.88	0.63	1.26	7.038
3	2	2.7	3.33	0.63	1.35	8.01
3	3	3.24	3.6	0.63	1.44	8.91
3	4 or more	3.456	3.78	0.72	1.44	9.396
4 or more	0	2.268	3.78	0.72	1.17	7.938
4 or more	1	2.484	4.5	1.8	1.44	10.224
4 or more	2	3.024	5.04	2.07	1.53	11.664
4 or more	3	3.672	5.4	1.8	1.62	12.492
4 or more	4 or more	4.86	5.58	1.8	1.71	13.95

As shown in the table, these rates are provided separately for four trip purposes – home-based work (HBW), home-based other (HBO), home-based school (HBSCH), and home-based shopping (HBSHOP).

The trip-rate table update was performed using two separate methods. The first method assumed that the household size and number of vehicles are indeed the most significant factors in home-based trip-productions and the rates in the table were updated directly from the NHTS. The second method re-estimated the most significant factors in home-based trip production in Vermont from the NHTS, then updated the trip rates using a new cross-classification scheme.

For the both methods, it was first necessary to isolate only those person-trips in the Person-Trip Table which started and ended in Vermont. These types of trips are denoted “internal-internal”, or I-I. I-I person-trips were identified in two supplemental ways, since only the location of the destination for each trip is explicitly provided by the NHTS. First, if the trip's destination state was Vermont and the destination state of the previous trip for the same person that day was Vermont, then the trip was taken to be I-I. Second, trip's which started the day for an individual who was confirmed to have begun the day at home (FRSTHM) and listed Vermont as their destination state were taken to be I-I. No other trips could be confirmed to be I-I. The total person-trip records in the Person-Trip Table was 13,119. Eliminating those trips whose purpose was unknown or were not home-based resulted in 8,892 records. Of these, 8,396 person-trips were confirmed to be I-I and 274 were confirmed to be internal-to-external (I-E). Another 222 of these person-trips could not be confirmed to be either I-I or I-E. Following this reduction, the tally of person-trips for each purpose in each household category in the table was weighted using the household-level weights and divided by the weighted number of households in each category.

During the reduction process, it was evident that there would not be enough home-based school trips in the NHTS to support defensible trip rates for any of the household categories. This lack may be evidence of an increasing trend for home-based school trips to be combined with other travel, such as travel by a parent to work, which would fall under HBW. Due to this trend, and the relatively low trip rates for the HBSCH purpose in the existing table, it was determined that the HBSCH purpose would be combined with the HBO purpose.

4.2.1 Method 1

Summing the weighted number of trips for each purpose and dividing by the weighted number of households in each of the existing cross-classification categories. With the HBSCH purpose eliminated, the trip rates shown in Table 12 resulted, with the standard deviations shown.

Table 12 Initial Trip-Rate Estimate from the NHTS

Category			Home-Based Trip Rates (and standard deviations, σ) for…					
No. of People in Household	No. of Vehicles	No. of Households	Shopping	σ	Other	σ	Work	σ
1	0	59	0.77	0.04	0.52	0.05	0.16	0.02
1	1	279	1.05	0.01	1.21	0.01	0.34	0.01
1	2	60	1.08	0.07	1.02	0.11	0.57	0.05
1	3	14	2.40	0.42	0.97	0.52	0.63	0.23
1	4 or more	4	0.68	1.17			0.97	0.80
2	0	7	1.47	0.47	1.48	0.65	0.27	0.28
2	1	121	1.24	0.02	1.89	0.03	0.50	0.01

Category		No. of Households	Home-Based Trip Rates (and standard deviations, σ) for…					
No. of People in Household	No. of Vehicles		Shopping	σ	Other	σ	Work	σ
2	2	455	1.53	0.01	1.89	0.01	1.09	0.01
2	3	140	2.04	0.04	1.67	0.06	1.03	0.03
2	4 or more	67	1.84	0.10	1.92	0.14	0.92	0.06
3	0	0						
3	1	15	2.71	0.13	3.15	0.17	0.63	0.07
3	2	85	1.38	0.03	3.16	0.04	1.66	0.02
3	3	82	1.88	0.05	3.71	0.08	1.69	0.04
3	4 or more	38	1.76	0.09	2.93	0.13	2.02	0.07
4 or more	0	1	5.00	1.11	4.00	1.08		
4 or more	1	18	2.63	0.10	7.71	0.17	0.60	0.05
4 or more	2	134	2.10	0.02	5.85	0.04	0.89	0.01
4 or more	3	62	1.54	0.06	7.68	0.11	1.64	0.04
4 or more	4 or more	49	2.19	0.07	4.47	0.11	1.47	0.05

Also shown in the table are the number of households in the NHTS that fit into the category shown. For one of the categories, there were no households in the NHTS that fit the cross-classification (households with 3 people and 0 vehicles are unusual), so it was impossible to estimate a trip rate. For other categories, there were very few households but no HBO trips. These classifications are indicated by the blank cells in Table 12. For these categories, the nearest rate with the strongest statistical power (lower standard deviation) in the table was used in order to ensure that the resulting rates were non-decreasing as both classifications increased. In other words, it was assumed that a household with 2 people and 2 vehicles had to take at least as many trips per day as a household with 1 person and 2 vehicles.

For other categories, the size of the household sample was low, and the standard deviation of the resulting trip rate was unacceptably high. These categories included the households with 1 person and 3 or more vehicles, and households with 2 or more people and no vehicles. These categories are boxed in Table 12. For most of these categories, the same non-decreasing substitution was conducted. However, for a few, the nearest rate corresponded with a category that was substantially different from the one in question. Where this was the case, the existing trip rate was used.

Following each of these substitutions, the final trip rates shown in Table 13 resulted. The resulting change in total trips per day from the existing rates to the new rates is also shown.

Table 13 Final Trip-Rate Updates Using the Existing Model Classifications

Category		New Home-Based Trip Rates for…				% Change
No. of People in Household	No. of Vehicles	Work	Other	Shopping	Total	

Category		New Home-Based Trip Rates for…				
No. of People in Household	No. of Vehicles	Work	Other	Shopping	Total	% Change
1	0	0.16	0.52	0.77	1.45	-65%
1	1	0.34	1.21	1.05	2.60	-21%
1	2	0.57	1.21	1.08	2.86	-16%
1	3	1.08	1.62	1.08	3.78	12%
1	4 or more	1.08	1.62	1.08	3.78	12%
2	0	0.50	1.48	0.72	2.70	-27%
2	1	0.50	1.89	1.24	3.64	-36%
2	2	1.09	1.89	1.53	4.52	-25%
2	3	1.09	1.89	2.04	5.02	-20%
2	4 or more	1.09	1.92	2.04	5.05	-32%
3	0	0.63	2.34	0.90	3.87	-40%
3	1	0.63	3.15	1.38	5.16	-36%
3	2	1.66	3.16	1.38	6.20	-29%
3	3	1.69	3.71	1.88	7.28	-22%
3	4 or more	2.02	3.71	1.88	7.61	-23%
4 or more	0	0.60	4.50	1.17	6.27	-27%
4 or more	1	0.60	5.85	2.10	8.55	-20%
4 or more	2	0.89	5.85	2.10	8.84	-32%
4 or more	3	1.64	7.68	2.10	11.42	-9%
4 or more	4 or more	1.64	7.68	2.19	11.51	-21%

4.2.2 Method 2

The second method of updating the trip rate table offers an alternative to the use of household size and number of vehicles as the most significant factors in trip-producing behavior amongst Vermont households. Other factors considered in this analysis included:

- Number of drivers in the household
- Household family income range
- Number of workers in the household
- Number of adults in the household

The goal here is to determine which two of these variables and the existing variables best explain trip-producing behavior in Vermont. Using the total I-I trip counts per household assembled for Method 1, a simple regression was performed, using the trip count as the dependent variable, and the household characteristics as the independent variables. To prepare for the regression, a correlation matrix with the R^2 value for all of the variables was developed, as shown in Table 14.

Table 14 Correlation Matrix of Household Characteristics from the Vermont NHTS

	I-I Trip Count	No. of Drivers	Income Range	Household Size	No. of Vehicles	No. of Workers	No. of Adults
I-I Trip Count	1						
No. of Drivers	0.47	1					
Income Range	0.25	0.35	1				
Household Size	0.51	0.70	0.30	1			
No. of Vehicles	0.25	0.62	0.31	0.43	1		
No. of Workers	0.41	0.58	0.40	0.51	0.43	1	
No. of Adults	0.34	0.83	0.26	0.68	0.55	0.52	1

Using an r^2 value of 0.80 or higher as an indication of correlation between two of the variables, it is apparent that none of the variables being considered are correlated. In addition, on their own, none of the independent variables exhibits a correlation with the dependent variable, I-I trip count. Interestingly, the number of vehicles owned by the household – a variable used in the existing model to predict trip-producing behavior, is shown to be one of the weakest correlations with the I-I trip count.

Not surprisingly, then, the first attempt to develop a regression model, using all of the independent variables to estimate trips produced per household, indicates that the two most weakly correlated independent variables, household income and number of vehicles, also contribute least to that model's fit. Based on these results, those two variables were not considered further in this analysis.

The next model developed resulted in a similar R^2 value but the strength of each variables contribution to the model fit was improved. However, this model resulted in a counter-intuitive result – the number of adults in the household was shown to negatively influence trip counts. Therefore, the number of adults was also eliminated from consideration.

In both of the previous models, household size was shown to contribute most to the model fit, so it was decided at this point to test this independent variable in a model with each of the other two remaining independent variables – number of drivers in the household (Model A) and number of workers in the household (Model B). The regression results for these two final models are shown in Table 15.

Table 15 Trip Production Per Household Regression Results for Model A and Model B

	Model A			Model B		
	No. in Household of..			No. in Household of..		
Regression Statistic	**People**	**Drivers**	**b**	**People**	**Workers**	**b**
β (or b)	1.337	1.130	-0.310	1.502	0.950	0.318

Regression Statistic	Model A			Model B		
	No. in Household of..		b	No. in Household of..		b
	People	Drivers		People	Workers	
standard error value	0.106	0.154	0.220	0.087	0.110	0.191
t-statistic	12.589	7.341	-1.409	8.612	17.184	1.665
coefficient of determination	0.285			0.293		
standard error for the y estimate	3.518			3.497		
F statistic	336			350		
degrees of freedom	1,687			1,687		
regression sum of squares	8,318			8,558		
residual sum of squares	20,874			20,633		

The models are similar, but the fit of Model B is better. The t-statistic for number of workers is higher (as it is for a model with both number of workers and number of drivers) and the resulting r^2 of Model B is slightly higher than that of Model A. In both models, the intercept (b) is shown to contribute very little to the model fit, when their t-statistics are compared with the critical t-statistic for the 95% confidence level of -1.65. This result is expected, since we would expect the real intercept to be 0. That is, for a household with no people in it, we would expect no trips to be produced. Enforcing a 0-intercept to Model B results in a considerably better fit, and the final accepted model, as shown in Table 16.

Table 16 Final Model B Trip Production Per Household Regression Results

Regression Statistic	Household Size	Number of Workers
coefficient (β)	1.605	0.970
standard error value	0.061	0.110
t-statistic	24.487	12.244
coefficient of determination	0.692	
standard error for the y estimate	3.499	
F statistic	1,900	
degrees of freedom	1,688	
regression sum of squares	46,527	
residual sum of squares	20,667	

Method B, then, revealed that, in fact, the number of vehicles owned by a household is not a significant contributor to trip-producing behavior in Vermont, and the number of workers is a preferable factor to use alongside the size of household to cross-classify a trip table for the Vermont Travel Model.

Using this new information, a new trip rate table was developed with cross-classification of household size and number of workers. Table 17 provides the new trip rates and number of households in each cross-classification category.

Table 17 Final Trip-Rate Updates Using the Updated Model Classifications

Category: No. of People in Household	Category: No. of Workers	No. of Households in the NHTS	New Home-Based Trip Rates for…: Work	Other	Shopping	Total
1	0	250	0.00	1.08	0.98	2.06
1	1	166	0.61	1.14	1.08	2.83
2	0	234	0.00	1.74	1.33	3.07
2	1	285	0.63	1.74	1.33	3.70
2	2	271	1.56	1.98	1.51	5.06
3	0	13	0.00	2.15	1.51	3.66
3	1	67	0.71	2.67	1.51	4.89
3	2	107	1.56	3.45	1.51	6.52
3	3 or more	33	2.27	3.45	1.91	7.63
4 or more	0	14	0.00	3.71	1.64	5.35
4 or more	1	87	0.71	4.25	1.64	6.61
4 or more	2	118	1.56	6.28	1.97	9.81
4 or more	3 or more	45	2.44	7.51	1.97	11.93

4.3 Regression Equations Update

Non-home-based trip productions and trip attractions for all purposes (except TRUCK) are determined by the model using regression equations for internal trips. The primary assumption here is that the factors which influence a region's propensity to attract travel (or produce NHB trips) are more complex than what can be captured by a simple cross-classification rate table. For example, it is widely accepted in the transportation community that the tendency for an area to attract shopping trips can be related primarily to the number of retail jobs in the area. Whereas the propensity to attract HBW trips will be more related to the total number of jobs in the area. For all of the regression equation updates performed in Year 3, the factors assumed to be significantly related to trip production or attraction counts were the same as those in the existing equations, as shown in Table 18.

Table 18 Existing Model Regression Equation Coefficients

<table>
<tr><th rowspan="3">Variable (No. of…)</th><th colspan="6">β (regression coefficients)</th></tr>
<tr><th rowspan="2">NHB (Productions)</th><th colspan="5">Attractions</th></tr>
<tr><th>NHB</th><th>HBW</th><th>HBSHOP (Urban)</th><th>HBSHOP (Rural)</th><th>HBO</th></tr>
<tr><td>Households</td><td>0.30</td><td>0.30</td><td></td><td></td><td></td><td>1.1432</td></tr>
<tr><td>Retail Jobs</td><td>1.14</td><td>1.14</td><td rowspan="4">1.45</td><td>4.11</td><td>6.66</td><td rowspan="4">1.18</td></tr>
<tr><td>Manufacturing Jobs</td><td>0.67</td><td>0.67</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Non-Manufacturing Jobs</td><td>1.72</td><td>1.72</td></tr>
<tr><td>Government Jobs</td><td>2.45</td><td>2.45</td></tr>
</table>

Variable (No. of…)	β (regression coefficients) NHB (Productions)	Attractions NHB	HBW	HBSHOP (Urban)	HBSHOP (Rural)	HBO
Primary School Jobs	1.48	1.48				
University Jobs	1.48	1.48				

Since most of these coefficients were assumed and not calculated, separate estimates for NHB productions and attractions were not possible, which explains why the two sets of coefficients are identical. With the NHTS, there is an opportunity to make separate estimates of NHB productions and attractions.

As a household-based survey, the NHTS is not an ideal data source for updating trip attractions. A household-based survey will naturally provide more information about trips that are home-based than a destination-based survey would. However, the NHTS still represents the best travel information for the state and it is possible to control potential mis-estimations that might result from a lack of data by aggregating the study region when appropriate. For this reason, the regression updates were repeated at the TAZ level, the town level, and the county level. Only statistically defensible data was used to update the model.

For all of the regression updates, the internal person-trip table developed previously was used as the data source. From this data, it was possible to count the weighted numbers of trips by purpose attracted to each internal TAZ, town, and County in the state, along with the number of NHB trips produced at each spatial level. All intercepts were assumed to be 0, meaning that if the factors affecting trip attractions were absent, then it was assumed that no trips would be attracted. This assumption also meant that areas where no trips had been attracted (or produced) were excluded in the regression estimation, which helped resolve the difficulties associated with a household-based survey being used for a destination-based update. The regression estimation results at the TAZ level are shown in Table 19.

Table 19 TAZ-Level Regression Equation Update Results

Variable (No. of…)	β (regression coefficients) Non-Home-Based Productions	Non-Home-Based Attractions	Attractions for Home-Based… Work	Shopping Urban	Shopping Rural	Other
Households	**2.20**	**0.82**				**2.06**
Retail Jobs	**1.07**	**2.93**	**0.60**	**2.41**	**0.83**	**0.31**
Manufacturing Jobs	-0.20	**0.93**				
Non-Manufacturing Jobs	0.03	**0.65**				
Government Jobs	-0.39	**1.30**				
Primary School Jobs	-1.03	0.42				
University Jobs	-0.05	0.15				
r-squared	0.42	0.64	0.47	0.30	0.05	0.55

Values shown in **bold** contributed significantly to the model fit, at a tolerance level of 0.05

Coefficients for home-based shopping trip attractions were performed separately for urban and rural TAZs, as was done in the existing model. The existing distinctions between urban and rural TAZs in the model were maintained for this analysis. Coefficients whose t-statistic revealed that they contributed significantly (at the 0.05 tolerance level) to the fit of the model are shown in bold, as is the r-squared statistic. Based on the r-squared values and the number of coefficients which significantly contributed to the model fit, it was determined that only the coefficients for NHB attractions would be used from the TAZ level regression estimate to update the model. This decision meant that those coefficients would also apply to the NHB productions, since the model assumes that NHB productions and attractions are equal at the TAZ level.

Each of the remaining regression estimates (for HBW, HBSHOP (urban and rural), and HBO attractions) was carried forward to be analyzed at a more aggregate spatial scale. Due to the low r-squared values yielded by the TAZ-level analysis, it was expected that the town-level analysis would not improve the estimates very much, so the next step was to estimate the regression coefficients for HBW, HBSHOP, and HBO at the County level. The results of this analysis are shown in Table 20.

Table 20 County-Level Regression Equation Update Results

<table>
<tr><th rowspan="3">Variable (No. of…)</th><th colspan="4">β (regression coefficients)</th></tr>
<tr><th colspan="4">Attractions for Home-Based…</th></tr>
<tr><th>Work</th><th>Shopping (Urban)</th><th>Shopping (Rural)</th><th>Other</th></tr>
<tr><td>Households</td><td></td><td></td><td></td><td>1.04</td></tr>
<tr><td>Retail Jobs</td><td rowspan="7">0.83</td><td>5.80</td><td>2.52</td><td rowspan="7">1.12</td></tr>
<tr><td>Manufacturing Jobs</td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td>Non-Manufacturing Jobs</td></tr>
<tr><td>Government Jobs</td></tr>
<tr><td>Primary School Jobs</td></tr>
<tr><td>University Jobs</td></tr>
<tr><td>r-squared</td></tr>
</table>

<table>
<tr><td>r-squared</td><td>0.96</td><td>0.90</td><td>0.45</td><td>0.99</td></tr>
<tr><td colspan="5">Values shown in bold contributed significantly to the model fit, at a tolerance level of 0.05</td></tr>
</table>

Although each of the estimates' coefficients at the County level contributes significantly to the model fit, that fit for rural HBSHOP travel is still fairly poor. In addition, the coefficient for the rural HBSHOP regression equation is unusually low when compared to the existing value (2.52 vs 6.66). Therefore, a third regression estimate was made at the town level for the rural HBSHOP coefficient only. At this level, a coefficient of 6.69 resulted, with an improved r-squared value of 0.54. Although this continues to be the most poorly-fit model in each of the updated regression estimates, the similarity of the new coefficient to the existing coefficient (6.69 vs 6.66) lends additional credibility to its use in the update. Including this value, then, the final set of regression coefficients used for this update is shown in Table 21.

Table 21 Final Regression Equation Update Results

<table>
<tr><th rowspan="3">Variable (No. of…)</th><th colspan="5">β</th></tr>
<tr><th rowspan="2">NHB (Productions & Attractions)</th><th colspan="4">Attractions</th></tr>
<tr><th>HBW</th><th>HBSHOP (Urban)</th><th>HBSHOP (Rural)</th><th>HBO</th></tr>
</table>

<table>
<tr><td>Households</td><td>0.82</td><td></td><td></td><td></td><td>1.043</td></tr>
<tr><td>Retail Jobs</td><td>2.93</td><td rowspan="6">0.83</td><td>5.80</td><td>6.69</td><td rowspan="6">1.119</td></tr>
<tr><td>Manufacturing Jobs</td><td>0.93</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Non-Manufacturing Jobs</td><td>0.65</td></tr>
<tr><td>Government Jobs</td><td>1.30</td></tr>
<tr><td>Primary School Jobs</td><td>0.42</td></tr>
<tr><td>University Jobs</td><td>0.15</td></tr>
<tr><td>r-squared</td><td>0.64</td><td>0.96</td><td>0.90</td><td>0.54</td><td>0.99</td></tr>
</table>

4.4 Vehicle Occupancy Rates Update

Vehicle occupancy rates are used in the model convert person-trips to vehicle trips by trip purpose. The primary assumption here is that often more than one person occupies a vehicle in Vermont, and that the tendency for increased vehicle-occupancy is related to the purpose of the trip. For example, most national statistics confirm that vehicles making commuting trips tend to have fewer occupants than vehicles making shopping trips. The NHTS provides an ideal data source for updating the vehicle occupancy rates in the model.

Before the NHTS could be used for this update, though, it was necessary to reduce the person-trip data in multiple steps. When person-trips were taken together (two or more people took a trip together), separate entries were made in the Person-Trip Table for each one. This process is correct when person-trips are being logged, but will result in a mis-estimation of vehicle occupancy rates if all but one of the person-trips for a group-trip is not eliminated before the calculation. The creation of a new field which concatenates the household ID, the start time, the end time, and the mode of travel revealed that there were in fact only 10,949 unique trips in the data set (of 13,119 total person-trips). Of these, only those trips which were taken in a privately-owned vehicle (car, van, SUV, pickup truck, other truck, RV, or motorcycle), or POV, were considered in the calculation of vehicle occupancy rates. This reduction step was performed for two reasons, the first is that the Vermont Travel Model only requires vehicle occupancy rates for privately-owned vehicles (POVs), other occupancy rates are assumed. The second reason is that there are alternative viewpoints in the modeling community about how occupancy rates should be counted on non-POV trips. For example, in a transit bus, should we consider the vehicle occupancy to be only those occupants of the bus who are indeed travelling together, or should we consider all of the bus' occupants? For two family members making a walking trip together, should we consider two separate trips, since no "vehicle" is involved? These types of questions make it infeasible to use the concept of vehicle occupancy in model for anything but POV trips. Following this reduction, 8,980 POV vehicle trips resulted.

Following this reduction to POV vehicle trips, it was also then necessary to isolate internal (I-I) and external (I-E or E-I) trips. This isolation used a similar process to the one used in the trip-rate table update described previously. Following this reduction, the 8,980 vehicle-trips had been brought down to 8,274 internal vehicle trips and 422 external vehicle trips.

Once all of the reductions had been performed, the vehicle occupancies could be directly calculated from an average of the field representing the number of people on the trip (NUMONTRP). The updated vehicle occupancy rates, compared to the existing rates, are shown in Table 22.

Table 22 Existing and Updated Vehicle-Occupancy Rates in the Model

	Existing		Updated		% Change	
Trip Purpose	Internal Trips	External Trips	Internal Trips	External Trips	Internal Trips	External Trips
Home-Based Work	1.15	1.74	1.13	1.05	-2%	-66%
Home-Based Shopping	1.37	1.74	1.48	1.93	7%	10%
Home-Based Other	1.56	1.74	1.75	1.85	11%	6%
Non-Home-Based	1.39	1.74	1.51	1.78	8%	2%
Truck	1.00	1.00	1.00	1.00	0%	0%

For the TRUCK purpose, there were only 5 vehicle-trips remaining after the reductions, so the calculation of a vehicle-occupancy was not feasible. Therefore, the existing vehicle occupancy for TRUCK trips of 1.00 was maintained.

4.5 External Trip-Fractions and External Daily Trip Counts Update

External trip rates are calculated directly from daily trip counts for all external TAZs in the model. This calculation is possible because there is an external TAZ for every major roadway leaving the state, so the daily traffic counts on these roadways represent feasible estimates of the daily trips taken to/from the state. These daily trip counts were taken from the AADTs for 2009 from the VTrans GIS.

The AADTs for most of these external links also include a vehicle classification, which distinguishes between commercial truck traffic and POV traffic. From this classification, expressed as a fraction of all traffic, it is possible to estimate the daily trip count to/from each external TAZ for the TRUCK purpose. Where this classification was not available, it was estimated from an adjacent roadway with similar capacity which also leaves the state. Again referring to Figure 2 for an example, if the truck classification was not available for the traffic count for Route 149 (exiting the state to external TAZ 934), then the TRUCK fraction from the nearest similar-capacity roadway (in this case, Route 31) was used as the TRUCK fraction for TAZ 934.

The remaining daily traffic at these external TAZs was assumed to be POV, whose trip purposes are represented in the model as HBW, HBO, HBSHOP, and NHB. The model uses a fractional split between these purposes to estimate the number of daily trips for each purpose at all external TAZs. In other words, it is assumed that the same fraction of the POV trips by trip purpose exists at all of the roadways leaving the state. Using the NHTS, it was possible to update this fraction with the 422 external vehicle trips isolated from the Person-Trip Table previously. The weighted fraction represented by each trip purpose in this set of trips was calculated and is shown in Table 23, along with the existing fractions in the model.

Table 23 Existing and Updated External Trip-Fractions in the Model

Purpose	Existing Fractions in the Model	Weighted Fractions in the NHTS
Home-Based Work	30.0%	8.8%
Home-Based Other	38.0%	21.3%
Home-Based Shopping	17.0%	15.0%
Non-Home-Based	13.6%	54.9%

It was important that vehicle-trips be used in this case, instead of person-trips, since the fractions apply directly to traffic counts, not to people. So once the external POV trips are classified by their trip purpose, that fraction can be applied to the POV traffic count and an estimate of daily external vehicle-trips by trip purpose can be incorporated into the model. From these estimates, the vehicle-occupancy rates calculated previously can be applied to get estimates of external person-trips by trip purpose, when that data is needed.

An example of this estimation of external daily vehicle trips for the three roadways leaving the state in Figure 5 is shown in Table 24 below.

Table 24 Sample Estimation of External Daily Trip Counts by Purposes

			2009	Daily Vehicle-Trips (Production and Attractions) in the Model				
		2009	AADT					
TAZ	Roadway	AADT	Truck %	Truck	Work	Other	Shopping	NHB
960	Route 153	890	7.0	62	72	176	124	454
959	Route 31	1,390	6.4	89	114	277	195	714
934	Route 149	4,030	6.2	250	333	805	567	2,075

4.6 Internal TRUCK Trips Update

Previously, updates have been described for internal and external POV trips for the four POV purposes (HBW, HBO, HBSHOP, and NHB) and for external trips for the TRUCK purpose. For internal TRUCK trips, it is not feasible to use regression methods to estimate trips, since these commercial trips are primarily based on proprietary data specific to industries in each of the TAZs. This type of data is difficult to obtain, so other methods must be explored.

The internal TRUCK trips update was performed using two separate methods. The first method assumes that truck traffic counts are roughly equivalent to daily truck trips, and bases the TRUCK trips off the fraction of trucks in the 2009 AADTs. The second method utilizes a newer O-D matrix estimation process, in which the traditional traffic assignment process is reversed. Each of these methods results in a O-D matrix of TRUCK trips for all internal TAZs in the state. Both methods rely on the AADTs for truck traffic statewide. Since the classification of vehicles requires a permanent traffic counter, truck counts are not as readily available as aggregate AADT estimates. Of the over 3,400 AADTs available for 2009, only 397 included classification of commercial trucks. The mean percentage of trucks from these counts was 5.8%.

4.6.1 Method 1

The first method, and the one used in the existing Model process, allows an input of the fraction of internal trips by RPC that are commercial trucks. This fraction is removed from the internal NHB trips determined previously, and assumed to represent TRUCK travel in the TAZ. The remainder of the NHB trips are assumed to be POV trips. In the past, these inputs presumably came from the average fractions trucks from traffic counts within the RPC. The current GIS of AADTs, however, allows these fractions to be calculated by TAZ, providing a more location-specific estimate of the fraction of truck traffic in the aggregated traffic counts.

The drawback of this method is that it equates truck traffic counts with truck trips, and that equation could lead to errors in the estimation of travel. For the same trip, a certain truck might appear in the daily traffic count at 3 or 4 different locations in a single TAZ. In addition, if a truck trip is relatively short, the same truck may appear twice at a certain count location on the same trip. Using each appearance of a truck as a contribution to counting the fraction of truck trips in the TAZ would be incorrect in both of these cases. So this approach assumes that truck counts are sparse, and truck trips are relatively long, so these types of errors are minimized.

4.6.2 Method 2

The second method takes advantage of a relatively recent computational process for estimating an O-D matrix directly from traffic counts. This method assumes that traffic counts themselves are stochastic, and their measurement includes some degree of error. In addition, traffic counts may present an infeasible balance of traffic flow. The O-D matrix estimation procedure used requires an initial O-D matrix. In this application, the existing Model O-D matrix for TRUCK trips was used, along with every available count of truck traffic from the 2009 AADTs.

4.7 Trip-Distribution Friction-Factor Update

The Model currently uses a table of friction factors by trip purpose to develop a matrix of productions and attractions between all TAZs. These friction factors are simply the output of the impedance functions for the standard Gravity Model for trip distribution. An impedance function describes a curve of values which are used to estimate a trip-length distribution for the Gravity Model trip-distribution. The trip-length distributions which result from the application of the Gravity Model to the existing Model impedance functions are shown in Figure 6.

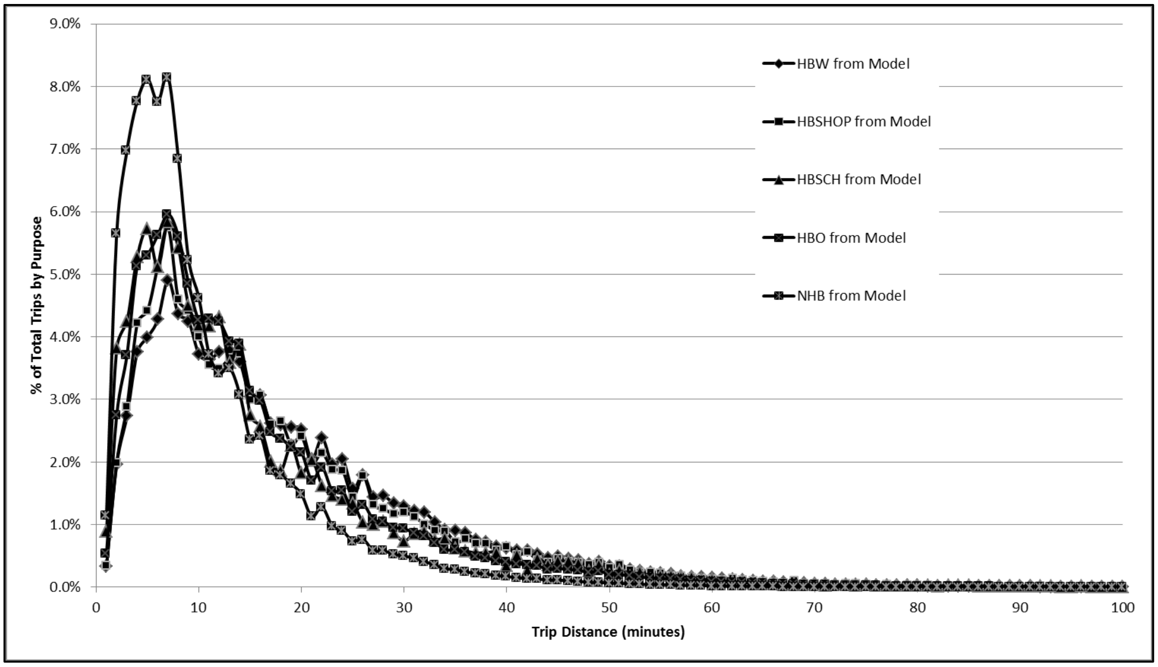

Figure 6 Existing Trip Distributions in the Model by Trip Purpose

The person-trips included in the Person-Trip Table of the NHTS can be used to update these curves. In fact, the goal of this step is to optimize the alignment of the Model curves with those resulting from the plotting of the NHTS data. However, the histograms corresponding to the trips included in the Person-Tip Table in the NHTS are distorted by a common rounding problem with survey-reported times and distances, as shown in Figure 7.

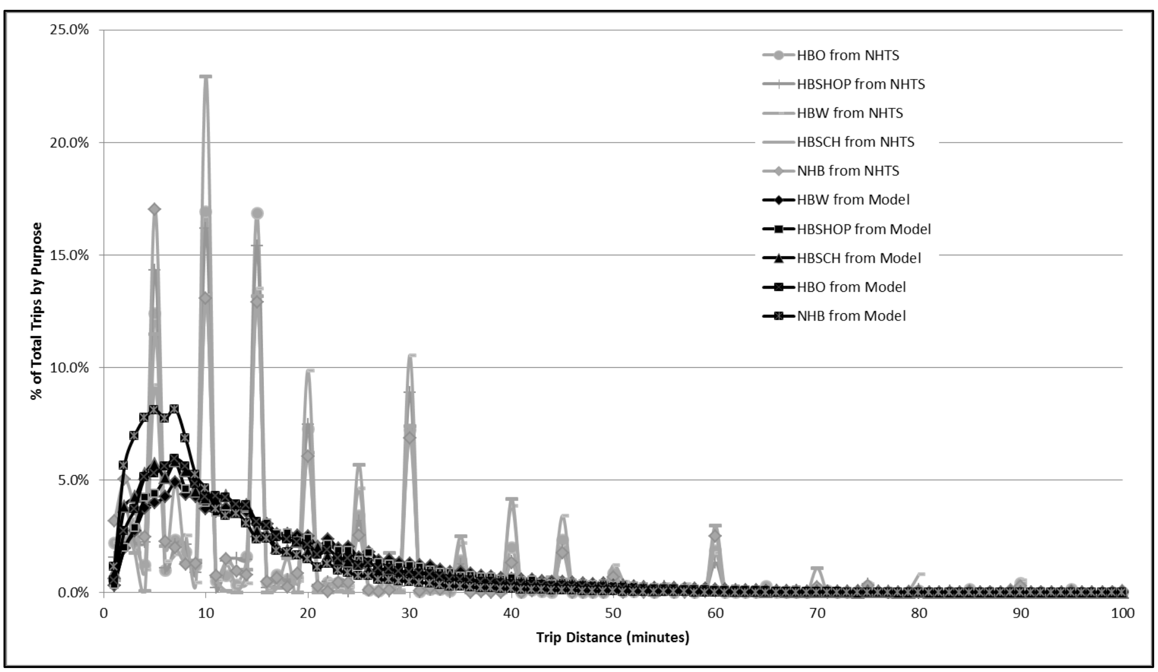

Figure 7 Existing Model and NHTS Trip Distributions by Trip Purpose

In Figure 7, it is apparent that respondents to the NHTS tended to round their travel times off to the nearest multiple of 5 or 10 minutes. This tendency does not complicate the calculation of averages or cumulative distributions, but it skews the histogram enough to make a direct determination of the real curve shape impossible. Even when both sets of curves are binned to aggregate the data, these rounding tendencies are apparent (Figure 8), particularly around the 30-minute and 60-minute distances.

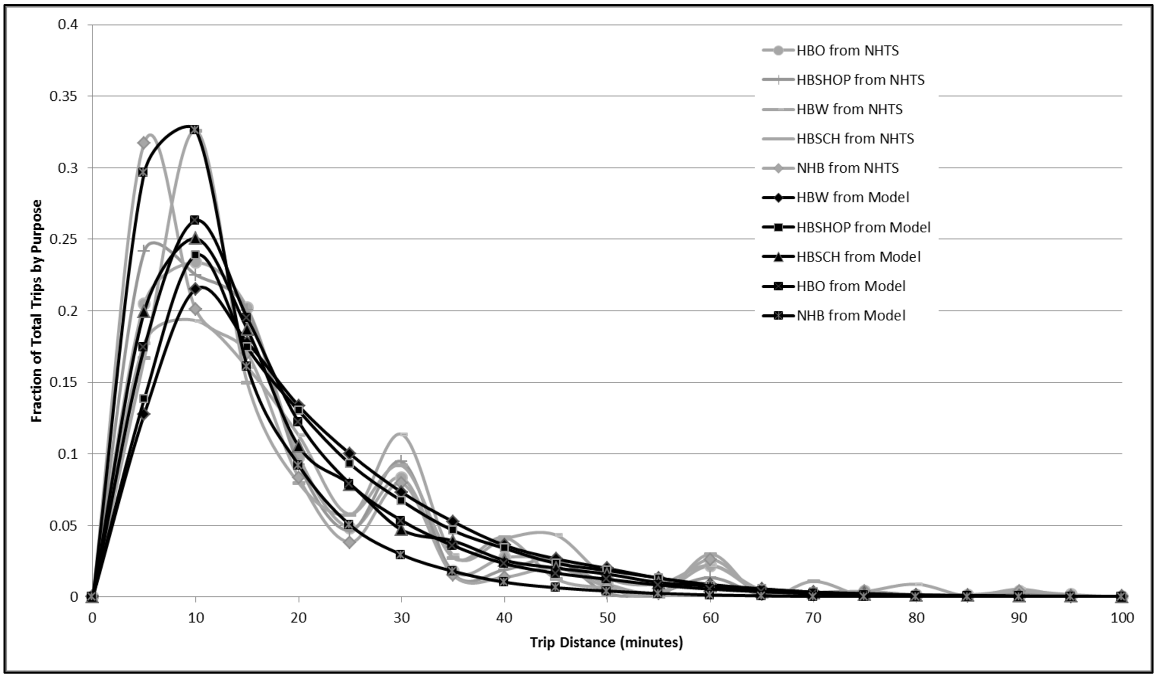

Figure 8 Existing and NHTS Binned Trip Distributions by Trip Purpose

The most accurate way of updating the Model to align the trip-distribution sub-module with the NHTS is by using TransCAD's Gravity-Model Calibration procedure. This procedure updates the impedance functions directly without explicit calculation of the friction-factors. The procedure uses the table of balanced trip production and attractions which is calculated by the trip-generation sub-module of the Model using the updated trip production information described previously, and the matrix of travel times between TAZs. Therefore, this update actually consisted of a gravity model calibration, and an update of the coefficients of the impedance functions by trip purpose described in Table 25.

Table 25 Existing and Updated Model Impedance Function Coefficients

	Existing Model Impedance Function Coefficients			Iterations Needed to Converge		Updated Impedance Function Coefficients		
Trip Purpose	**a**	**b**	**c**	**Initial**	**Final**	**a**	**b**	**c**
HBO	139,173	1.285	0.094	100	67	34,560	1.658	0.061
HBSHOP			0.150	104	63			0.111
HBW	28,507	0.020	0.123	83	55	901	0.398	0.086
NHB	219,113	1.332	0.100	61	60	94,608	1.317	0.101

Trip Purpose	Existing Model Impedance Function Coefficients			Iterations Needed to Converge		Updated Impedance Function Coefficients		
	a	b	c	Initial	Final	a	b	c
TRUCK			0.065	15	15			0.065

As shown in the table, the adjustments made to the impedance function coefficients were significant with the exception of the TRUCK purpose, whose coefficient did not change. This finding is not surprising since the TRUCK update came entirely from the AADTs whereas the other updates came from the NHTS. All of the calibrations converged and a comparison of the Model average travel times is provided in Table 26.

Table 26 Existing Model and NHTS Average Travel Times

Trip Purpose	Average Travel Times (minutes)		
	Existing Model	NHTS	Updated Model
Home-Based Other	18.6	20.5	21.4
Home-Based Shopping	20.8	17.4	25.4
Home-Based Work	21.8	20.9	26.4
Non-Home-Based	14.5	19.1	15.0
Truck	28.5		30.6

The values in this table illustrate that it was not possible to balance the trips estimated by the NHTS in a way that would create identical average travel times. This finding is not surprising since the NHTS is still a relatively sparse sample of the Vermont population, so the complete network of O-D travel is primarily estimate from the Gravity Model, and the specific trips in the NHTS are superseded by the need to balance all travel between TAZs.

Figure 9 provides the existing binned trip distribution from Figure 8 alongside the binned distribution that results from the updated impedance functions.

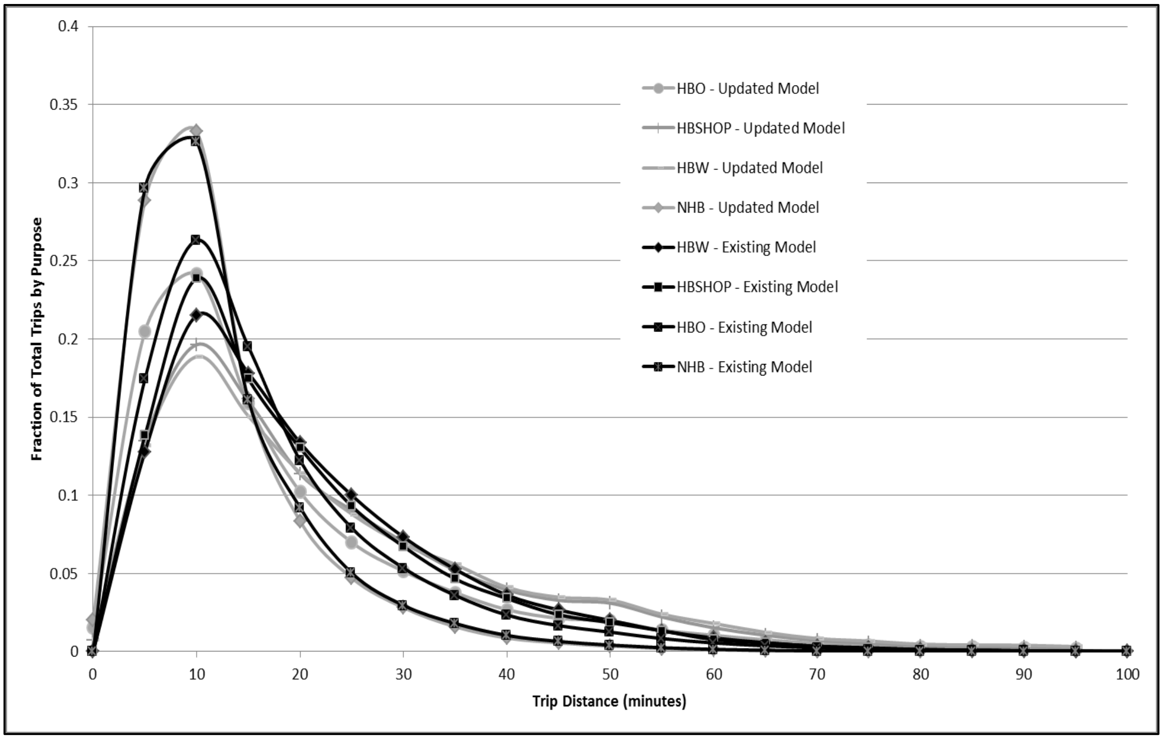

Figure 9 Updated and Existing Binned Model Trip Distributions

5 Discussion and Conclusions

This update to the Vermont Travel Model relied heavily on the 2009 NHTS. The data quality assessment of the NHTS revealed its usefulness and its limitations. Overall, it provides the first opportunity to "tune" the Model to the unique travel behaviors of Vermonters. Model inputs and coefficients were updated in the trip generation, trip distribution, and mode choice sub-modules using not only the NHTS, but other recent data as well. These updates revealed some important differences between Vermont travelers and others, along with the behaviors that may have been more prevalent in the mid-1990s, when the Model was likely to have been updated last.

The number of households in Vermont have exhibited a general increases consistent with the slow but steady growth Vermont has seen in population in the last two decades. The total number of households in the Model before the update was about 240,000. Using the 2009 ACS, that number is shown to increase to about 250,000, representing a growth rate of about 0.4% per year. Employment numbers are a bit less ubiquitous, and therefore it is not clear how the apparent decrease in total employment in from 333,000 jobs in the existing Model to about 291,000 jobs in the 2009 VDOL update can be explained without knowing where the original data came from. Although Vermont's unemployment rate was beginning to increase in 2009, this difference cannot be explained by increased unemployment. It is more likely that the VDOL data is more refined than the source of the original employment numbers, perhaps not taking into account job vacancies. In any event, the most accurate estimate of current employment in Vermont is about 291,000 jobs.

Trip-making behavior by Vermonters exhibited consistent trends in the trip-generation characteristics of the Model, including the trip-rate tables and the regression equations. In each case, the rates and frequency of home-based work trips has declined significantly, perhaps as a result of an increase in teleworking, and/or an increase in Vermonters reaching retirement age between 2000 and 2009. It may also be possible that Vermonters have a tendency to take fewer commuting trips by nature. Of course it might also be possible that Vermonters are combining their commuting trips with other purposes, causing those trips to be re-categorized to a different purpose. The NHTS certainly supports this hypothesis, as evidenced by the trip-fractions in Table 27, which exhibit increases in both HBSHOP and NHB trips with a corresponding decrease in HBW trips.

Table 27 Existing Model and NHTS Total Trip Fractions

	% of Total Trips	
Purpose	**NHTS**	**Existing**
Home-Based Other	35.3%	34.1%
Home-Based Shopping	20.6%	13.6%
Home-Based Work	13.3%	24.7%
Non-Home-Based	30.8%	21.3%

The trip-rate table in the Model was improved by regressing new classification factors, which showed that number of workers is a more effective predictor of trip-making behavior in a Vermont household than is the number of vehicles owned by the household. The new trip-rate table which includes number of workers will be accepted into the Model, since the regression statistics did not support the continued use of number of vehicles.

More refined vehicle-occupancy rates were calculated from the NHTS, providing better information about how Vermonters travel together for different purposes. Interestingly, almost all occupancy rates were higher than had been assumed in the existing Model, with the exception of commuting trips to external TAZs, which were very close to consisting of entirely single-occupancy vehicles. This finding is not surprising, since it is likely to be more difficult to share a ride to a commuting trip out of state, whose travel distance is likely to be longer than those in-state. For all other trip purposes (including HBW in-state), it appears that Vermonters are doing what they can to share fill their vehicles.

Two methods were used to provide competing updates to the TRUCK trip purpose matrix. From an early assessment, it appears that the method which used an O-D matrix estimation procedure (Method 2) may have produced a more accurate picture of commercial truck travel in Vermont. However, a more comprehensive evaluation of these methods using the root-mean-square-normalized error (RMSNE) will not be possible until the road network has been updated in the coming year. Once that update is complete, the method which produces the lower RMSNE when the flows resulting from the assignment are compared to truck traffic counts statewide will be accepted into the Model.

The differences between the average travel times in the NHTS and the updated Model may be explained by two factors, one involving the spatial resolution of the Model road network and the other involving the use of self-reported travel times. The poor resolution of the Model road network within TAZs may explain why the Model estimated travel times do not match those reported by surveyed respondents. With more network connectivity at the local level, it may be possible for travelers to reach their destination faster than the time predicted by the aggregated connector. This explanation is supported by the consistently lower travel times in the NHTS for home-based trips, which would be more affected by local “short-cuts”. It may also be true, though, that respondents to the NHTS simply under-estimate their travel times, leaving out terminal times (time spent before and after the active portion of the trip to actually reach the origin and the destination, like parking time). This omission would also explain the consistently lower average travel times in the NHTS when compared to the updated Model.

Overall, the updated Model demonstrates a substantially reduced tendency to travel by POV than the existing Model was estimating. Again, this reduction may simply be due to the use of more refined, Vermont-specific data in this update, but it might also be reflective of national travel trends in the last 10-15 years. Miles traveled by users of the highway network in the United States plateaued around 2004, and even declined in 2008 for the first time in nearly 30 years (Brookings, 2008). In fact, VMTs per capita in the United States have shown a consistent decrease since 2005, further evidence that this trend may be a long-term peak, and not simply the result of short-term gas-price hikes in 2008 (Brookings, 2008). Although the increase in gas prices in August 2008 to over $4 a gallon for the first time undoubtedly caused a further decrease in POV travel. Traffic counts in Chittenden County, for example, have not shown statistically significant increases for the last ten years. From 2004 to 2009, trends on specific roads in Chittenden County have ranged from a 10% reduction to 3% growth (VTrans, 2010). This decrease in general travel behavior has meant that as the number of households in the state has increased over the last ten years, the daily travel by each household has decreased. Indeed, daily trips by Vermont households were at 9.2 in the existing Model, but have been reduced to about 8.5 after this update. Following the Year 4 Model improvements, it will be important to compare the Vermont Travel Model to other models for states similar to Vermont to see if their trends are similar.

6 Next Steps

In Year 4, we expect to complete the update of the Model to a new base year of 2009-2010. The update will continue with relevant new data as it becomes available from the 2010 US Census and the 2006 – 2010 ACS. This data will include the number of households and population by TAZ from the US Census for 2010 and the cross-classification of number of household members and number of household workers by town from the ACS. The cross-classification will be applied to all TAZs within the town and calibrated with the population per household estimate from the US Census.

Once the updates are complete, we can begin make functional improvements to the model. First, roadways which have been constructed or improved since 2000 will be identified and we will confirm that these are correctly represented in the model network. Roads that may have been added or altered include:

- The Bennington By-Pass
- Route 2 in Danville
- Route 7 in Pittsford and Brandon
- Shelburne Road in South Burlington
- The Circulator and Adjoining Streets in downtown Winooski

The next functional improvement to the road network used by the Model will target roadways that have not been modified recently, but are simply not shown in the Model, or are shown incorrectly. Not all roads are included in the Model, and some roads may be represented without proper restrictions on turning or direction of travel (for one-way streets). Minor roads are excluded and represented in aggregate by centroid connectors. In fact, whereas there are over 21,900 miles of public roadway in the state, the model only includes about 6,200 miles of roadway. These excluded local roads might reasonably increase robustness as they offer alternatives for main routes. Therefore, without these links, when before & after analysis are conducted like the bridge closures that were investigated in Year 1, the results of the traffic analysis might be inaccurate. Using the Network Robustness' Index developed by the UVM TRC (Sullivan et al, 2010), we can identify these potentially critical links which have been omitted from the Model network. Critical links which are discovered which are not currently included in the Model road network will be properly coded and included.

Once these roadway improvements have been made, it will be possible to run the model through the assignment sub-module for the entire state, and determine the RMSNE of the updated 2009-2010 model. It will also be possible to confirm which of the TRUCK trip-estimation methods described above is more accurate. Of course, though, the Gravity Model calibration will have to be re-run using the new roadway network to calibrate the trip-distribution impedance functions.

Additional functional improvements will be made to align the Model to the extent possible with the new daily travel model of the Chittenden County Regional Planning Commission (CCRPC) to take advantage of the increased accuracy of the

CCRPC model. Zone geography and Model inputs & outputs within and around Chittenden County will be forced to match the CCRPC Model.

The feasibility and usefulness of adding a truck freight module to the Model will be explored in Year 4. The addition of a truck freight module may require the purchase of County-to-County freight flow data, and it is not yet known how much that will cost. In addition, there are several different approaches that can be taken to including truck freight. One approach is to use freight flows to estimate the number of light, medium, and heavy trucks that will be travelling so that truck travel is better understood. Another approach can focus more on the specific commodities transported intra-state without as much concern for the size of truck being used. These options will be explored further to determine the feasibility of each, based on the data required and the needs of VTrans staff.

In the long-term future, the development of a seasonal component to the model will be explored. The justification for such an advancement would be statistically significant differences in travel behavior throughout the state between winter and summer. It should also be possible to fine-tune the household and jobs numbers using the number of buildings in the commercial and residential classes from the E911 habitable-structures GIS. The E911 data was collected originally from 1996 to 1998 as part of the Enhanced 911 Data Development Project in Vermont. Site coordinates and site information were captured by GPS at each location requiring a new address, or for grandfathered towns that requested GPS work. In addition to the typical sub-meter GPS systems for capture of coordinate data, the data collection system utilized a "dead-reckoning" system that enhanced the GPS data by providing coordinate and heading data during periods of poor GPS reception. Ortho-photography was used for sites not accessible in the field. Data are continually being updated with information including existing features being imported and new features that are created. Since 1999, a bi-monthly update has been produced geographically by the state's E911 maintenance contractor. Future advancements of the Vermont Travel Model will take advantage of the availability of this GIS for the entire state.

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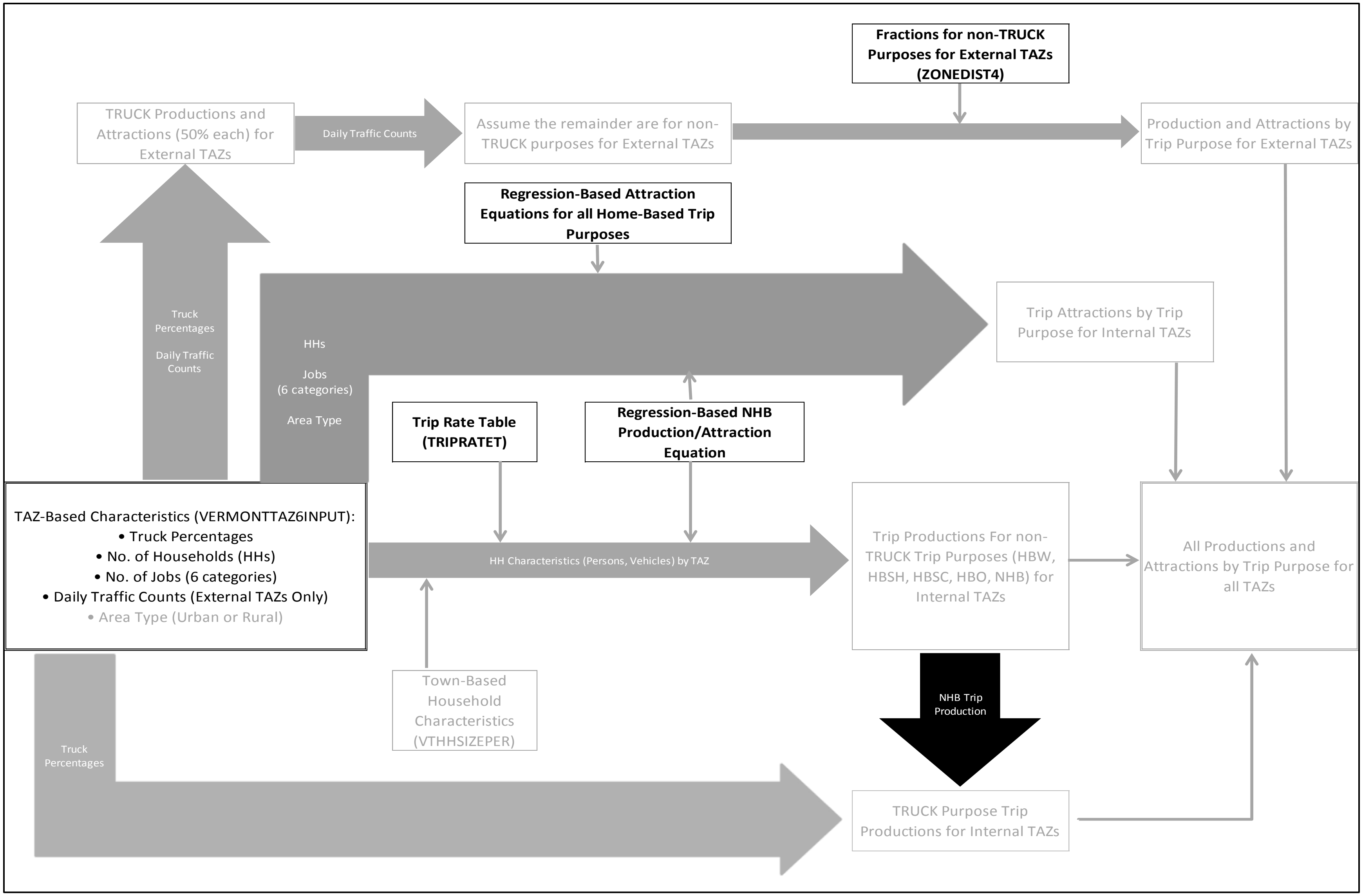
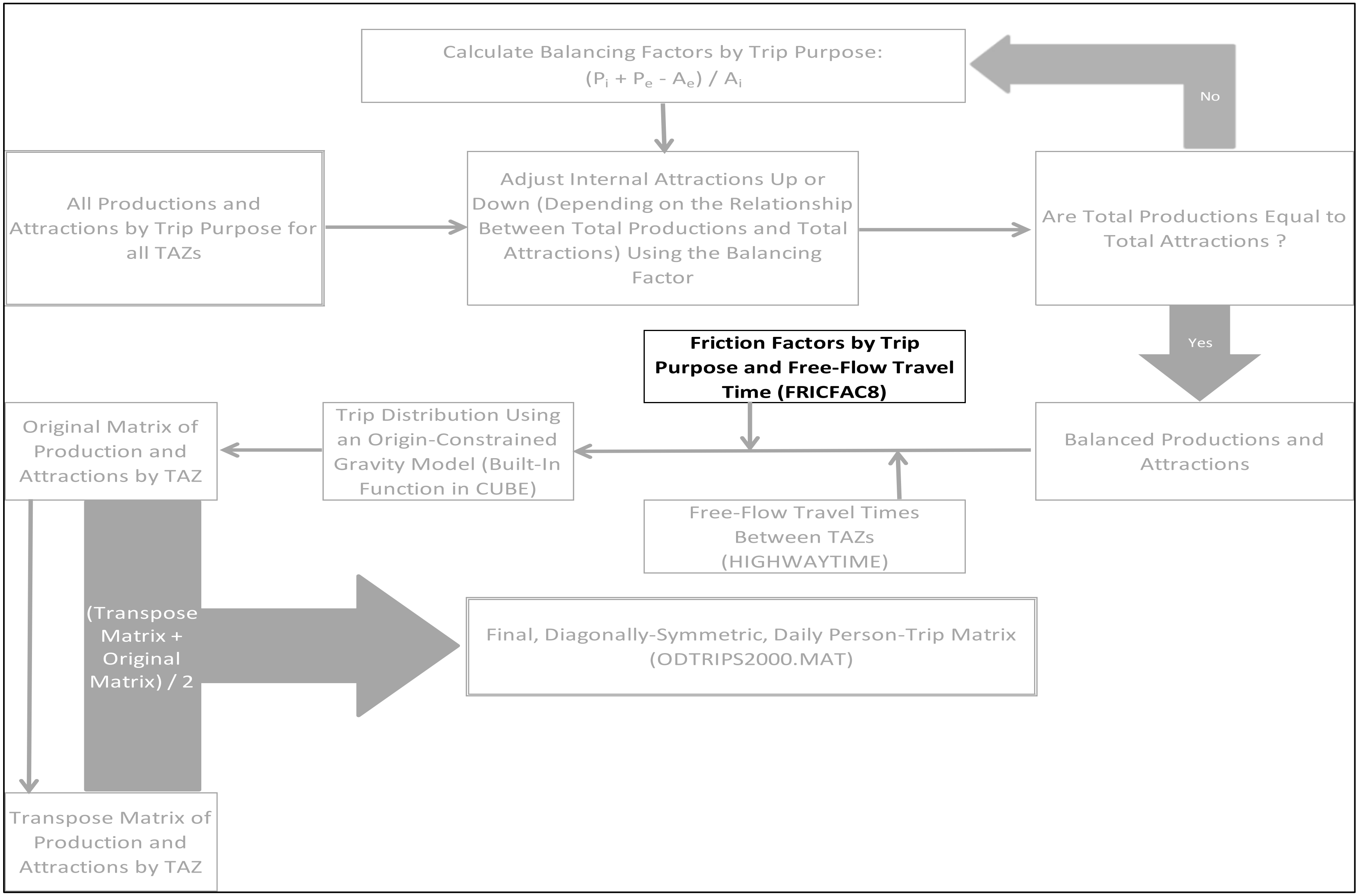
8 Attachment A


Fractions for non-TRUCK Purposes for External TAZs (ZONEDIST4)
TRUCK Productions and Attractions (50% each) for External TAZs
Daily Traffic Counts
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 Percentages
Daily Traffic Counts
HHs
Jobs (6 categories)
Area Type
Trip Attractions by Trip Purpose for Internal TAZs
Trip Rate Table (TRIPRATET)
Regression-Based NHB Production/Attraction Equation
TAZ-Based Characteristics (VERMONTTAZ6INPUT):
• 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, Vehicles) by TAZ
Trip Productions For non-TRUCK Trip Purposes (HBW, HBSH, HBSC, HBO, NHB) for Internal TAZs
All Productions and Attractions by Trip Purpose for all TAZs
Town-Based Household Characteristics (VTHHSIZEPER)
NHB Trip Production
Truck Percentages
TRUCK Purpose Trip Productions for Internal TAZs


Calculate Balancing Factors by Trip Purpose:
(Pi + Pe - Ae) / Ai
No
All Productions and Attractions by Trip Purpose for all TAZs
Adjust Internal Attractions Up or Down (Depending on the Relationship Between Total Productions and Total Attractions) Using the Balancing Factor
Are Total Productions Equal to Total Attractions ?
Yes
Friction Factors by Trip Purpose and Free-Flow Travel Time (FRICFAC8)
Original Matrix of Production and Attractions by TAZ
Trip Distribution Using an Origin-Constrained Gravity Model (Built-In Function in CUBE)
Balanced Productions and Attractions
Free-Flow Travel Times Between TAZs (HIGHWAYTIME)
(Transpose Matrix + Original Matrix) / 2
Final, Diagonally-Symmetric, Daily Person-Trip Matrix (ODTRIPS2000.MAT)
Transpose Matrix of Production and Attractions by TAZ