Model Technical Documentation

Triangle Regional Model

Version 6

Note to Reader: This is an incomplete draft, but represents the best available documentation for TRMv6.

Prepared for:

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1 Introduction

The following technical report documents the development of version six of the Triangle Regional Model (TRM). The TRM is a joint project of the Capital Area Metropolitan Planning Organization, the Durham Chapel Hill Carrboro Metropolitan Planning Organization, North Carolina Department of Transportation, and GoTriangle. The purpose for the document is to serve as a technical reference for model developers and users for approaches used in developing the TRM v6 model. A model documentation report with fewer technical details has been prepared for model users that may not want all the details presented here.

The TRM is the travel demand forecasting tool for the Triangle region of North Carolina. The study area region is composed of all of Orange, Wake and Durham counties, and parts of Chatham, Person, Granville, Franklin, Nash, Johnston, and Harnett counties. The model region covers 3,380 square miles. The model was developed using population and employment data for 2010. The model region had a population of 1,619,204 (does not include 4,813 other non-institutional persons in the census, but not used for modeling) and 853,585 employees in 2010. The model region is divided into 2,857 Traffic Analysis Zones (TAZs) and there are ninety nine external stations. The model region is shown in the map below in Figure 1-1.

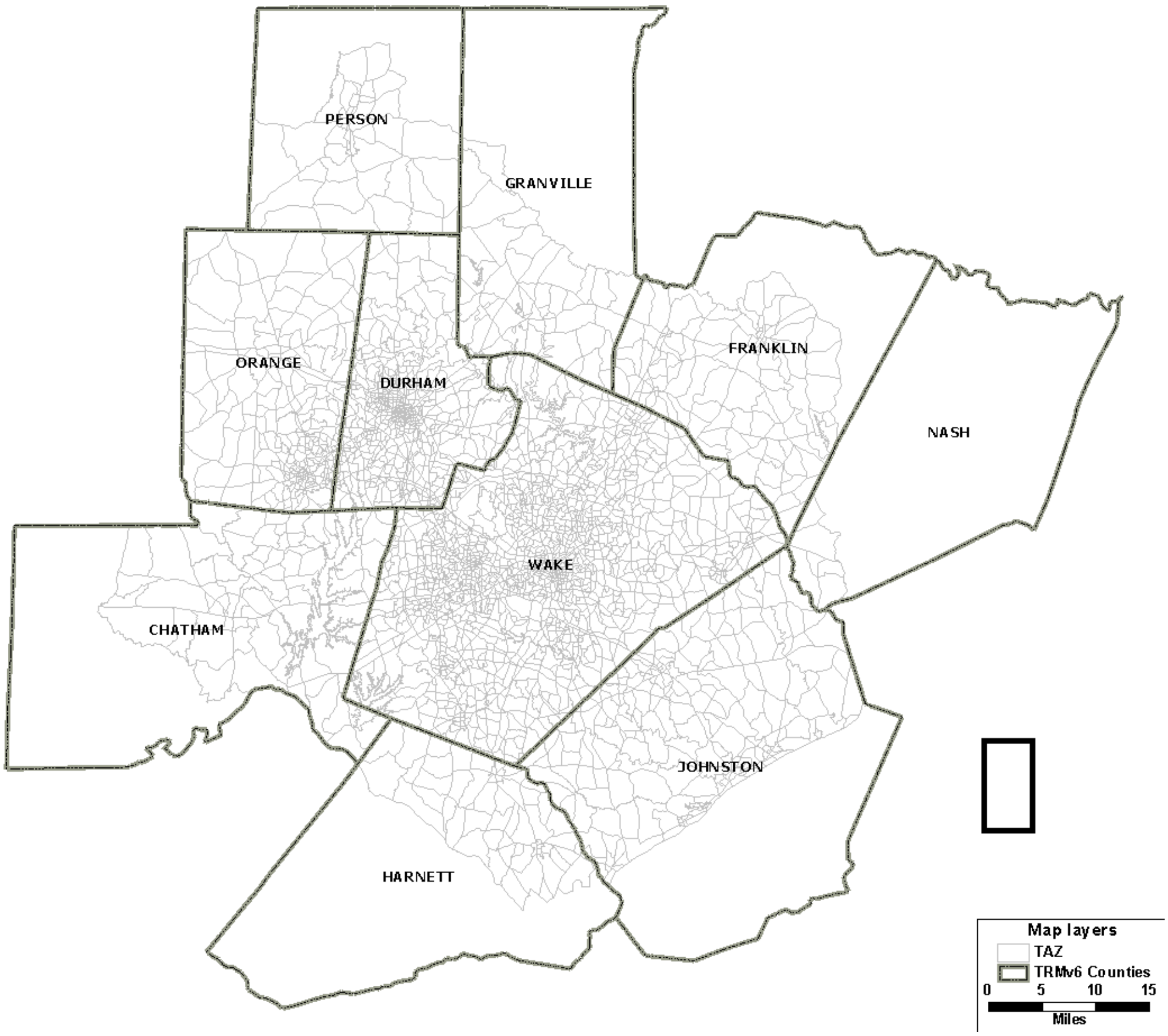


Figure 1-1 TRM v6 Model Region

1.1 Overall Model Description

The TRM is an aggregate trip based four step model. In models of this type the four steps are: trip generation (number of trips made and for what purpose), trip distribution (where the trips go), mode choice (what transportation mode is used to make the trip), and trip assignment (what route and facilities are used to make the trip). The TRM includes these four steps, so could be said to be a typical four step model. Many advanced features have been built into the TRM, making it a state of the practice four step model.

Advanced features of the TRM include:

- Logit choice models for the first three model steps
- Congested highway speeds fed back to trip distribution

- Mode choice logsum used for trip distribution impedance
- Non-motorized binary split model
- Airport passenger model
- Commercial vehicle model

New features added for TRM v6 include:

- New procedures for calculating free flow speeds and capacities for links in the highway network
- New commercial vehicle model using local commercial vehicle survey data
- New university student model separate from general public travel
- New volume delay function for highway traffic assignment
- Off peak divided into mid-day and night time periods

The next section describes data used in developing the TRM v6 model.

2 Travel Behavior Data Used for Model Development

2.1.1 Household Travel Behavior Survey

In 2006 a household travel behavior survey (HHS) was conducted for the region by NuStats, LLC. The survey collected information on the activities for twenty four hours from a sample of 5,107 households in twelve counties. Of the sample households, 4,383 are in the study area for TRM v6. The household survey data are used throughout the model development process.

The 2006 household survey was prepared for use in developing the TRM v6 model in the following way. First TRM v6 TAZ numbers were assigned to survey records. Then the survey data was re-weighted to reflect a 2010 model estimation year using the 2006-2010 American Community Survey data for the region with an objective of making the weighted survey data be consistent with the census data. This was done using households by size and number of vehicles, and households by county and income group. In the weighting process, iterative proportional fitting was used as described below.

To implement the IPF procedure, two vectors of the desired distributions are prepared using the 2006-2010 ACS and which are referred to as marginal values. The first vector used is the number of households by household size and number of vehicles. This is shown in Table 2-1 below.

Table 2-1 Distribution of households by household size and by number of vehicles (2006-2010 American Community Survey)

Category	0 Vehicle	1 Vehicle	2 Vehicles	3+ Vehicles	Total
1 - Person Household	18,258	119,179	21,894	5,334	164,665
2 - Person Household	7,363	40,629	112,831	39,142	199,965
3 - Person Household	2,936	18,910	44,395	33,343	99,584
4+ - Person Household	3,195	15,905	66,449	47,620	133,169
Total	31,752	194,623	245,569	125,439	597,383

The second vector used is the number of households by county and by income group. This is shown in Table 2-2 below.

Table 2-2 Distribution of households by county and by income group (2006-2010 American Community Survey)

County	Low	Medium Low	Medium High	High	Total
Chatham	2,779	3,071	3,923	5,102	14,875
Durham	28,645	28,008	23,703	24,845	105,201
Franklin	5,066	5,755	3,993	3,569	18,383
Granville	2,518	2,646	2,770	2,175	10,109
Harnett	3,874	3,468	2,794	2,482	12,618
Johnston	12,558	12,666	11,861	11,099	48,184
Nash	591	423	218	131	1,363
Orange	13,754	11,563	10,167	14,601	50,085
Person	3,451	3,054	2,368	2,207	11,080
Wake	63,526	76,632	80,847	104,481	325,486
Total	136,762	147,286	142,644	170,692	597,384

In the IPF process, Table 2-1 is formatted to be a vector with sixteen numbers used for the column targets and Table 2-2 is formatted to be a vector with forty numbers used for the row targets. The seed matrix (with dimension of 16 X 40) is the number of survey samples in the household survey data in each category (defined by two factors; one based on county and income group, and the other based on household size and number of vehicles). For example, the first cell of the seed matrix (row 1, column 1) shows the number of surveyed households in Chatham County, low income group, with one person, and no vehicles. After the IPF process, the final weights are calculated as the final matrix divided by the seed matrix (cell by cell). The final weights ensure the weighted household survey data have the same distribution as shown in Table 2-1 and Table 2-2.

2.1.2 Transit On Board Survey

Also in 2006 a transit on board survey was conducted for the region by NuStats, LLC. Data was collected on transit services provided by all transit providers in the model study area. Providers surveyed included Capital Area Transit (CAT), Durham Area Transit Authority (DATA), Chapel Hill Transit (CHT), Cary Transit (CTRAN), Triangle Transit, Wolfline (NCSU), and Duke University Transit. A total of 6,567 transit riders responded to the survey. Transit riders provided information about where their trip started and ended, their trip purpose, and demographic information (and much more).

2.1.3 University Student Survey

In 2001 a survey of students at North Carolina State University (NCSU) was conducted for CAMPO by MAB and CB & A Research. Responses were received from 429 on campus students and 414 off campus students. The survey collected information on the activities of students for a twenty-four hour period. This survey data was used during the development of the v6 university student model to represent on and off campus student behavior at universities in the Triangle region.

2.1.4 Commercial Vehicle Survey

In 2010 a commercial vehicle survey was conducted for the region by PTV NuStats (NuStats). Data was collected from 500 establishments that own commercial vehicles used to transport goods or services. Data was collected on the activities and travel carried out by establishments for up to ten commercial vehicles. If an establishment had more than ten commercial vehicles, first single unit and multi-unit trucks were sampled and then other types (autos, pickups, and vans) in order to obtain as much data as possible on the use of single and multi-unit trucks. The data collected in this survey were used for the development of the commercial vehicle model.

3 Model Inputs

3.1 Maintain and Update Highway and Transit Networks and SE Data

3.2 Zone Geography

3.3 Network Procedures

For TRMv6 several improvements or enhancements were made to network procedures focusing on the highway networks. The definition of facility types was reduced and simplified, new free flow speed procedures were prepared, and new link capacity procedures were developed. These are described in the next sections.

3.3.1 Definition of Facility Types

For TRMv6 the definitions of facility types were investigated to determine if they could be reduced and improved. In the TRMv5 model there are 120 facility types defined for various combinations of link attributes, but it was found that these could not cover all combinations of link attributes. It was determined that for some facility types the difference in capacities could be as little as one, suggesting that some definitions could be combined. Finally, area type was not included in the facility type definitions. Facility type definitions in travel demand models for Southeast Florida, Atlanta, New York, North Central Texas, and Southern California were reviewed for the investigation. The review determined that the number of facility types varied from nine to thirty two. Following the practice of the models reviewed, it was recommended for TRMv6 to use a look up table and a reduced set of facility types. Fifteen facility types by four area types were recommended for TRMv6.

The fifteen suggested facility types for TRMv6 are listed in Table 3-1. If four area types are used in TRMv6, as shown in Table 3-1, TRMv6 will then have sixty facility type and area type combinations. For each of the combinations, values or formulas for free flow speeds, capacities and volume delay functions will be determined.

The recommendation to use these 15 facility types considered:

- The literature review of facility types used in other models;
- The study of the latest edition of Highway Capacity Manual, HCM 2010, which will be used to calculate the capacities, assign the free flow speeds, and determine the volume delay functions;
- The facility types used in TRMv5 so that facility types in TRMv6 would be able to cover all facility types used in TRMv5. The correspondence relationship for facility types in TRMv5 and TRMv6 is shown in Table 11.

Table 3-1 Facility Types for TRMv6

ID	Facility Types in TRMv6	Area Type			
		CBD	Urban	Suburb	Rural
1	Freeway				
2	Freeway to Freeway Ramp				
3	Freeway to Freeway Loop Ramp/Weave Section				
4	On Ramp				
5	Off Ramp				
6	HOV				
7	Multilane Highway				
8	Two Lane Highway				
9	Major Arterial				
10	Minor Arterial				
11	Arterial to Arterial Ramp				
12	Collector/Local				
13	Centroid Connector				
14	Park and Ride Links				
15	Transit Only Links				

Table 3-2 Correspondence Table for Facility Types in TRMv5 and TRMv6

ID	Suggested Facility Types in TRMv6	Facility Type IDs for Corresponding Facility Types in TRMv5				
		CBD	Urban	Suburb	Rural	Area Type Doesn't Matter
1	Freeway		19 to 24	10 to 18	1 to 9	
2	Freeway to Freeway Ramp					25
3	Freeway to Freeway Loop Ramp/Weave Section					26, 27, 34
4	On Ramp					29, 31
5	Off Ramp					28, 30
6	HOV					32
7	Multilane Highway				33, 37, 38	
8	Two Lane Highway				35, 36	
9	Major Arterial		58 to 69	45 to 57	39 to 44	
10	Minor Arterial		89 to 108	77 to 88	71 to 76	
11	Arterial to Arterial Ramp					70
12	Collector/Local		109, 110			111, 112
13	Centroid Connector					113
14	Park and Ride Links					114
15	Transit Only Links					115

The advantages to use the new facility types in TRMv6 are as follows:

- The facility types in TRMv6 can cover all combinations of link attributes, because link attributes are not used to determine facility types during model runs. Therefore, the no-match-found issue which is occasionally encountered while running TRMv5 will not occur for TRMv6.
- Area type is now explicitly included in the determination of free flow speeds, capacities, and volume delay functions in TRMv6. As the cities in the Triangle region develop in future years, the area types of some TAZs will change, which will be able to affect the free flow speeds and capacities of the links in the network. This is a desired feature that is not available in TRMv5.
- Facility type is now required as an input in TRMv6, instead of being determined based on link attributes as was done in TRMv5. This change avoids incorrectly classifying facility types.
- The facility types in TRMv6 are more intuitive and easy to follow.

3.3.2 Link Free Flow Speed Procedure

The procedure to define the link free flow speeds has been updated for TRMv6. First the approach used for TRMv5 free flow speeds is briefly described, then the new procedures for TRMv6 are described.

The link free flow speeds in TRMv5 are posted speeds plus or minus a constant as shown in Table 3-3 below.

Table 3-3 Free-flow Speeds in TRMv5

Categories	IDs of Facility Types in TRMv5	Free-flow Speeds Used in TRMv5
Freeway, HOV and Ramp	1 to 34	Posted Speed + 5 mph
Two-lane Highway	35, 36	Posted Speed - 2 mph
Multilane Highway and Arterial	37 to 108	Posted Speed + 3 mph
Collector and Local	109 to 112	Posted Speed - 3 mph
Other (Centroid Connector, Park-n-ride Links, Transit-only Links)	113 to 115	Posted Speed

The advantages of the TRMv5 approach are that the free flow speeds are simple and make sense in many cases. It is expected that the free flow speeds are higher than posted speeds on freeways and lower than posted speeds on collectors and local streets (considering the effect of traffic control devices). Disadvantages include that area types and link attributes are not considered, and intersection delay is not explicitly considered for arterials, collectors, and local streets. Free flow speeds form the basis for all link speeds used in network skims used for trip distribution, mode choice, and trip assignment, so are an important foundation for the model.

Free flow speeds were reviewed in six other models: Southeast Florida, Atlanta, New York, North Central Texas, Southern California, and Indiana Statewide Model. This review showed that half the models use lookup tables and the other half use formulas. The models that use formulas also consider intersection delays and include signal location information. Two models used formulas based on the Highway Capacity Manual (HCM).

Based on the review of the models listed above, it was recommended to develop an approach for TRMv6 based on the HCM 2010 formulas to calculate free flow speeds. When detailed link attributes such as lane width and access density are not available, default values will be used. In cases where formulas are not available in the HCM, other models were used for guidance on the formulas to use for TRMv6.

3.3.2.1 Free-flow Speeds for Freeways

Chapter 11 of HCM2010 covers basic freeway segments. The formula to estimate the free-flow speed on a basic freeway segment is shown in Equation 4 (same as Equation 11-1 in HCM2010).

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84} \tag{4}$$

where,

FFS is the free-flow speed (mph);
f_{LW} is the adjustment for lane width (mph);
f_{LC} is the adjustment for right-side lateral clearance (mph); and
TRD is the total ramp density (ramps/mile).

Adjustment for lane width can be found in Exhibit 11-8 in HCM2010, and adjustment for right-side lateral clearance is in Exhibit 11-9. Lane width, right-side lateral clearance and the number of lanes are needed for these two adjustments, but the first two terms are not currently coded in the TRM network. It was suggested to add two new columns, “LaneWidth” and “LateralClearance” in the link attribute table. The default value for lane width can be set as 12 feet, and for right-side lateral clearance can be set as 6 feet. With these two default values, $f_{LW} = f_{LC} = 0$.

Total ramp density is defined as the average number of ramps (including on-ramps, off-ramps, major merges, and major diverge junctions) per mile over a 6-mile freeway segment, 3-mile upstream and 3-mile downstream of the midpoint of the study segment. It is the most critical factor, and Figure 3-1 shows how it affects FFS when $f_{LW} = f_{LC} = 0$.

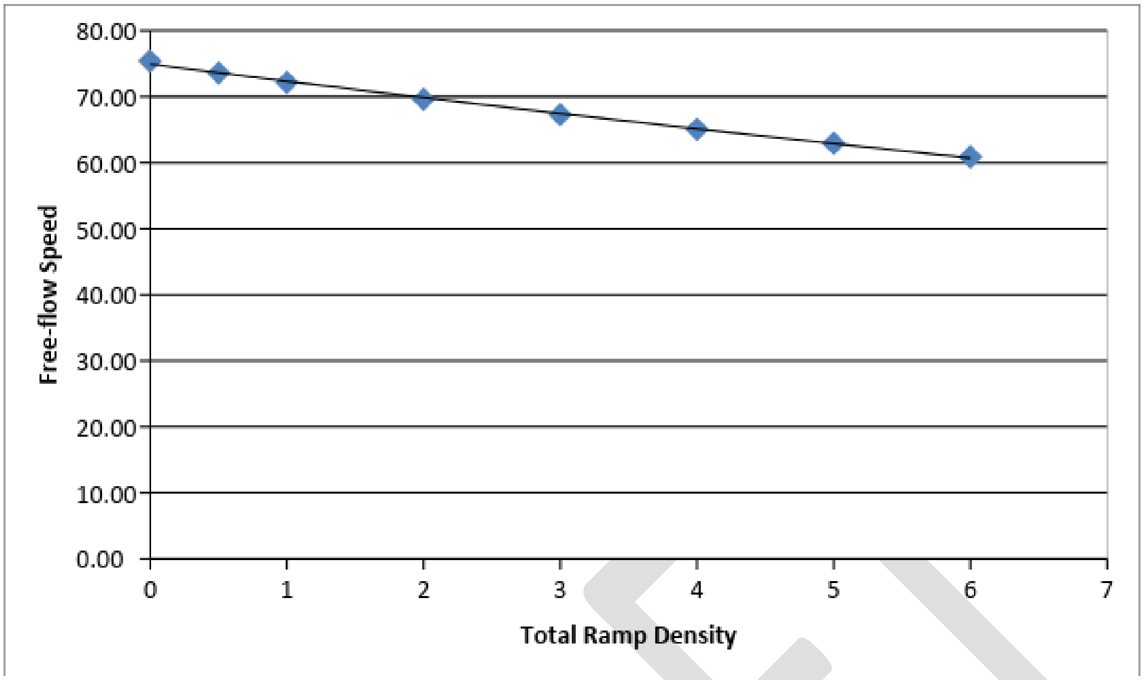


Figure 3-1 How Total Ramp Density Affects Free-flow Speeds on Basic Freeway Segments

Equation 4 covers basic freeway segments with free-flow speeds ranging from 55 mph to 75 mph. While the equation is provided in Chapter 11 of HCM2010, Basic Freeway Segments, it is also applied in Chapter 12, Freeway Weaving Segments and Chapter 13, Freeway Merge and Diverge Segments. Thus, Equation 4 can be used for all basic, weaving, merge, and diverge segments on freeways.

Posted speed is not included in Equation 4 as a factor to affect free-flow speeds on freeway facilities. The possible reason is that posted speed is highly correlated with total ramp density. It is recommended to pay special attention to the reasonableness of free-flow speeds when implementing Equation 4, to see if the missing posted speed in the formula is an issue.

3.3.2.2 Free-flow Speeds for Multilane Highways

Chapter 14 of HCM2010 covers multilane highways. In general, uninterrupted flow may exist on a multilane highway if there are 2 miles or more between traffic signals. Where signals are more closely spaced, the facility should be analyzed as an arterial. The formula to estimate the free-flow speed on a multilane highway is shown in Equation 5 (same as Equation 14-1 in HCM2010)

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \tag{5}$$

where,

FFS is the free-flow speed (mph);
$BFFS$ is the base free-flow speed (mph);
f_{LW} is the adjustment for lane width (mph);
f_{LC} is the adjustment for total lateral clearance (mph);
f_M is the adjustment for median type (mph); and

f_A is the adjustment for access point density (mph).

Equation 5 covers multilane highway segments with free-flow speeds ranging from 45 mph to 60 mph. The base free-flow speed ($BFFS$) is like the design speed – it represents the potential free-flow speed based only upon the horizontal and vertical alignment of the highway. While speed limits are not always uniformly set, the base free-flow speed may be estimated as the posted speed plus 5 mph for posted speed of 50 mph and higher, and the posted speed plus 7 mph for posted speed less than 50 mph, as shown in Equation 6.

$$BFFS = \{Posted\ Speed + 5 \qquad if\ Posted\ Speed \geq 50\ mph\ Posted\ Speed + 7 \qquad if\ Posted\ Speed < 50\ mph \tag{6}$$

The adjustment for lane width (f_{LW}) and total lateral clearance (f_{LC}) are shown in Exhibits 14-8 and 14-9 of HCM2010, respectively. The adjustment for median type (f_M) is -1.6 mph for undivided multilane highways, and 0 mph if the median is divided or is a two-way left-turn lane. The adjustment for access point density (f_A) is -0.25 for each access point per mile. The number of access points per mile is determined by dividing the total number of access points (i.e., driveways and unsignalized intersections) on the right side of the highway in the direction of travel, by the length of the segment in miles. An intersection or driveway should only be included in the count if it influences traffic flow. Access points that go unnoticed by drivers, or with little activity, should not be used to determine access-point density.

3.3.2.3 Free-flow Speeds for Two-Lane Highways

Chapter 15 of HCM2010 covers two-lane highways. The principal characteristic that separates two-lane and multilane highways is that passing maneuvers have to take place in the opposing lane of traffic for two-lane highways. The formula to estimate the free-flow speed on a two-lane highway is shown in Equation 7 (same as Equation 14-1 in HCM2010)

$$FFS = BFFS - f_{LS} - f_A \tag{7}$$

where,

FFS is the free-flow speed (mph);
$BFFS$ is the base free-flow speed (mph);
f_{LS} is the adjustment for lane and shoulder width (mph); and
f_A is the adjustment for access point density (mph).

Equation 7 covers two-lane highway segments with free-flow speeds ranging from 45 mph to 70 mph. The design speed might be an acceptable estimator of base free-flow speed ($BFFS$), as it is based primarily on horizontal and vertical alignment. Posted speed may not reflect current conditions or driver desires. A very rough estimate of $BFFS$ might be taken as the posted speed plus 10 mph, as shown in Equation 8.

$$BFFS = Posted\ Speed + 10 \tag{8}$$

The adjustment for lane and shoulder width (f_{LS}) and total lateral clearance (f_{LC}) are shown in Exhibit 15-7 of HCM2010. The adjustment for access point density (f_A) is -0.25 for each access point per mile. The access-point density is computed by dividing the total number of unsignalized intersections and driveways on both sides of the roadway segment by the length of the segment (in miles).

3.3.2.4 Free-flow Speeds for Arterials and Collectors

Chapter 17 of HCM2010 covers arterials and collectors. This chapter's methodology is applicable to an urban or suburban street segment. The segment can be part of an arterial or collector street with one-way or two-way vehicular traffic flow. The intersections on the segment can be signalized or unsignalized. Chapter 18 of HCM2010 covers signalized intersections of arterials and collectors, which can be used to estimate the signalized intersection delays. Chapters 19 and 20 of HCM2010 cover two-way stop controlled intersections and all-way stop controlled intersections, respectively. These two chapters can be used to estimate delays at unsignalized intersections.

Free-flow Speeds without the impact of intersection delays

The formula to estimate the free-flow speed on an arterial or collector without considering intersection delays is shown in Equation 9 (a compilation of Equations 17-2 and 17-3 in HCM2010).

$$FFS_S = (S_0 + f_{CS} + f_A) f_L \tag{9}$$

where,

FFS_S is the free-flow speed without the impact of intersection delays;
S_0 is the speed constant (mph);
f_{CS} is the adjustment for cross section, that is median and curb (mph);
f_A is the adjustment for access point (mph); and
f_L is the signal spacing adjustment factor.

The speed constant (S_0) is a linear function of posted speed, as shown in Equation 10.

$$S_0 = 25.6 + 0.47 \times Posted\ Speed \tag{10}$$

The adjustment for cross section (f_{CS}) reflects the impact of median type and presence of curb, and the formula is shown in Equation 11.

$$f_{CS} = 1.5 p_{rm} - 0.47 p_{curb} - 3.7 p_{rm} p_{curb} \tag{11}$$

where,

p_{rm} is the proportion of link length with restrictive median (decimal); and

p_{curb} is the proportion of segment with curb on the right-hand side (decimal).

The adjustment for access points is a function of access point density and number of through lanes, as shown in Equation 12.

$$f_A = -0.078 D_a / N_{th} \tag{12a}$$

$$D_a = 5280(N_{ap,s} + N_{ap,o})/(L - W_i) \tag{12b}$$

where,

D_a is the access point density on segment (points/mile);
N_{th} is the number of through lanes in the subject direction of travel;
$N_{ap,s}$ is the number of access points on the right side in the subject direction of travel;
$N_{ap,o}$ is the number of access points on the right side in the opposing direction of travel;
L is the segment length (feet); and
W_i is the width of signalized intersection (feet).

The signal spacing adjustment factor (f_L) accounts for the observation that drivers tend to choose slower free-flow speed on shorter segments, all other factors being the same. Equation 13 can be used to compute the value of this factor.

$$f_L = 1.02 - 4.7 \frac{S_0 + f_{CS} + f_A - 19.5}{L} \leq 1.0 \tag{13}$$

In Equation 13, if L is less than 400 feet, it should be set to 400 feet.

Free-flow Speeds with the impact of intersection delays

The formula to estimate the free-flow speed on an arterial or collector with the impact of intersection delays is shown in Equation 14 (same as Equation 17-12 in HCM2010)

$$FFS_{S,I} = \frac{3600L}{5280(t_R + d)} \tag{14}$$

where,

$FFS_{S,I}$ is the free-flow speed with the impact of intersection delays;
t_R is the segment running time (seconds), that is, the time to traverse a segment; and
d is the control delay at the downstream intersection.

Equation 14 is the same as the formulas used in the Florida, Texas and Indiana models. In Equation 14, t_R is the time a vehicle takes to traverse a segment, and d is the time to traverse the downstream intersection. t_R can be calculated based on Equation 15 (a revision of Equation 17-1 in HCM2010).

$$t_R = \frac{6.0 - l_1}{0.0025L} + \frac{3600L}{5280FFS_S} \quad (15)$$

where,

l_1 is the start-up lost time, which is 2.0 for signalized intersections and 2.5 for stop or yield-controlled intersections (seconds);

The first term in Equation 15 accounts for the time required to accelerate to the running speed, less the start-up lost time used to compute the through movement delay. The divisor in this term is an empirical adjustment that minimizes the contribution of this term for longer segments.

Equation 15 is a revision of Equation 17-1 in HCM2010 to fit the free-flow condition when the traffic volume is low. It assumes that the impact of traffic density on travel speed can be ignored, therefore the vehicle proximity adjustment factor (f_v) is equal to 1. It also assumes that the delays due to turning vehicles and other factors are zero. FFS_S in Equation 15 is calculated from Equation 9.

Delays at signalized intersections

In Equation 14, d is the control delay at the downstream intersection. If the intersection is a signalized intersection, Equation 18-19 in HCM2010 can be used to calculate the control delay. Equation 18-19 shows that the control delay is the sum of uniform delay, incremental delay and initial queue delay. Uniform delay is the delay when arrivals are random throughout the cycle (uniform arrivals). Incremental delay accounts for the delays caused by random or sustained oversaturation. Initial queue delay accounts for the additional delay incurred due to an initial queue. For the purpose of calculating delays in free-flow condition, incremental delay and initial queue delay can be assumed to be zero.

Compared to HCM2000, HCM2010 adopted a new procedure to calculate uniform delay. This new procedure is called "incremental queue accumulation." It requires detailed data that are difficult for a travel demand model to get, such as saturation flow rate and arrival rate. No formulas are available for this procedure, so it was decided to continue using the procedure described in HCM2000, which was also adopted in the Florida and Indiana models.

The formula to estimate delays at signalized intersections is shown in Equation 16 (a compilation of Equations 16-9 to 16-11 in HCM2000)

$$d = 0.5C\left(1 - \frac{g}{C}\right)^2 \times PF \quad (16)$$

where,

C is the cycle length (seconds);
g is the effective green time (seconds); and
PF is the progression adjustment factor.

Progression adjustment factor (PF) is used to account for the quality of signal progression, and can be calculated using Equation 17 (based on Equation 16-10 in HCM2000)

$$PF = \frac{(1-P)f_{PA}}{1-\left(\frac{g}{C}\right)} = \frac{\left(1 - R_p \cdot \frac{g}{C}\right) f_{PA}}{1-\left(\frac{g}{C}\right)} \tag{17}$$

where,

P is the proportion of vehicles arriving on green;

f_{PA} is the supplemental adjustment factor for platoon arriving during a green indication, and its default values for each arrival type is listed in Exhibit 16-12 in HCM2000; and

R_p is the platoon ratio, and its default values for each arrival type are listed in Exhibit 16-12 in HCM2000.

Delays at unsignalized intersections

In Equation 14, d is the control delay at the downstream intersection. If the intersection is an unsignalized intersection, Chapters 19 and 20 in HCM2010 can be used to estimate the control delay.

Chapter 19 of HCM2010 introduces the procedures to evaluate the level of service of Two-Way Stop-Controlled (TWSC) intersections. One typical configuration of a TWSC intersection is a four-legged intersection, where one street – the major street – is uncontrolled, while the other street – the minor street – is controlled by stop signs. The other typical configuration is a three-legged intersection, where the single minor-street approach is controlled by a stop sign. Equation 19-64 in HCM2010 can be used to calculate the control delay, but it requires flow rate and capacity for each movement. In free-flow conditions, flow rate is very low and this equation can be simplified, as shown in Equation 18.

$$d = \frac{3600}{c_{m,x}} + 5 \tag{18}$$

where,

$c_{m,x}$ is the capacity of movement x;

In free-flow conditions, there are few vehicles on the major street, and vehicles on the minor street do not have to wait for the acceptable gap on the major street. The capacity of movement ($c_{m,x}$) is then subject to the follow-up headway, whose default value is 4 seconds based on Exhibit 19-11 in HCM2010. Therefore, the default value of $c_{m,x}$ is 900 veh/h, and the default value for the control delay at TWSC intersections is 9 seconds. It is suggested to use this value (9 seconds) for all TWSC intersections, since it makes sense that the control delay at a TWSC intersection does not change along with area type or facility type in free-flow conditions.

Chapter 20 of HCM2010 introduces the procedures to evaluate the level of service of All-Way Stop-Controlled (AWSC) intersections. AWSC intersections require every vehicle to stop at the intersection before proceeding. Equation 20-30 in HCM2010 can be used to calculate the control delay, and it can be simplified for free-flow condition, as shown in Equation 19.

$$d = t_s + 5 \tag{19}$$

where,

t_s is the service time, which is the average time spent by a vehicle in the first position waiting to depart.

In free-flow conditions, the service time can be assumed to be 0. Then the control delay at AWSC intersections is 5 seconds. Similar to TWSC intersections, it is suggested to use this value (5 seconds) for all AWSC intersections.

3.3.2.5 Free-flow Speeds for Ramps

After reviewing the free-flow speeds for ramps in other models, and corresponding chapters in HCM2010, it was suggested to use the free-flow speeds shown in Table 3-4 for ramps in TRMv6.

Table 3-4 Suggested Free-flow Speeds for Ramps in TRMv6 (mph)

D	ty Type	Straight	Loop
2	way-to-freeway Ramp	55	40
4	amp	45	35
5	amp	35*	25
11	ial-to-arterial Ramp	35	25

* Can be 45 mph for long off-ramps.

In Table 3-4, freeway-to-freeway ramps have the highest free-flow speeds. On-ramps have higher free-flow speeds than off-ramps, because the downstream ends of these two types of ramps are different. The downstream ends of on-ramps are ramp-freeway junctions, which are usually not controlled by any devices (there are no ramp meters in the Triangle area). The downstream ends of off-ramps are ramp-street junctions, which are usually STOP-controlled, YIELD-controlled, or signalized, and intersection delays will reduce the average speed on off-ramps. Arterial-to-arterial ramps are similar to off-ramps in terms of the control types at the downstream ends, so they have similar free-flow speeds. Loop ramps have lower free-flow speeds than straight ramps because roadway curves usually will slow traffic.

The values in Table 3-4 should be used as posted speeds when TRM users code ramps in the TRM highway network. There are two reasons: 1) posted speeds are generally not available for ramps (only some loop off-ramps have posted speed signs, so TRM users need to enter a posted speed value based on personal judgments and Table 3-4 provides guidelines that will ensure consistency); 2) only 4 facility types are defined for ramps in TRMv6, and straight and loop ramps can only be differentiated visually.

3.3.2.6 Free-flow Speeds for Other Facility Types

Chapter 12 of HCM2010 provides the methodology for analyzing the operation of freeway weaving sections. This chapter indicates that the method used to estimate the free-flow speed for basic freeway segments (described in Section 3.3.2.1) can also be used for freeway weaving sections.

HCM2010 does not provide a methodology to analyze HOV lanes. Since HOV lanes are a part of freeways, it makes sense to use the method for basic freeway segments (described in Section 3.3.2.1) to estimate the free-flow speeds on HOV lanes. The Atlanta model also used the same free-flow speeds for freeways and HOV lanes.

Centroid connectors used a fixed free-flow speed of 15 mph in previous versions of TRM. However, TAZs in rural areas are usually large and centroid connectors are long, so the time spent to traverse a centroid connector could be unreasonably long if the speed is set equal to 15 mph. It was suggested to use free flow speed by area type in TRMv6 for centroid connectors, and the values are shown in Table 3-5.

Table 3-5 Suggested Free-flow Speeds for Centroid Connectors in TRMv6 (mph)

D	ty Type	CBD	Urban	Suburb	Rural
l3	roid Connector	15	25	35	45

Park and ride links are virtual short links and there are only a few of them in the TRM network. Therefore, it is suggested to use posted speeds coded in the highway network as their free-flow speeds.

3.3.3 Link Capacity Calculation Procedure

The procedure to define the link capacity has been updated for TRMv6. First the approach used for defining TRMv5 capacities will be briefly described, then the new procedures for TRMv6 will be described.

Link capacities in TRMv5 are defined in a lookup table based on facility type. The capacity values were developed in 2006 using HCS+ based on a set of default values borrowed from previous TRM models, NCLOS or HCM2000. They are LOS E capacities, and the unit is mixed vehicle (not passenger car) per hour per lane. Two issues were identified with using the lookup table approach: 1) that not all combinations of link attributes could be covered in the lookup table, and 2) that area type was not explicitly used in determining capacity.

Procedures for determining capacities were reviewed in six other models: Southeast Florida, Atlanta, New York, North Central Texas, Southern California, and Indiana Statewide Model. Most of the models use lookup tables to determine link capacities. All lookup tables are based on facility type and area type, but some consider more factors, such as number of lanes, access density, signal density and/or posted speed. In some models, the values from lookup tables are further adjusted for one-way facility, median, left turn bay and/or on-street parking. The Indiana Statewide Travel Demand Model calculates link capacities by multiplying maximum hourly service flows and capacity reduction factors. Such a procedure considers more factors, such as lateral clearance, heavy vehicles, lane width and directional distribution.

The six models reviewed indicate that lookup tables were employed by most models to determine link capacities, and the Highway Capacity Manual (HCM) was the major source for capacity values. It was recommended for TRMv6 to follow the practice of other models and use HCM2010 to determine link capacities. It was also recommended to employ formulas instead of lookup tables because:

- The formulas to calculate link capacities are available in HCM2010 for most facility types defined in TRMv6. Using these formulas directly ensures that the link capacity values are consistent with HCM2010;
- It is easier to capture the impact of link attributes on link capacities by using formulas. By contrast, in order to consider these impacts, the reviewed models had to develop complicated lookup tables with several dimensions, or adjust the values obtained from lookup tables for links with certain attributes (such as one-way links); and
- TRMv6 also uses formulas from HCM2010 to determine the free-flow speeds.

It was also recommended that when detailed link attributes, such as peak hour factor, are not available, default values be used. If formulas were not available for certain facility types, values used in other models were used to determine appropriate values or formulas for TRMv6.

The review of other models shows that half of the models use passenger car per hour per lane (pc/h/ln) as the unit of capacities, and the other half did not provide clear information. This unit is different from what was used in TRMv5 and previous versions of TRM models (they are in vehicle per hour per lane, that is, v/h/ln). It is more convenient and reasonable to follow other models' practices and use pc/h/ln as the unit because:

- In order to get the capacities in v/h/ln, assumptions have to be made for the percentage of heavy vehicles, and it is quite different on different links. TRMv5 assumed that links with the same facility types had the same percentage of heavy vehicles, which might not be an unreasonable assumption, but the capacities in pc/h/ln do not need these assumptions.
- The number of trucks obtained from the highway assignment can easily be converted to passenger cars based on the preset passenger car equivalent (PCE), and added to passenger cars to get the total volume in the unit of passenger cars. This total volume divided by the capacity in pc/h/ln is then the volume capacity ratio (v/c). In this way, the modeled number of heavy vehicles is reflected in the calculation of v/c, which is usually more accurate than the assumed values.

3.3.3.1 Capacities for Freeways

Chapter 11 of HCM2010 covers basic freeway segments. The formula to estimate the capacity on a basic freeway segment is shown in Equation 1, which is a rearrangement of Equation 11-7 in HCM2010 by assuming the number of lanes equals one.

$$Capacity_E = MSF_E \times f_p \times PHF \tag{1}$$

where,

$Capacity_E$ is the capacity at level of service E (pc/h/ln),
MSF_E is the Maximum Service Flow Rate at level of service E (pc/h/ln),
f_p is the adjustment factor for unfamiliar driver populations, and
PHF is the peak hour factor.

MSF_E can be selected from Exhibit 11-17 in HCM2010 based on FFS (Free-flow Speed) on the studied freeway segments. Details about how to determine free-flow speed in TRMv6 can be found in Section 3.3.2.

Adjustment for driver population addresses the fact that unfamiliar drivers use freeways less efficiently. Since the Triangle area is not a major recreational area, most drivers are commuters or drivers who are familiar with the facility, $f_p = 1$ can be used following the suggestion in HCM2010.

Peak Hour Factor (PHF) is the hourly volume during the analysis hour divided by the peak 15-minute flow rate within the analysis hour, which is a measure of traffic demand fluctuation within the analysis hour. Reasonable PHF values by area type were determined during the implementation of capacities in TRMv6.

3.3.3.2 Capacities for Multilane Highways

Chapter 14 of HCM2010 covers multilane highways. Uninterrupted flow on multilane highways is in most ways similar to that on basic freeway segments. Therefore, the equations used for freeways, Equation 1, can also be used for multilane highways, but with different parameters. For example, the MSF_E and PHF used for multilane highways are different from those for freeways.

3.3.3.3 Capacities for Two-Lane Highways

Chapter 15 of HCM2010 covers two-lane highways. The capacity of a two-lane highway under base conditions is 1,700 pc/h in one direction, with a limit of 3,200 pc/h when both directions are totaled. The formulas to estimate the capacity on a two-lane highway segment under prevailing conditions are shown in Equations 2 and 3, which are based on Equations 15-12 and 15-13 in HCM2010 by converting the unit of capacities from flow rate to hourly volume and assuming evenly directional distribution (that is, 50/50 directional split).

$$Capacity_{E,ATS} = 1600 \times f_{g.ATS} \times PHF \tag{2}$$

$$Capacity_{E,PTSF} = 1600 \times f_{g.PTSF} \times PHF \tag{3}$$

where,

$Capacity_{E,ATS}$ is the capacity at level of service E base on the analysis of ATS (Average Travel Speed),
$f_{g.ATS}$ is the grade adjustment factor for the analysis of ATS,
$Capacity_{E,PTSF}$ is the capacity at level of service E base on the analysis of PTSF (Percent Time-Spent-Following),

$f_{g.PTSF}$ is the grade adjustment factor for the analysis of PTSF, and
PHF is the peak hour factor.

For Class I highways, both capacities must be computed. The lower value represents capacity. For Class II highways, only the PTSF-based capacity is computed. For Class III highways, only the ATS-based capacity is computed. Refer to Page 15-2 and Page 15-3 of HCM2010 for the definition of Class I to Class III highways.

Based on Exhibits 15-9 and 15-16 of HCM2010 (level terrain), $f_{g.ATS} = f_{g.PTSF} = 1$. Therefore, Equations 2 and 3 can be simplified as Equation 4 for the Triangle region:

$$Capacity_E = 1600 \times PHF \quad (4)$$

3.3.3.4 Capacities for Arterials and Collectors

The capacities of facilities with interrupted flow are different from those with uninterrupted flow: they are subject to the capacities of intersections, not the capacities of links. The procedures to estimate the capacities on arterials and collectors are provided in one of Chapters 18-20 of HCM2010, depending on the type of control used at the intersection: Chapter 18 for signalized intersections, Chapter 19 for two-way stop controlled intersections of arterials, and Chapter 20 for all-way stop controlled intersections.

Capacities at signalized intersections

The formula to estimate the capacity at a signalized intersection is shown in Equation 5 (same as Equation 18-15 in HCM2010)

$$Capacity = Ns\frac{g}{C} \quad (5)$$

where,
N is the number of through lanes (ln),
s is the adjusted saturation flow rate (veh/h/ln),
g is the effective green time (seconds), and
C is the cycle length (seconds).

The adjusted saturation flow rate can be estimated by Equation 6 (same as Equation 18-5 in HCM2010).

$$s = s_0 f_w f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} \quad (6)$$

where,
s_0 is the base saturation flow rate (pc/h/ln),
f_w is the adjustment factor for lane width,
f_g is the adjustment factor for approach grade,

f_p is the adjustment factor for existence of a parking lane and parking activity within intersection area,
f_{bb} is the adjustment factor for blocking effect of local buses that stop within intersection area,
f_a is the adjustment factor for area type,
f_{LU} is the adjustment factor for lane utilization,
f_{LT} is the adjustment factor for left-turn vehicle presence in a lane group,
f_{RT} is the adjustment factor for right-turn vehicle presence in a lane group,
f_{Lpb} is the pedestrian-bicycle adjustment factor for left-turn lane groups, and
f_{Rpb} is the pedestrian-bicycle adjustment factor for right-turn lane groups.

The default value of base saturation flow rate (s_0) is 1900 pc/h/ln for metro areas with population equal to or greater than 250,000, and 1750 pc/h/ln otherwise. The adjustment factors for lane width (f_w) are shown in Exhibit 18-13 in HCM2010.

If no parking is present, the parking adjustment factor (f_p) has a value of 1. If parking is present, then the value of this factor is computed using Equation 7 (same as Equation 18-8 in HCM2010).

$$f_p = \frac{N - 0.1 - \frac{18N_m}{3600}}{N} \geq 0.050 \tag{7}$$

where,

N_m is the parking maneuver rate within 250 feet upstream of stop line (maneuvers/h), and
N is the number of through lanes (ln).

The area type adjustment factor f_a accounts for the inefficiency of intersections in certain areas, such as central business districts (CBDs). This factor should be used in areas where the geometric design and the traffic or pedestrian flows, or both, are such that the vehicle headways are significantly increased. When used, it has a value of 0.90.

It was not recommended to include the other adjustment factors in the calculation of capacities for TRMv6. The adjustment factor for approach grade (f_g) requires the grade of approaches, which are not currently coded in the TRM network and are difficult to obtain. Most of the Triangle region is level, and this is another reason to ignoref_g. The adjustment factor for bus blockage (f_{bb}) requires the bus stopping rate (buses/h). None of the six models reviewed consider the impact of bus blockage, and this factor (f_{bb}) will not significantly change the capacities: it ranges from 0.976 to 0.996 on the roadways with bus stops based on the default values provided in HCM2010. As demand approaches capacity, the use of the available lanes is more uniform and the adjustment factor for lane utilization (f_{LU}) is close to 1. The other adjustment factors (f_{LT}, f_{RT}, f_{Lpb}, and f_{Rpb}) are related to left-turn and right-turn vehicles and lanes. In a regional travel demand model, such as TRM, only through lanes and shared lanes (such as a lane with through and right-turn movements) are coded in the network, that is, the exclusive left-turn or right-turn lanes are usually not coded. Therefore, it was not recommended to consider these adjustment factors in TRMv6.

Capacities at stop-controlled intersections

Chapter 19 of HCM2010 introduces the procedures to evaluate the level of service of Two-Way Stop-Controlled (TWSC) intersections. One typical configuration of a TWSC intersection is a four-legged intersection, where one street – the major street – is uncontrolled, while the other street – the minor street – is controlled by stop signs. The other typical configuration is a three-legged intersection, where the single minor-street approach is controlled by a stop sign.

The procedure to estimate the capacities at two-way stop-controlled intersections is complicated: There are up to 14 movements and the capacity for each movement depends on the conflicting flows from other movements, the critical headway, and the follow-up headway. The critical headway is defined as the minimum time interval in the major-street traffic stream that allows intersection entry for one minor-street vehicle. The follow-up headway is the time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major-street headway, under a condition of continuous queuing on the minor street. A typical equation to calculate the potential capacity of a movement is shown in Equation 8 (same as Equation 19-32 in HCM2010).

$$c_{p,x} = v_{c,x} \frac{e^{-v_{c,x} t_{c,x}/3600}}{1 - e^{-v_{c,x} t_{f,x}/3600}} \tag{8}$$

where,

$c_{p,x}$ is the potential capacity of movement x (veh/h),
$v_{c,x}$ is the conflicting flow rate for movement x (veh/h),
$t_{c,x}$ is the critical headway for movement x (s), and
$t_{f,x}$ is the follow-up headway for movement x (s).

Equation 8 requires too many details that are not available to a regional travel demand model. Instead, a rough estimate of the capacity can be made by studying the follow-up headway. Based on the definition of follow-up headway, the capacity of movement x is $3600/t_{f,x}$ in an ideal situation in which there is always enough critical headway in the conflicting flow. In any practical situations, the capacity should be lower than $3600/t_{f,x}$ since vehicles usually need to wait for critical headway to appear to proceed through the intersection.

Exhibit 19-11 in HCM2010 shows that the base follow-up headways for right-turn from minor, through traffic on minor, and left-turn from minor are 3.3 seconds, 4.0 seconds and 3.5 seconds, respectively. Therefore, the upper limits of the capacities for these three movements are 1091 veh/h, 900 veh/h and 1029 veh/h.

Chapter 20 of HCM2010 introduces the procedures to evaluate the level of service of All-Way Stop-Controlled (AWSC) intersections. AWSC intersections require every vehicle to stop at the intersection before proceeding. The capacities at AWSC intersections depend on intersection geometry, the number of lanes on each approach and traffic volumes. The calculation of capacities requires running an iterative procedure many times, which is not practical for a regional travel demand model.

Discussion on the capacities for arterials and collectors

The capacity for arterials or collectors is the maximum throughput on an approach. It is determined by the capacity of the downstream intersection, instead of the capacity of the roadway segment itself.

If the intersection is controlled by signals, the dominant factor is the g/C ratio (effective green time over cycle length). If the intersection is controlled by stop signs, the dominant factor is the flow rate of the conflicting travel direction(s). However, the current TRM network does not code any information on traffic control devices at intersections, which makes it impossible to differentiate the intersections with signals and stop signs.

In TRMv6, major arterials should all be controlled by signals, and the procedure described for signalized intersections can be used to estimate the capacities. For a regional travel demand model like the TRM, most of the minor arterials and collectors/locals should be controlled by signals, with some controlled by stop signs. Since no formulas are readily available to calculate the capacities at stop controlled intersections, and TRMv6 does not have traffic control information coded, it was recommended to use the procedure described for signalized intersections to calculate the capacities for minor arterials and collectors/locals with carefully selected parameters.

3.3.3.5 Capacities for Ramps

A ramp is a dedicated roadway providing a connection between two highway facilities. Based on the facility types of the two highway facilities that a ramp connects, 4 ramp facility types were recommended for TRMv6. They are freeway-to-freeway ramp, on-ramp, off-ramp, and arterial-to-arterial ramp, in which on-ramps and off-ramps connect freeways and arterials.

A ramp consists of three elements: the ramp roadway and two junctions. Junctions vary greatly in design and control features, but generally fit into one of these categories: ramp-freeway junctions or ramp-street junctions. Chapter 13 of HCM2010 focuses on ramp-freeway junctions, and Chapter 22 focuses on ramp-street junctions. HCM2010 does not have an exclusive chapter to discuss the ramp roadway (instead, it is covered in Chapter 13), most probably because its capacity and performance is usually determined by the downstream junctions.

The downstream junction of a freeway-to-freeway ramp or an on-ramp is a ramp-freeway junction. According to Chapter 13 of HCM2010, the capacity of the ramp-freeway junction is usually larger than that of the ramp roadway. Therefore, the capacity of a freeway-to-freeway ramp or an on-ramp is the capacity of the ramp roadway, which is listed in Table 3-6 Capacity of Ramp Roadway (same as the Exhibit 13-10 in HCM2010).

Table 3-6 Capacity of Ramp Roadway

Ramp Free-flow Speed (mi/h)	Capacity of Ramp Roadway (pc/h/ln)
>50	2,200
>40-50	2,100
>30-40	2,000
≥20-30	1,900
<20	1,800

The downstream junction of an off-ramp or an arterial-to-arterial ramp is a ramp-street junction. Ramp-street junctions may be uncontrolled, STOP-controlled, YIELD-controlled, or signalized, and they could have very different capacities. Unfortunately, TRMv6 does not code any information on traffic control devices at intersections, which makes it impossible to differentiate these ramp-street junctions. It was recommended to determine later if traffic control information at intersections needs to be coded for the TRM. Although this information will add more accuracy in determining the free-flow speeds and capacities on some roadways, the effort required will be substantial.

It was recommended to make reasonable assumptions on the traffic control information at the ramp-street junctions by area type. These assumptions should hold for most of the ramp-street junctions in a certain area type. For example, ramp-street junctions are usually signalized in CBD, urban, and even suburban areas, and they are usually STOP-controlled in rural areas. For a signalized ramp-street junction, Chapter 22 of HCM2010 shows that its capacity can be determined using Equations 5 and 6 in this document (based on Equations 22-3 and 22-25 in HCM2010). For a STOP-controlled ramp-street junction, its capacity is not discussed in HCM2010. However, Chapter 19 can be used as a reference. At a STOP-controlled ramp-street junction, the capacity for each movement depends on the conflicting flows from other movements, the critical headway and the follow-up headway. Based on the discussions in the section above on stop controlled intersections, the upper limit of the capacities for STOP-controlled ramp-street junction should be around 1000 pc/h.

3.3.3.6 Capacities for Other Facility Types

The previous sections present the formulas to calculate the capacities of ten of the fifteen suggested facility types, that is, freeway, multilane highway, two-lane highway, major arterial, minor arterial, collector/local, freeway-to-freeway ramp, on-ramp, off-ramp, and arterial-to-arterial ramp. This section will discuss the rest of the facility types.

Chapter 12 of HCM2010 provides the methodology for analyzing the operation of freeway weaving sections, and Equations 12-5 to 12-8 can be used to determine their capacities. However, it is difficult to implement these equations in the TRM since they require detailed traffic and geometry information, such as the ratio of weaving demand flow rate and total demand flow rate, the length of weaving section, and the number of lanes from which a weaving maneuver may be made with one or no lane changes. Fortunately, these equations calculate the total capacity of through lanes and auxiliary lanes, which are usually higher than the capacity of the same through lanes without the disturbance of weaving vehicles. That is to say, freeway weaving sections are usually carefully designed to have higher capacities so that they are not bottlenecks on freeways. In the TRM, the number of lanes of freeway weaving sections only includes the number of through lanes (not including auxiliary lanes). Therefore, it was recommended to treat freeway weaving sections in the same way as the basic freeway segments (described in Section 3.3.3.1), so that a freeway weaving section and a basic freeway segment with the same number of through lanes will have the same capacity. Such an approach will lead to lower capacity than the actual capacity for the freeway weaving section, but will not pose a negative impact on the network since the freeway weaving section still has the same capacity as the upstream and downstream basic freeway segments.

HCM2010 does not provide a methodology to analyze HOV lanes. Since HOV lanes are a part of freeways, it makes sense to use the method for basic freeway segments (described in Section 3.3.3.1) to estimate the capacities of HOV lanes. The Dallas and Southern California models also used the same capacities for freeways and HOV lanes.

The remaining three facility types, centroid connector, park-and-ride links and transit-only links, are special. Centroid connectors and park-and-ride links are usually fictitious to connect the centroids or parking lots to the highway network. A large enough capacity should be assigned to these two facility types so that no extra delays are introduced because of congestion on both types of facilities. It is suggested to use the value of 10,000, the same as what was used for TRMv5. Transit-only links are only used by buses, and are not a part of the highway network. Therefore, it is not necessary to determine the capacities of transit-only links.

3.3.4 Intersection Delay Procedures

Based on a literature review and the fact that TRMv6 uses formulas from HCM 2010 to calculate free-flow speeds, it was decided to follow an approach similar to that used in the Florida Southeast Regional Planning Model VI (SERPM6), Dallas-Fort Worth Regional Travel Model (DFWRTM) and Indiana Statewide Travel Demand Model (ISTDM) models. In detail, TRMv6 uses Equation 1 to calculate the free-flow speed with delay, and Equation 2 to calculate the delay at signalized intersections.

$$Free - flow\ Speed\ with\ Delay = \frac{Segment\ Length}{\frac{Segment\ Length}{Free\ Flow\ Speed\ without\ Delay} + Delay} \tag{1}$$

$$d = 0.5C \times \left(1 - \frac{g}{C}\right)^2 \times PF \tag{2}$$

where,

d is the delay per vehicle,
g is the effective green time,
C is the cycle length, and
PF is the progression adjustment factor.

There is an important difference between the approach used for TRMv6 and the approach used in the SERPM6, DFWRTM and ISTDM models. The latter three models all coded the signal locations in the highway network. The advantage is that this information ensures a more accurate calculation of intersection delays. However, there are some concerns with using the same approach for TRMv6:

a) TRM currently does not have any traffic signals coded in the highway network, and it was determined to be too time consuming to collect, clean and code this information for TRMv6.
b) Once the traffic signals are coded in the highway network, the TRM script would need to be modified to use the information.
c) It would still need to be determined how to deal with the signals for future development, that is, how to determine the signal locations on a new road, and more importantly, how to determine the locations of added new signals on existing roads due to the increase of traffic.

It was therefore proposed to not code the signals in the highway network. Instead, a default signal spacing (the distance between two adjacent signals) will be used for all the segments with the same facility type and area type. For example, the default signal spacing for major arterials in urban areas is 0.4 miles, which was determined by sampling the segments and calculating the average signal spacing from the samples. The default signal spacing is then used to calculate the intersection delays along with some other default signal parameters, i.e., the default cycle length, g/C (ratio of the green time and the cycle length) and the vehicle arrival type, which were also used in the SERPM6, DFWRTM and ISTDM models. The approach used in TRMv6 differs from the other 3 models in that it uses default signal spacing, instead of the actual signal spacing.

The advantage to using default signal spacing is that when a segment's area type is changed, e.g. from suburban to urban due to development, its default signal spacing will also be changed; partly addressing concern (c) listed above.

3.3.4.1 Free-flow Speeds with Intersection Delays in TRMv6

TRMv6 first calculates the free-flow speeds without considering intersection delays by following the formulas in HCM2010. Then TRMv6 calculates the free-flow speeds with the impact of intersection delays using the approach described above. Both speeds are kept in the highway network layer, and Table 3-7 compares them.

Table 3-7 Comparison of the Average Free-flow Speed with and without Intersection Delays

		CBD	Urban	Suburb	Rural
Major Arterial	Free-flow Speed without Delay (mph)	35.0	43.6	47.6	50.8
	Free-flow Speed with Delay (mph)	16.5	30.8	38.3	44.9
Minor Arterial	Free-flow Speed without Delay (mph)	34.5	39.6	43.6	46.8
	Free-flow Speed with Delay (mph)	14.6	28.8	34.7	39.4
Collector/Local	Free-flow Speed without Delay (mph)	32.4	35.8	41.7	48.2*
	Free-flow Speed with Delay (mph)	13.3	19.5	34.2	45.7*

* Rural collector/local streets are treated as uninterrupted facilities. They are designed in TRMv6 as a slower version of rural two-lane highways. Therefore, their free-flow speeds should not be compared to the free-flow speeds of the interrupted facilities in Table 3-7.

There are three types of facilities that are affected by intersection delays; major arterials, minor arterials and collector/local streets, and they can be called interrupted facilities. Table 3-7 shows the average free-flow speeds of these three facility types by area type. Note that the free-flow speeds of the facilities with the same facility type and area type could be different, since they could have different posted speeds, different numbers of lanes or other different characteristics that affect free-flow speeds. What are shown in Table 3-7 are the average speeds by facility type and area type.

Figure 3-2, Figure 3-3, and Figure 3-4 below visualize the impact of intersection delays.

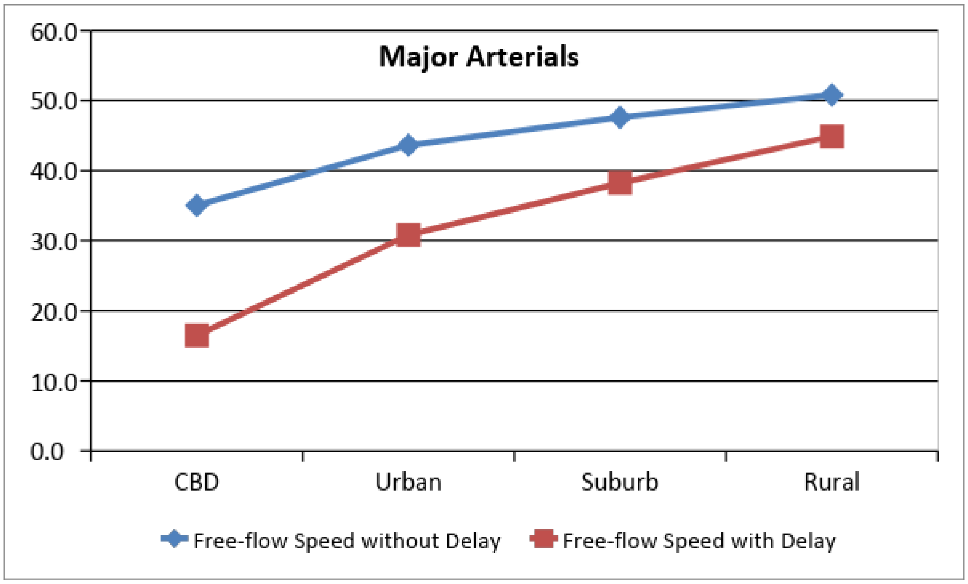


Figure 3-2 Comparison of the Average Free-flow Speeds with and without Intersection Delays for Major Arterials

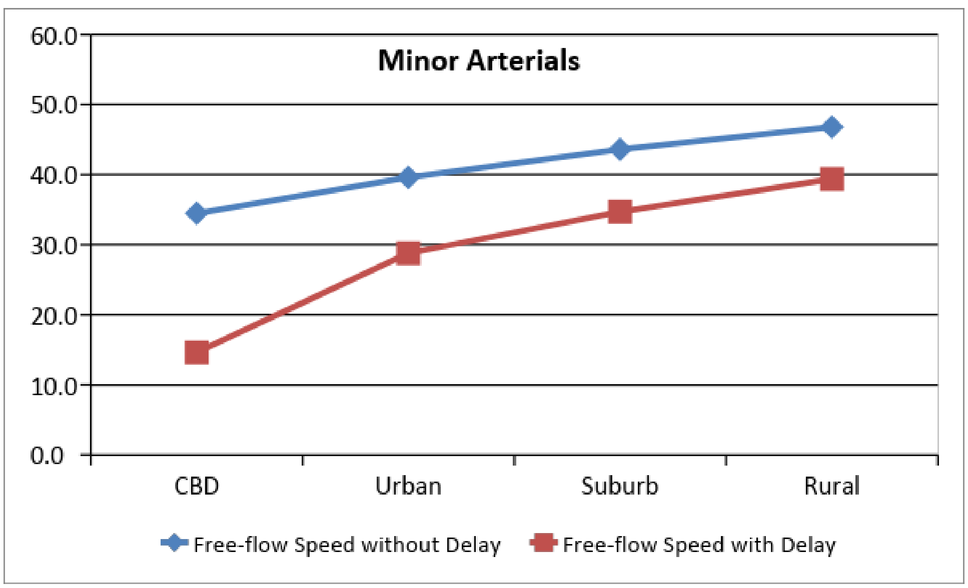


Figure 3-3 Comparison of the Average Free-flow Speeds with and without Intersection Delays for Major Arterials

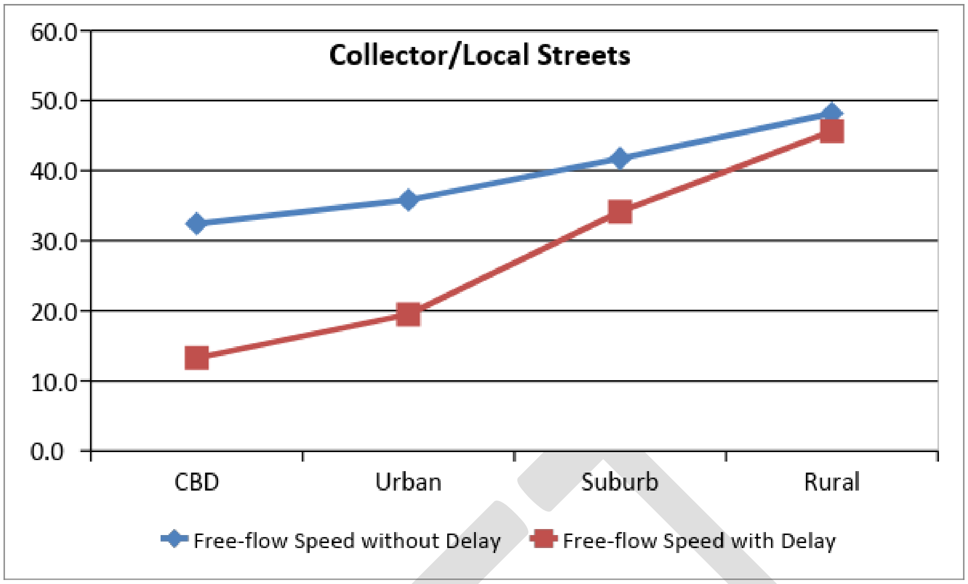


Figure 3-4 Comparison of the Average Free-flow Speeds with and without Intersection Delays for Major Arterials

The figures show that intersection delays have the biggest impact on urban roads, and smallest impact on rural roads, which is expected, because there are fewer signals in a less dense area. These figures also show that if intersection delays are not considered, the TRM will well overestimate the free-flow speeds, and underestimate the travel times, especially in CBD and urban areas.

3.3.4.2 Validation of Free-flow Speeds with Intersection Delays in TRMv6

The Floating Car Survey is the most common travel-time collection technique currently employed. This survey consists of driving a GPS-quipped vehicle along a preselected route and measuring the elapsed time and distance traveled. The DCHC Floating Car Survey was conducted in 2011. It surveyed forty eight routes that cover Durham, Chapel Hill and Hillsborough, with each route having two directions. There are nine vehicle runs for each direction, three in the AM peak (about 6:30AM to 9:30AM), three in the mid-day (about 11:00AM to 2:30PM), and three in the PM peak (about 4:00PM to 7:00PM). Although the major purpose of the survey is to measure congestion, some of the vehicle runs were actually conducted when the traffic was light. For example, in the early morning such as 6:30AM to 7:00AM, the urban area has few vehicles; and most of the streets have few vehicles between 1:00PM and 2:30PM, especially in the suburban areas. Therefore, it was decided to use the DCHC floating car survey to validate the free-flow speeds with intersection delays by comparing the travel time from the survey and the travel time from TRMv6 to see if TRMv6 yields reasonable travel times for the surveyed routes.

Thirteen of the forty eight routes include a significant length of freeways, and they are excluded from the validation work. Figure 3-5 shows the thirty five routes used in the validation. Table 3-8 summarizes the surveyed street length by facility type and area type. It shows that these thirty five routes cover almost 130 miles of roadways in the DCHC area, and most of them are major or minor arterials in urban and suburban areas. Few collector/local streets were surveyed. There is no coverage in the rural area, though since roadways in the rural area usually have no intersections delays or the intersection delays have very little impact on the average travel times, this is not expected to be an important issue. In TRMv6, very few links are coded as rural major or minor arterials.

Table 3-8 Surveyed Street Length by Facility Type and Area Type (miles)

Facility Type ID	Facility Type	CBD	Urban	Suburb	Rural
9	Major Arterial	5.5	53.4	15.3	
10	Minor Arterial	1.9	31.7	20.0	
12	Collector/Local	0.6	1.4		

For each route and direction, three vehicle runs were carefully selected that were likely collected in free-flow conditions, and their average travel time was used as the observed free-flow travel time. Sometimes two or four or more vehicle runs were selected. The reason not to use the shortest travel time as the free-flow travel time is that the shortest travel time is more likely a “lucky” run that was not stopped by signals or stopped less frequently than a representative run.

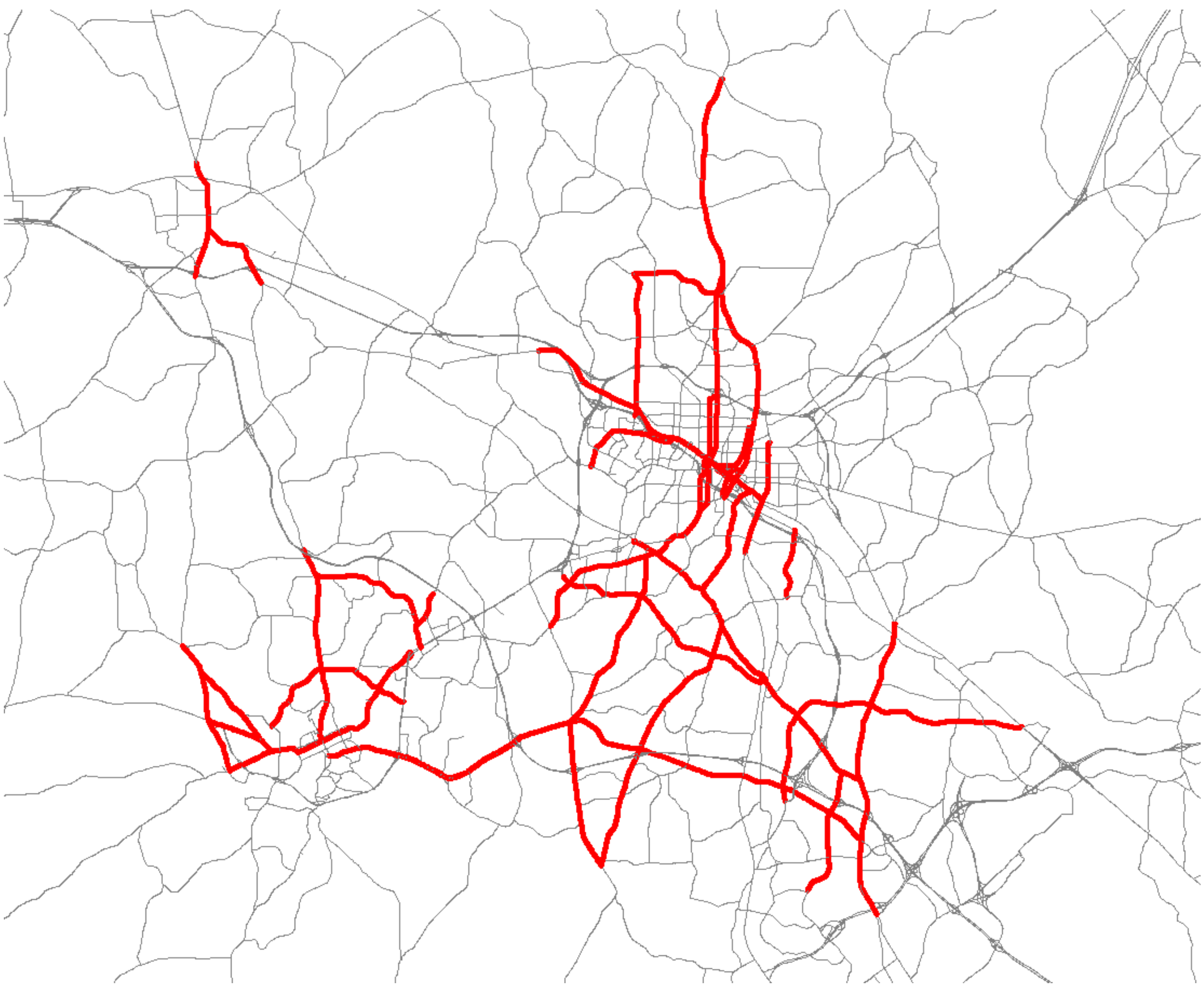


Figure 3-5 Routes in the DCHC Floating Car Survey that were used in the Validation of Intersection Delays

The surveyed routes were coded in the highway network, and a script was written to generate the modeled travel times for the coded routes. Figure 3-6 shows the comparison of the observed and the modeled travel time with intersection delays. Thirty five routes were studied with each having two directions, so there are seventy data points in Figure 3-6. The thin black line is the regression line, and the thick red line is the reference line of Y=X. The regression equation is Y=0.9824X, which implies that the modeled travel time is very close to (slightly smaller than) the observed value. The R-squared value is as high as 0.9688. So, the modeled travel times match the observed travel times very well.

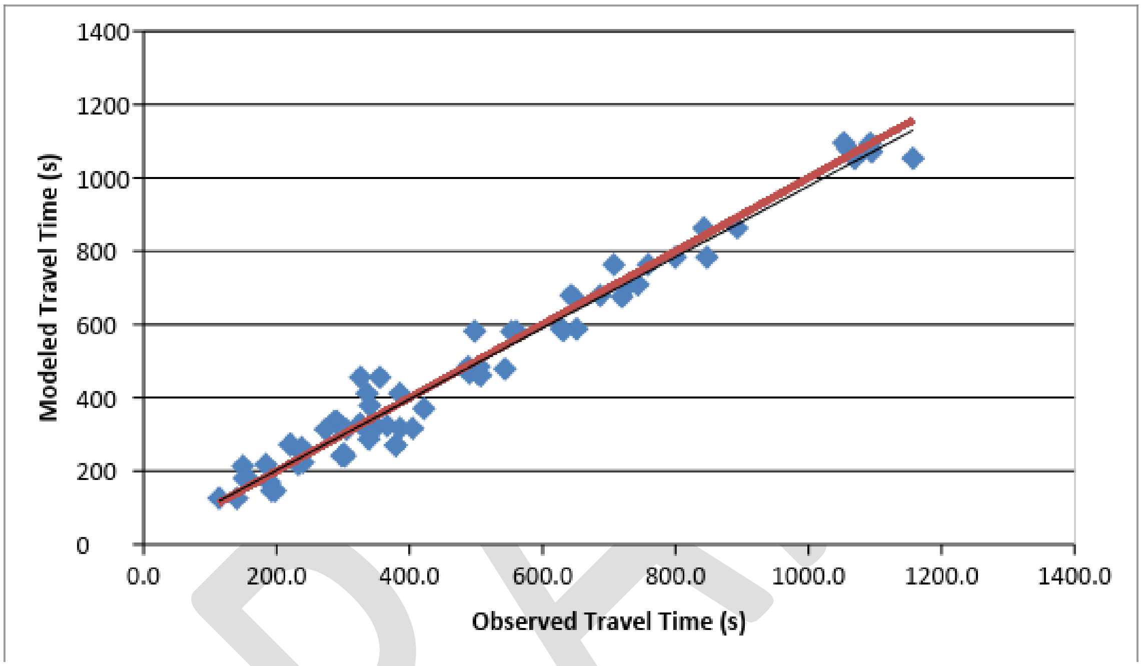


Figure 3-6 Comparison of the Observed Travel Time and the Modeled Travel Time with Intersection Delays

For comparison, Figure 3-7 uses the modeled travel time without intersection delays. It shows that although the R-squared value is high, the modeled travel time is much smaller than the observed travel time, i.e., the modeled free-flow speeds are too fast if intersection delays are not considered.

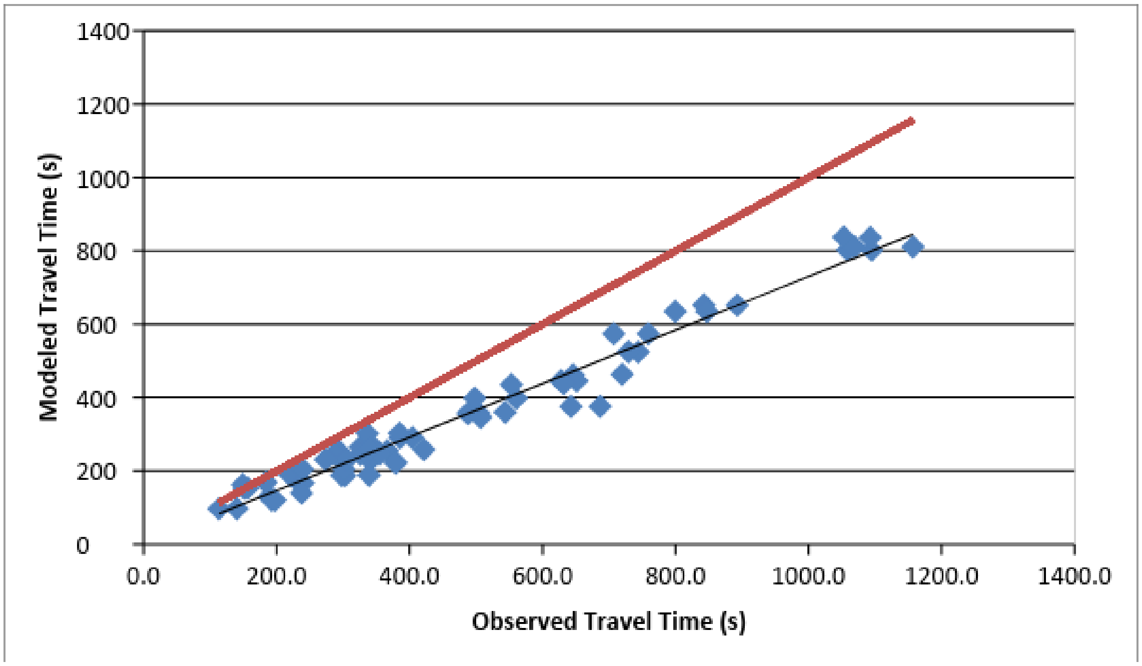


Figure 3-7 Comparison of the Observed Travel Time and the Modeled Travel Time without Intersection Delays

3.3.5 Future Road Characteristics Procedures

Link attributes change as development patterns change from rural to suburban and urban patterns in future years. Failure to update the link attributes in the future year leads to an over-estimate of link capacity, and under-estimate of congestion. An approach was developed to modify the link attributes systematically for future year model runs, so that the links have correct future road characteristics, i.e., correct free-flow speeds and link capacities.

The steps to address future road characteristics include:

1. Determine TAZ area type based on development patterns
2. Determine link area type based on TAZ area type
3. Develop formulas that use link area types in the determination of free-flow speeds and link capacities
4. Apply formulas to calculate free-flow speeds and link capacities using appropriate assumed default link attributes by facility type and area type.

The formulas for link free flow speeds and capacities require many link attributes as inputs, which can be classified into two groups shown in Table 3-9 below. Link attributes in the first group are easier to get for future model runs than those in the second group.

Table 3-9 Classification of Link Attributes that are Used in TRMv6

Link Attributes that are Easier to Get for Future Model Runs (First Group)	Link Attributes that are more Difficult to Get for Future Model Runs (Second Group)
1) Number of lanes 2) Median/left turn lane 3) Posted speed 4) Lane width 5) Shoulder width 6) Lateral clearance 7) On-street parking allowed or not	1) Access point density (number of access points per mile) 2) Signal spacing (distance between two adjacent signals) 3) Signal cycle length 4) g/C ratio (the ratio of green time and cycle length) 5) Vehicle arrival type at intersections 6) Peak Hour Factor (PHF) 7) Parking maneuver rate (number of parking activities per hour)

The link attributes in the first group are usually specified in the MTP and therefore easy to get for future model runs. Most of them are link physical attributes, and they do not necessarily change along with the area type. For example, when a suburb major arterial with posted speed of 45 mph becomes an urban major arterial, its posted speed could be lowered to 35 mph, but could also remain 45 mph.

The link attributes in the second group are more difficult to develop for future model runs. They are mostly operational attributes, and could change frequently. For example, signal timings at intersections (“Signal cycle length” and “g/C ratio”) are usually adjusted frequently to accommodate new traffic patterns. Different signal timing plans could be set up for different time periods during a day. Most of the attributes in the second group have strong correlations with area type. For example, when a major arterial’s area type changes from suburban to urban, usually more access points will be created to access this major arterial, and more signals will be installed to allow signalized control of the traffic from some of the access points to the major arterial. Therefore, default values by area type are assumed for these and other attributes in group two. This section documents how default values for the link attributes in the second group in Table 3-9 were developed.

3.3.5.1 Access Point Density

- **Access Point Density on Freeways (Ramp Density)**

Access points on freeways are ramps, so access point density on freeways can also be called ramp density. According to HCM2010, ramp density is defined as “the number of ramps (on and off, one direction) located within a distance of three miles upstream to three miles downstream of the midpoint of the basic freeway segment under study, divided by six miles.” No default values are provided in HCM2010 for ramp density. Freeway segments by area type were sampled across the region. The average ramp density for each area type is used as the default ramp density. The sample size, average ramp density and the standard deviation are shown in Table 3-10.

Table 3-10 Summary of Ramp Density

Area Type	Sample Size	Average Ramp Density (Ramp/mile)	Standard Deviation of Ramp Density
CBD	2	3.3	0.24
Urban	10	2.6	0.46
Suburb	10	1.1	0.19
Rural	10	0.9	0.15

Only two segments were sampled for CBD freeways, because there are only two CBD freeway segments in the TRM highway network. The sampled segments are at least six miles long, so these samples cover a big portion of freeways in the Triangle region. It is clear from Table 3-10 that the ramp density decreases when the area becomes less dense. The standard deviations are relatively small, indicating that the ramp densities for different area types are significantly different.

Facility types “freeway waving section” and “HOV” are treated as freeways in TRMv6. They use the same ramp densities as shown in Table 3-10.

- **Access Point Density on Other Facilities**

Access point density is very important to determine the free-flow speeds on multilane highways, two-lane highways, major arterials, minor arterials and collector/local streets. Table 3-11 shows the default access point densities by facility type and area type used in TRMv6.

Table 3-11 Summary of Access Point Density (unit: access points/mile)

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
7	Multilane Highway	35	25	16	8
8	Two-lane Highway	50	40	32	16
9	Major Arterial	38	31	19	9
10	Minor Arterial	45	37	23	11
12	Collector/Local	70	61	48	22

Most of the values in Table 3-11 are from Exhibit 14-16, Exhibit 15-5 and Exhibit 17-23 in HCM2010, for multilane highway, two-lane highway and the rest of the facility types in Table 3-11, respectively. Exhibit 17-23 only provides the access point density for arterials, without differentiating major and minor arterials. Those values were decreased by 10% and used for major arterials, and were increased by 10% for minor arterials. It is possible for the default value for a certain cell in Table 3-11 to not be available from HCM2010. These cells are usually facility type and area type combinations that are rare, such as major arterials in rural areas. Very few (or even no) links in the TRMv6 base year highway network fall into these cells. For these cells in Table 3-11, a judgment was made to apply changes between adjacent rows or columns of the table, based on logical relationships. This method is also used in some of the following tables.

3.3.5.2 Signal Spacing

HCM2010 does not provide default values for signal spacing. Segment samples were selected by facility type and area type throughout the Triangle region, and the average signal spacing was used as the default signal spacing, as shown in Table 3-12.

Table 3-12 Summary of Signal Spacing (unit: mile)

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
9	Major Arterial	0.12	0.40	0.80	1.50
10	Minor Arterial	0.12	0.51	1.09	1.74
12	Collector/Local	0.15	0.40	1.40	N/A

Collector/local streets are different from major arterials and minor arterials because some of them have stop signs. It is also possible that a crosswalk is located far from an intersection on collector/local streets, for example, crosswalks like this can be found at university campuses. When the signal spacing for collector/local streets is calculated, each stop sign is counted as one signal, and each crosswalk is counted as 1/5 signals. A rural collector/local street is treated as an uninterrupted facility in TRMv6, so its default signal spacing is not provided in Table 3-12.

Table 3-12 shows that signal spacing increases when area type is changed from CBD to rural as we would expect. It also shows that the signal spacing for collector/local streets could be larger than that for minor arterials or major arterials. It is possible since the traffic volumes on major arterials are usually high, so more signals are needed to stop the traffic on major arterials and allow vehicles from the intersecting streets to access the major arterials. By contrast, collector/local streets are usually used to provide accessibility and their traffic volumes are low, so fewer signals are needed.

The sample size, average signal spacing and the standard deviation for major arterials are shown in Table 3-13. It was attempted to sample at least ten samples for each facility type and area type, but it was difficult to find enough segments with significant length for some categories. No rural major arterials were sampled because only few short links in transition areas fall into this category. Its signal spacing was determined based on logical relationship shown in Table 3-12.

Table 3-13 Summary of Signal Spacing on Major Arterials

Area Type	Sample Size	Average Signal Spacing (mile)	Standard Deviation of Signal Spacing
CBD	11	0.12	0.06
Urban	11	0.40	0.11
Suburb	6	0.80	0.27
Rural	0	N/A	N/A

The sample size, average signal spacing and the standard deviation for minor arterials are shown in Table 3-14.

Table 3-14 Summary of Signal Spacing on Minor Arterials

Area Type	Sample Size	Average Signal Spacing (mile)	Standard Deviation of Signal Spacing
CBD	7	0.11	0.04
Urban	9	0.51	0.22
Suburb	13	1.09	0.32
Rural	2	1.74	0.21

The sample size, average signal spacing and the standard deviation for collector/local streets are shown in Table 3-15. Rural collector/local streets are treated as uninterrupted facilities in TRMv6, so no segments are sampled for this category.

Table 3-15 Summary of Signal Spacing on Collector/Local Streets

Area Type	Sample Size	Average Signal Spacing (mile)	Standard Deviation of Signal Spacing
CBD	11	0.14	0.05
Urban	8	0.40	0.23
Suburb	5	1.40	0.43
Rural	0	N/A	N/A

3.3.5.3 Signal Cycle Length

Signal cycle lengths are usually shorter in urban areas and longer in suburb and rural areas. There are no default signal cycle lengths in HCM2010. The default values developed for the North Carolina Level of Service (NCLOS) Program were reviewed, and the values shown in Table 3-16 were used.

Table 3-16 Summary of Cycle Length (unit: second)

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
9	Major Arterial	90	120	150	200
10	Minor Arterial	90	120	150	200
12	Collector/Local	90	120	150	200

3.3.5.4 G/C Ratio

G/C ratio is the ratio of green time and cycle length. It is an important factor in the determination of intersection delays and link capacities. There are no default g/C ratios in HCM2010. The default values developed for the NCLOS Program were reviewed and these were used after making some adjustments. The g/C ratios used in TRMv6 are shown in Table 3-17.

Table 3-17 Summary of G/C Ratio

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
5	Off-ramp	0.45	0.48	0.50	0.55
9	Major Arterial	0.45	0.48	0.50	0.55
10	Minor Arterial	0.40	0.43	0.45	0.50
11	Arterial-to-arterial Ramp	0.45	0.48	0.50	0.55
12	Collector/Local	0.30	0.30	0.35	N/A

G/C ratios are needed to calculate the capacities on off-ramps and arterial-to-arterial ramps. They use the same values as those for major arterials. Rural collector/local streets are treated as uninterrupted facilities in TRMv6, and no default g/C ratios are provided in Table 3-17.

3.3.5.5 Arrival Type

Arrival type is used in HCM to represent progression quality. There are six arrival types, with one for very poor progression and six for exceptional progression. The default values developed for the NCLOS Program were reviewed, and the values shown in Table 3-18 were used.

Table 3-18 Summary of Arrival Type

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
9	Major Arterial	5	4	4	4
10	Minor Arterial	4	4	3	3
12	Collector/Local	3	3	3	3

3.3.5.6 Peak Hour Factor

Peak Hour Factor (PHF) is a measure of traffic demand fluctuation within the peak hour, and is used in the calculation of capacities. Table 3-19 shows the default PHFs by facility type and area type used in TRMv6.

Table 3-19 Summary of Peak Hour Factor

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
1	Freeway	0.96	0.96	0.95	0.94
3	Freeway Weaving Section	0.96	0.96	0.95	0.94
6	HOV	0.96	0.96	0.95	0.94
7	Multilane Highway	0.94	0.93	0.93	0.88
8	Two-lane Highway	0.88	0.88	0.88	0.88

The PHFs for urban and suburb freeways in Table 3-19 are obtained based on an analysis of the volume data from traffic.com. Traffic.com uses microwave sensors to collect speed, volume, occupancy and vehicle classifications on freeways. These data are aggregated at 5-min, 15-min, 1-hr and 24-hr intervals. There are sixty sensor stations in the Triangle area. Ten sensor stations were selected in urban areas and ten were selected in suburban areas. Their locations are shown in Figure 3-8, red dots for sensor stations in urban areas and blue dots for suburb areas.

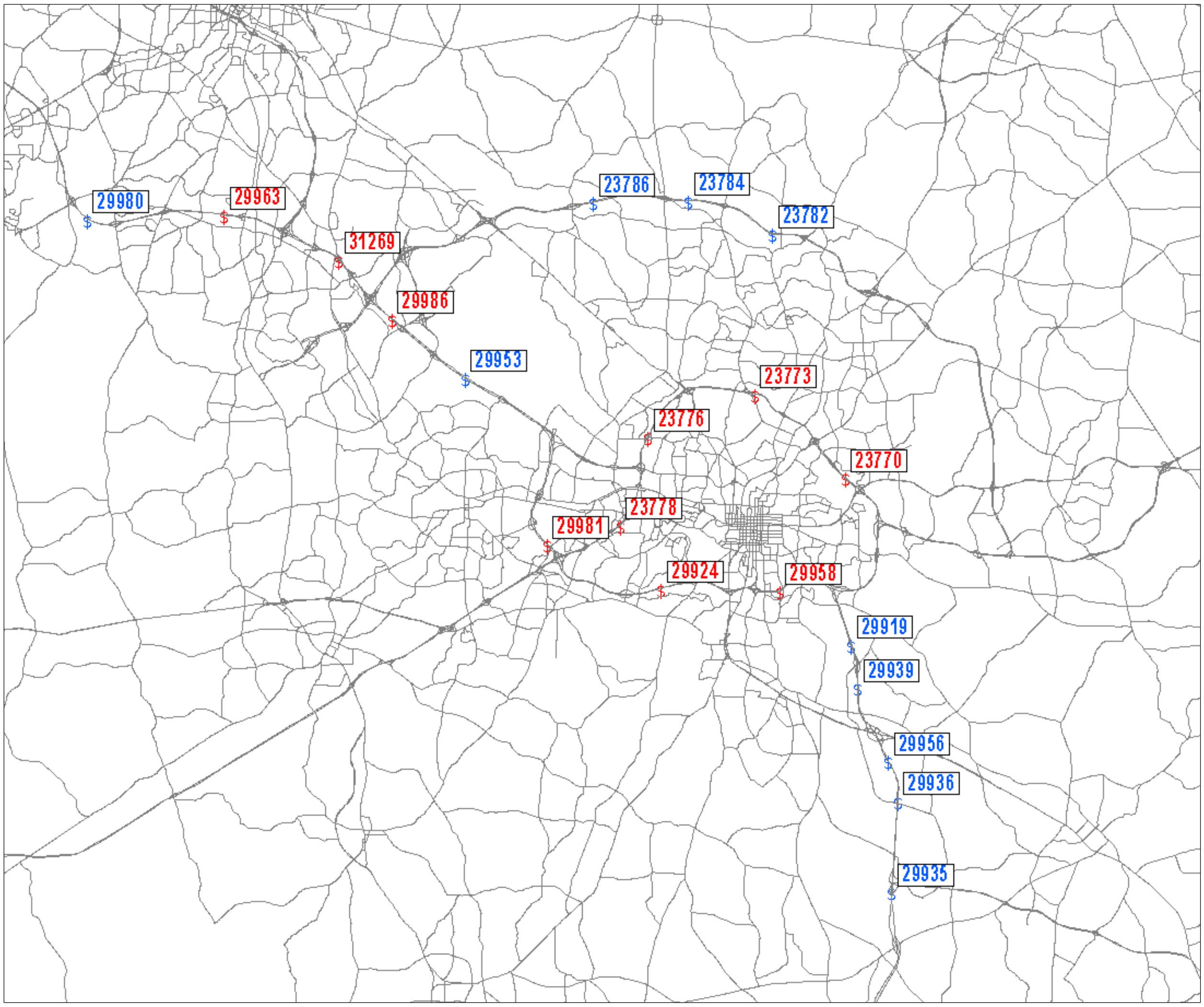


Figure 3-8 Locations of Sampled Sensor Stations

The 15-min data for March 28, 2012 (Wednesday) were downloaded for these 20 sensor stations to calculate the PHFs. There are no sensor stations in the CBD and rural areas. Their PHFs shown in Table 3-19 are based on logical relationships and Exhibit 11-16 in HCM2010. Since freeway weaving sections and HOVs are parts of freeways, they use the same PHFs as freeways. The PHFs for multilane highways and two-lane highways in Table 3-19 are from Exhibit 14-16 and Exhibit 15-5 in HCM2010.

3.3.5.7 Parking Maneuver Rate

On-street parking affects free-flow speeds and link capacities, and its impact can be reflected by introducing parking maneuver rate. The default parking maneuver rates used in TRMv6 are shown in Table 3-20. They are determined based on Exhibit 18-31 in HCM2010.

Table 3-20 Summary of Parking Maneuver Rate (unit: maneuvers/h)

FT ID	Facility Type (FT)	CBD	Urban	Suburb	Rural
9	Major Arterial	16	8	0	0
10	Minor Arterial	16	8	0	0
12	Collector/Local	16	8	0	0

The parking maneuvers only affect the free-flow speeds and link capacities on streets that allow on-street parking. A dummy link attribute "Parking" is added to the TRMv6 highway network. Because no parking information has been collected, all the links have "Parking=0", i.e., on-street parking is not allowed on all the links in the current TRM highway network. Therefore, the impact of on-street parking is not considered yet in TRMv6. However, the model script and input files have been modified so that when the on-street parking information has been collected, it will be reflected in the calculations.

3.3.6 Implementation of TRMv6 Network Procedures

This section provides information on the implementation of the new network procedures developed for TRMv6.

3.3.6.1 New Link Attributes for the New Highway Network Procedures

New link attribute fields have been added to the TRMv6 highway network ("Highway.dbd" in the "Input\Master Geography" folder) in order to apply the new highway network procedures, and they are listed in Table 3-21.

Table 3-21 New Fields Added to the TRMv6 Highway Network

ID	Name	Type	Width	Decimal	Note
1	FacilityType	Integer (4 bytes)	10	0	Facility type of the link. Values are 1 to 15. Should be filled for all links.
2	AreaType	Integer (4 bytes)	10	0	Area type of the link. Values are 1 to 4. Calculated based on TAZ SE data by the model.
3	Lane_Width	Real (8 bytes)	10	2	Lane width in feet. Should be filled for all links. The default value is 12 feet.
4	Shoulder_Width	Real (8 bytes)	10	2	Shoulder width in feet. Should be filled for all links. The default value is 1.5 feet for two-lane highway and 6 feet for other facility types.
5	Lateral_ClearanceAB	Real (8 bytes)	10	2	Lateral clearance for the AB direction in feet. Should be filled for all links. The default value is 6 feet.
6	Lateral_ClearanceBA	Real (8 bytes)	10	2	Lateral clearance for the BA direction in feet. Should be filled for all links. The default value is 6 feet.
7	Parking	Integer (2 bytes)	6	0	If on-street parking is allowed. 0 means no and 1 means yes. Should be filled for all links.

The field "FacilityType" should be filled for all links before running a model. Fifteen facility types are defined in TRMv6, and they are presented in Table 3-22, along with instructions on how to determine a facility type. Table 3-23 summarizes the roadway length by facility type and area type in the TRMv6 base year highway network. The length of a two-way roadway is counted twice in Table 3-23, and the length of a one-way roadway is counted only once. The empty cells in Table 3-23 are the facility types and area types that do not have any roadways in the TRMv6 base year highway network.

Table 3-22 Facility Types for TRMv6 and Instructions on how to Determine a Facility Type

ID	Facility Types in TRMv6	Instructions
1	Freeway	Should be an uninterrupted facility with full control of access.
2	Freeway-to-freeway Ramp	Ramps (including loop ramps) connecting two freeway sections
3	Freeway Weaving Section	Weaving section on freeway
4	On-ramp	On-ramp connecting non-freeway to freeway
5	Off-ramp	Off-ramp connecting freeway to non-freeway
6	HOV	HOV lane on freeway
7	Multilane Highway	Uninterrupted facility (signal spacing is more than 2 miles) without full control of access. There is more than 1 lane in each direction.
8	Two-lane Highway	Uninterrupted facility (signal spacing is more than 2 miles) without full control of access. There is only 1 lane in each direction.
9	Major Arterial	Interrupted facility (signal spacing is less than 2 miles) whose major function is to provide high-speed movement.
10	Minor Arterial	Interrupted facility (signal spacing is less than 2 miles) that is not major arterial or collector/local.
11	Arterial-to-arterial Ramp	Ramp connecting two interrupted facilities.
12	Collector/Local Street	Interrupted facility (signal spacing is less than 2 miles) whose major function is to provide accessibility.
13	Centroid Connector	Virtual link connecting centroid and roadway, whose "special" value is 31.
14	Park and Ride Links	Virtual link connecting roadway to park and ride node, whose "special" value is 54.
15	Transit Only Links	Links that only transit (such as buses and trains) use, whose "special" value is 55.

Table 3-23 Summary of Roadway Lengths by Facility Type and Area Type in the Base Year Highway Network of TRMv6 (Unit: miles)

ID	Facility Type	CBD	Urban	Suburb	Rural
1	Freeway	3	165	207	199
2	Freeway-to-freeway Ramp		17	12	6
3	Freeway Weaving Section		3	1	0
4	On-ramp	1	34	21	13
5	Off-ramp	1	33	23	12
6	HOV				
7	Multilane Highway		13	40	137
8	Two-lane Highway	1	22	606	2,722
9	Major Arterial	25	684	233	23
10	Minor Arterial	15	433	608	115
11	Arterial-to-arterial Ramp		9	1	3
12	Collector/Local Street	56	442	612	2,108
13	Centroid Connector	39	850	1,095	2,145
14	Park and Ride Links	0	5	1	
15	Transit Only Links				

For “AreaType” see below. Default values should be entered for all the other new fields in Table 3-21, i.e., “Lane_Width”, “Should_Width”, “Lateral_ClearanceAB”, “Lateral_ClearanceBA” and “Parking”. Default values are used because these link attributes are not currently available, and the default values should be correct for most of the links in the Triangle region. If a link is known to have a different link attribute value from these default values, for example, has a lane width narrower than twelve feet, users should input the correct link attribute in the highway network. The model script is able to use the corrected link attribute in the calculation of free-flow speed and link capacity.

3.3.6.2 Area Type Assigned to Links

Section 3.6 describes the development of smoothed area types for TAZs. An appropriate smoothed area type also needs to be assigned to links based on the TAZ area type. Several goals were established for carrying out this task:

Goal 1: Parallel one way links should not have different area types

Most roads in the TRMv6 network are coded as two way links on which travel in both directions is allowed. All freeways and some high speed roads are coded as two parallel one way links with travel coded in opposite directions. The links on these facilities should have the same area type in each direction, because they are part of the same facility.

Goal 2: Link area types should be consistent with TAZ area types

It was decided that link area type should be consistent with TAZ area type rather than to define a separate smoothed area type for links.

Goal 3: Denser area types should have priority

If a road is the boundary for two adjacent TAZs with different area types, then the area type for the road should be consistent with the TAZ with a denser area type.

The following procedures were developed to assign area type to links based on the three goals:

Step 1: Create a 0.05 mile buffer for all TAZs with area type 1 (CBD). Tag the TAZ area type to links.

Step 2: Repeat step one for all TAZs with area type 2 (Urban)

Step 3: Repeat step one for all TAZs with area type 3 (Suburb)

Step 4: All remaining links without an assigned area type, are assigned area type 4 (Rural).

[Placeholder for map of TRMv6 network assigned area type]

3.4 Zonal Data and Models

3.4.1 Population Synthesis

The TRM has included a process to create a traveling population for the model region to provide inputs for trip generation. TRMv6 extends the process by adding a component to sample Public Use Microdata Samples (PUMS) to create a list of individual households for each TAZ. The process starts by creating a set of targets to match for households by size, income, workers, children, and vehicles which are called marginal values. The data used to prepare these marginal values are described below along with the process to use the marginal values to sample the PUMS household and person data and to create the list of synthesized households.

3.4.1.1 Preparation of Inputs for 2010 Model Estimation Year

Table 26 Data Sources and Process Summary Table for Population and Employment Inputs for 2010

Input type	TRM categories	Source	Geographic level	Note
HH by Size	Six categories: 1, 2, 3, 4, 5, and 6+ persons	Data: 2010 SF1 100% data Tables: QT-P11 – Households and Families: 2010	Census Block	1) Count of households in SF1 is tabulated by seven size categories with the top category being seven plus. For use with the TRM, categories 6 and 7+ in SF1 were aggregated to the six plus (6+) category. 2) The allocation of households to TAZ was done using a geographic overlay procedure in GIS. 3) The allocation was reviewed and households allocated to water bodies for example were moved to adjacent TAZs.
HH by Income	Four HH income categories:	Data: American Community Survey (ACS) five year	Census Block Group	1) The number of households (ACS five year estimate) was factored to match the

	\$0 - \$25k, \$25k - \$50k, \$50k – \$75k, \$75k+	summary files for 2006-2010 Table: B19001_12E		number of households by size, because households by size were tabulated based on the 100% count SF1 data rather than ACS samples. 2) The households by income group were allocated to TAZs using GIS.
HH by size & income	Six size categories by four income categories (see above)	Data: ACS Public Use Microdata Sample (PUMS) for 2006-2010 Full HH sample used for TRM region	Public Use Microdata Area (PUMA)	1) Prepared a joint 2 way percent distribution table 2) Seed table used to prepare a joint distribution table of households by size and income for each TAZ using iterative proportional fitting
HH by number of workers	Four categories: 0, 1, 2, 3+ workers	Data: ACS PUMS	PUMAs in Triangle region	1) For all combinations of HH size and income, prepare shares of number of workers
HH by number of children	Four categories: 0, 1, 2, 3+ children	Data: ACS PUMS	PUMAs in Triangle region	1) For all combinations of HH size, income, and workers, prepare shares of number of children
Number of vehicles owned	Four categories: 0, 1, 2, 3+ vehicles	Data: ACS PUMS	PUMAs in Triangle region	1) For all combinations of HH size, income, and workers, prepare shares of number of vehicles owned
University student enrollment	Two categories by residence location: On-campus (resident), Off-campus (commute)	- Duke: University 'Common data source"; - NCSU 2010 Spring: Excludes distance education students - UNC: “Common data source”, by the Office of Institutional Research and Assessment was used; - NCCU: “Common Data Set 2008-09”	University campus: NCSU UNC Duke NCCU	1) Students living on campus (on-campus students) were defined as non-institutionalized population living in college/university housing (2010 census SF1 definition) in table P42 at the block level. 2) The number of enrolled under graduate and graduate students were obtained from campus web sites for 2010. Off campus students were calculated for each university by subtracting on campus students from total enrolled under graduate and graduate students. 3) These were allocated to TAZs using GIS overlays 4) If information is available for the number of distance education students as it is for NCSU, the number of enrolled students does not include those enrolled in distance education. The number of off campus students equals total enrolled students minus on campus students.
Employer establishment type	Five categories: Industry, Office, Service – Low attraction rate per employee (service – rate low), Service – High attraction rate per	InfoUSA 2010	Point = address of each establishment record in the data, geocoded to TRMv6 TAZ	1) Data QAQCed by local planners 2) TRM v.6 establishment type assigned via NAICS (6-digit) to Establishment type equivalency table TRM team developed

	employee (service – rate high), retail			3) The distribution of TRM establishment type within each CTPP industry was derived
Worker (employee) earning level	Two categories Earn low: < \$50,000 Earn High: ≥ \$50,000	Year 2010: Census 2000 CTPP – Part 2, Table 11 (12 earning categories and 15 Census Industry categories)	Census TAZ	1) The distribution of low and high earning employees by census industry category were developed 2) The distribution of TRM establishment type within each CTPP industry was applied to obtain the percent shares of high earning workers within each TRMv6 establishment type 3) The percent shares were applied to TRM TAZ (work location) jobs total to derive the number of employees by establishment type and earning level each TAZ (work location)

3.4.1.2 Model Population Resident Workers Input Data 2010

The TRMv6 model uses two populations for representing travel in the Triangle region: population in households (using the census definition), and university students (using the census non-institutionalized group quarters in college/university student housing population). General population inputs were prepared for the 2010 model estimation year for households by size, and households by income level by TAZ. University student population inputs were prepared using 2010 SF1 table information.

3.4.1.3 Household Income Distribution Table Creation

Households by income group were developed for four household income categories: \$0 - \$25k, \$25k - \$50k, \$50k – \$75k, \$75k+. The data sources used were American Community Survey (ACS) five year summary files for 2006-2010 at the block group level. The table used was B19001_12E. The number of households (ACS five year estimate) was factored to match the number of households by size, because households by size were tabulated based on the 100% count SF1 data rather than ACS samples. The households by income group were allocated to TAZs using GIS.

3.4.1.4 Household Size Table

Households by size were developed for six household size categories: 1, 2, 3, 4, 5, and 6+ persons. The data source used was the 2010 SF1 100% data at the block level. Note that the count of households in SF1 is tabulated by seven size categories with the top category being seven plus. For use with the TRM, categories 6 and 7+ in SF1 were aggregated to the six plus (6+) category. Tables used include QT-P11 – Households and Families: 2010. The allocation of households to TAZ was done using a geographic overlay procedure in GIS. The allocation was reviewed and households allocated to water bodies for example were moved to adjacent TAZs.

3.4.1.5 Joint Distribution of Households by Size and Income

A joint distribution of households by size and income was prepared. The data source for this procedure was the ACS 2006-2010 Public Use Microdata Sample (PUMS). The household sample for Public Use Microdata Areas (PUMAs) in the Triangle region (32,915 records) was used to prepare a two way joint distribution percent table of households by income (groups 1-4) by households by size (groups 1-6). This seed table was used to create a joint distribution of households by size and income by TAZ.

3.4.1.6 Worker Distribution Table

A distribution of households by number of workers (0, 1, 2, and 3+) was prepared based on household income and household size. PUMS household data were used again to prepare the distribution of households by number of workers.

3.4.1.7 Vehicle Distribution Table

A distribution of households by number of vehicles owned (0, 1, 2, and 3+) was prepared. This is based on household size, household income, and number of workers. The ACS PUMS data were used to prepare this distribution.

3.4.1.8 Child (<18) Distribution Table

A distribution of households by number of children (0, 1, 2, and 3+) was prepared. This is based on household size, household income, and number of workers. The ACS PUMS data were used to prepare this distribution.

3.4.1.9 Resident Workers by Employment Type and Earning

This process also included for TRMv6 a person element for resident workers. This synthesizes workers by employment type and earnings. The employment types based on resident worker's employer type are: retail, service, and non-service, non-retail. The worker earning levels are low (< $50,000), and high (> $50,000). The combined worker' employer establishment type and earning levels result in six categories of workers by type and earnings. The data source for this distribution is the ACS 2006-2010 PUMS person records (72,672 records). The individual person records were assigned to one of the three worker's establishment types (or unemployed) using a NAICS to TRM job category based on employer establishment type equivalence table developed specifically for the purpose. The equivalence table is consistent with the way that establishments are classified for counting employment in the InfoUSA data. Workers >17 years of age are selected to be consistent with the definition of person types for the model: working adults 18 years and older. A tabulation was created for workers in all possible combinations of household size, income, and number of workers. Shares were calculated for the six categories of workers by type and earning (and unemployed). When this model is applied to TAZs, it creates the distribution of number of workers by type and earnings including unemployed persons. This is included in the person marginal values for population synthesis.

3.4.1.10 Preparation of TRMv6 Marginal Values

The process to prepare the marginal distributions by TAZ of households by workers, children, and vehicles employs a process developed for the TRMv5 model (except that households by size and income distributions are input directly rather than calculated). It is important to distinguish between the distribution tables for workers, children, and vehicles from the households by size and income tables. Households by size and income tables describe the socio-economic makeup of the aggregated model region. The following tables describe the makeup of individual households, so PUMS data is used rather than census tables. This process applies the percent shares for each variable to the count of households by size and income joint distribution and iterates over all combinations of size and income. The product of the iterative process is a count of households in each TAZ by size, income, workers, children, and vehicles. These become household targets for the population synthesis process described below.

3.4.1.11 Population Synthesis

The process for synthesizing the population of households and workers at the TAZ level was carried out using the PopGen application created by Arizona State University. This applies a process of sampling from ACS 2006 - 2010 PUMS household samples (32,915 household records in TRM region PUMAs) for each marginal target in the distribution for each TAZ. Person samples from PUMS are sampled for workers by type and earning. To insure that the persons synthesized are consistent with the household synthesis, a process of Iterative Proportional Updating is employed by PopGen. This ensures that both households and persons synthesized match. The output of the process is a table of individual synthesized household records with a record for each household in a TAZ. The individual household and person worker records are used as the input for the trip generation step in the model.

3.4.1.12 University Student Inputs 2010

University student population was developed for students living on campus and students living off campus. Students living on campus (on-campus students) were defined as non-institutionalized population living in college/university housing (2010 census SF1 definition) in table P42 at the block level. These were allocated to TAZs using GIS overlays. Note that while other non-institutionalized population was also collected from census and is entered in SE data tables, it is not used as an input currently in the TRM model. In order to obtain the number of off campus students (living in households), the number of enrolled under graduate and graduate students were obtained from campus web sites for 2010. Off campus students were calculated for each university by subtracting on campus students from total enrolled under graduate and graduate students. Details can be found in "University_student_trip_model_data_collection_MK_11-30-2012.xlsx". If information is available for the number of distance education students as it is for NCSU, the number of enrolled students does not include those enrolled in distance education. The number of off campus students equals total enrolled students minus on campus students.

Table 27 University Student Inputs 2010

Students by location	NCSU	Duke	UNC	NCCU
On-campus students	9,663	5,735	9,732	2,135
On-campus graduate	241	205	1,186	24
On-campus undergraduate	9,422	5,530	8,546	2,111
Off-campus undergraduate	12,648	1,133	10,033	4,330
Off-campus graduate	6,442	8,114	9,625	2,122
Total students	28,753	14,982	29,390	8,587

3.4.1.13 Employment 2010

Developing the employment (not resident workers) at the work location for 2010 started with acquiring InfoUSA data for the region for 2010. The employment records were verified by local government planners using the Employment Geocoder online tool. This tool allowed planners to review individual employer locations and to verify employment category. TRMv6 defines five establishment type categories (based on the NAICS code for the employer establishment). The categories used are: Industry, Office, Service rate low, Service rate high, and Retail. Service rate low and service rate high refer to low or high customer attraction rate per employee. The establishment type was assigned to each establishment record based on the NAICS to Establishment Type Equivalency table created for the purpose.

Table 28 County Summary of Employment by TRMv6 Establishment Type Category for 2010

County	Industry	Office	Service rate lo	Service rate hi	Retail	Total
Chatham	1,553	2,251	2,890	493	1,588	8,775
Durham	23,224	76,265	58,862	9,832	22,901	191,084
Franklin	3,478	3,281	3,888	762	1,775	13,184
Granville	2,355	1,282	5,815	267	1,151	10,870
Harnett	1,338	1,693	1,696	434	1,107	6,268
Johnston	9,228	11,062	10,598	2,721	8,980	42,589
Nash	341	202	53	10	99	705
Orange	5,219	23,774	28,158	4,095	10,139	71,385
Person	1,912	2,922	3,190	496	1,840	10,360
Wake	89,056	159,739	134,083	35,865	79,622	498,365
Totals	137,704	282,471	249,233	54,975	129,202	853,585

Employment at the work location was also classified by employee type; a combination of employer establishment type and employee earning level: Industry/Office, Service, and Retail by Low (< \$50,000) and High (>= \$50,000) earnings. This estimation was performed using the InfoUSA 2010 and Census Transportation Planning Products (CTPP) 2000 Part 2 Table 11 which contains employee distributions by earnings (12 categories) and by industry (15 categories). The 2010 employees by census industry and TRMv6 establishment type were summarized by TAZ, district, and county. The distribution of TRM establishment type within each CTPP industry was derived. The distribution of low and high earning employees by TRMv6 establishment type were developed. The shares were applied to TRM TAZ employment to derive the number of employees by establishment type and earning level for each TAZ. This is summarized at the county level in the table below.

Table 29 County Summary by Employee Establishment Type and Earning Level for 2010 (low earning < $50k, high earning >= $50k)

County	Ind/Off low	Ind/Off high	Service low	Service high	Retail low	Retail high
Chatham	2,838	966	2,787	595	1,361	227
Durham	50,249	49,240	43,617	25,077	19,935	2,966
Franklin	5,023	1,735	3,791	859	1,605	170
Granville	2,873	764	4,963	1,119	1,050	100
Harnett	2,396	635	1,908	222	1,070	37
Johnston	15,670	4,620	10,967	2,352	8,182	798
Nash	506	37	61	2	74	26
Orange	21,476	7,517	24,080	8,173	9,014	1,125
Person	3,722	1,112	3,166	520	1,804	35
Wake	147,077	101,718	118,158	51,790	66,922	12,700
Totals	251,830	168,344	213,498	90,709	111,017	18,184

3.4.1.14 Preparation of Inputs for 2013 Model Estimation Year

Table 30 Data Sources and Process Summary Table for Population and Employment Inputs for 2013

Input type	TRM categories	Source	Geographic level	Note
University student enrollment	Two categories by residence location: On-campus (resident), Off-campus (commute)	- Duke: University 'Common data source"; - NCSU 2013 Fall: Excludes distance education students - UNC: the *Fact Book, Twenty-Seventh Edition, 2013-2014*, by the Office of Institutional Research and Assessment was used; - NCCU: Quick Facts page online	University campus: NCSU UNC Duke NCCU	Year 2013 – NCSU: Additional on-campus dwelling units were identified by consulting web sites (particularly for NCSU including the construction progress and building opening schedule) and by personal contacts with the on campus housing offices.
Employer establishment type	Five categories: Industry, Office, Service – Low attraction rate per employee (service – rate low), Service – High attraction rate	- InfoUSA 2013	Point = address of each establishment record in the data, geocoded to TRMv6 TAZ	1) Data QAQCed by local planners 2) TRM v.6 establishment type assigned via NAICS (6-digit) to Establishment type equivalency table TRM team developed

	per employee (service – rate high), retail			The distribution of TRM establishment type within each CTPP industry was derived
Worker (employee) earning level	Two categories Earn low: < $50,000 Earn High: ≥ $50,000	- American Community Survey 2006-2010 5-year data – CTTP – Part 2, Table A202205C (6 earning categories and 15 census industry categories)	Census TAZ	1) The distribution of low and high earning employees by census industry category were developed 2) The distribution of TRM establishment type within each CTPP industry was applied to obtain the percent shares of high earning workers within each TRMv6 establishment type 3) The percent shares were applied to TRM TAZ (work location) jobs total to derive the number of employees by establishment type and earning level each TAZ (work location)

3.4.1.15 Model Population and Resident Workers Input Data 2013

In order to develop 2013 estimates of population in households (TRM general population) the 2010 households were used as a base for the estimate. MPO staff collected certificates of occupancy for the period 4/1/2010 through 9/30/2013. These were obtained with address data and were geocoded and the resulting points were then assigned to TAZs. The certificates of occupancy carried a designation for single family and multi-family units. Single family units were assumed to have 2.8 persons per household (except for Durham County which was assumed to have 2.6 persons per household) and multi-family units were assumed to have 2 persons per household. These rates were used to allocate the population to TAZs. The results by county for Durham, Orange, and Wake counties are shown below and compared with the NC Office of State Budget and Management estimates. Note that the TRM population for this comparison includes university student and other non-institutional group quarters population to more closely match the definition of population used by the NC Office of State Budget and Management which includes those populations.

Table 31 Population for 2013 for Three Core Counties Comparing the TRM to NC Office of State Budget and Management Estimates

County	2010 Population TRM	2013 Population TRM	NC OSBM 2013	TRM % of NC OSBM
Durham	265,482	277,944	286,239	97%
Orange	133,067	137,234	139,103	99%
Wake	894,701	955,470	964,022	99%

Source: For NC OSBM https://files.nc.gov/ncosbm/demog/countygrowth_2013.html

This comparison shows that the 2013 TRM population closely matches the NC OSBM estimate for the three core counties.

3.4.1.16 University Student Inputs 2013

The university student inputs were updated for 2013. Enrollment was updated for Fall semester, 2013. At NCSU, the "NC State On-Campus Enrollment Report – Fall 2013 (Excludes distance education students) was consulted. Web sites were consulted for the "common data source" at Duke University. For UNC Chapel Hill, the *Fact Book, Twenty-Seventh Edition, 2013-2014*, by the Office of Institutional Research and Assessment was used. For NC Central University, the Quick Facts page online was consulted. Additional on-campus dwelling units were identified by consulting web sites (particularly for NCSU including the construction progress and building opening schedule) and by personal contacts with the on campus housing offices.

The following table shows the university student inputs developed for each campus for 2013.

Table 32 University Student Inputs 2013

Students by location	**NCSU**	**Duke**	**UNC**	**NCCU**
On-campus students	11,040	5,735	9,732	2,135
On-campus graduate	254	219	1,282	24
On-campus undergraduate	10,786	5,516	8,450	2,111
Off-campus undergraduate	12,500	1,130	9,920	4,258
Off-campus graduate	7,104	8,600	9,475	1,762
Total students	30,644	15,465	29,127	8,155

3.4.1.17 Employment 2013

Developing the employment at the work location started with acquiring the InfoUSA employment data for the region for 2013. This data with a record for each establishment was reviewed by local government planners using the Employment Analyst on line review tool. During this review process employers were checked for location and for TRMv6 establishment type assigned. TRMv6 establishment types were assigned based on NAICS code to: Industry, Office, Service_Rate Low, Service_Rate High, and Retail.

Table 33 County Summary of Employment by TRMv6 Establishment Type for 2013

County	Industry	Office	Service Rate low	Service Rate high	Retail	Total
Chatham	2,086	1,705	2,887	935	1,726	9,339
Durham	21,633	90,205	45,394	10,256	25,389	192,877
Franklin	3,607	2,898	3,492	1,056	1,940	12,993
Granville	2,037	1,155	3,661	356	1,164	8,373
Harnett	1,272	1,149	1,727	610	1,047	5,805
Johnston	8,824	7,550	12,125	2,522	9,703	40,724
Nash	193	69	26	0	12	300
Orange	7,102	19,337	23,810	3,660	10,303	64,212
Person	1,858	2,147	2,586	1,151	2,237	9979
Wake	72,985	179,331	127,807	31,792	94,051	505,966
Totals	121,597	305,546	223,515	52,338	147,572	805,568

The relationships between establishment type and earning level developed for 2010 were updated using ACS-2006-2010, CTPP Part 2 - Table "A202205C" (6 earning categories) and 15 census Industry categories (based on 2-digit NAICS). These updated relationships were applied to the Employment Analyst records for 2013 to create the distribution of TRMv6 establishment type and earning level for each TAZ. The county level summary of employee establishment type (Industry/Office, Service, and Retail) by earning level (low, high) are shown in the table below.

Table 34 County Summary by Employee Establishment Type and Earning Level for 2013 (low earning < $50k, high earning >= $50k)

County	IndOff low	IndOff high	Service low	Service high	Retail low	Retail high
Chatham	2,624	1,167	3,170	652	1,530	195
Durham	56,028	55,809	36,463	19,186	22,011	3,377
Franklin	4,779	1,726	3,783	765	1,720	220
Granville	2,561	631	3,251	766	1,022	142
Harnett	1,852	569	2,114	222	957	90
Johnston	12,144	4,230	11,905	2,742	8,779	924
Nash	215	47	23	3	9	3
Orange	18,469	7,969	18,728	8,741	8,979	1,323
Person	3,393	612	3,166	571	2,189	48
Wake	148,635	103,680	109,950	49,648	79,432	14,618
Totals	250,700	176,442	192,555	83,297	126,629	20,942

3.4.2 Socio Economic Model Performance

The use of census information for developing 2010 general population inputs (population in households) allowed many comparisons to be made between census and model, and particularly for the three core counties included in their entirety in the model study area. Comparing the whole county data means that the census data does not need to be adjusted for geography outside the TRM study area, and county level data is the most dependable (lowest error) tabulation of census data available for the TRM geography. The first comparison is for households and population for the three core counties: Durham, Orange, and Wake. The comparisons of TRM socio economic data counts of households and population match very closely the census counts. This result is expected, because census household counts at the block level were allocated to TAZs.

Table 35 Households for 2010 in TRM Compared to Census SF1

County	Households TRM	Households SF1	Population TRM	Population SF1
Durham	109,345	109,348	257,454	257,466
Orange	51,456	51,457	124,245	124,244
Wake	345,640	345,645	879,997	880,010
Total 3 Counties	506,441	506,450	1,261,696	1,261,720

Sources: TRM SE data for 2010, and US Census SF1 2010 table DP-1

Comparisons were also made for resident workers and children calculated from the joint disaggregation process used to prepare the marginal values for population synthesis. First the workers comparison is shown. It should be noted that two adjustments have to be made to the ACS data in order to make comparisons: ACS households need to be adjusted to match SF1 households, and 16 and 17 year old workers need to be subtracted. For the latter it was assumed that 16 and 17 year olds are employed at the same rate as the 16-19 year old group reported in the ACS.

Table 36 Workers in HHs in 2010 for TRM Compared to ACS Employment

County	Workers TRM	ACS Civilian Employment	2010 ACS employment status for persons 18+
Durham	123,438	124,817	119,416
Orange	60,618	58,927	58,099
Wake	434,943	429,627	429,951
Totals	618,999	613,371	607,466

Sources: TRM marginal values used for population synthesis assuming 3.17 workers in 3+ worker households from Triangle HH Survey

ACS Civilian Employment 1 yr. 2010 table DP03

Estimated 2010 ACS employment for household population 18+ years old based on civilian employment DP03 adjusted for employed <18 years and group quarters employed population

Next the comparison for children is shown. Unlike for workers, tabulations of population in households by age are available from the SF1 one hundred percent tabulation data.

Table 37 Comparison of 2010 TRM Children in HHs to Child Population in Census SF1

County	Children <18 TRM	Population <18 in HHs SF1
Durham	63,846	60,130
Orange	31,485	27,884
Wake	238,006	234,144
Totals	333,337	322,158

Sources: TRM marginal values used for population synthesis using 3.34 children per 3+ child households from the Triangle HH Survey

US Census SF1 2010 table P16 Population in Households by Age

These comparisons show that the inputs used for model estimation closely match available census data. In general the workers are more closely matched than are children.

3.4.3 Validation Results

The population synthesis procedure aims to create a list of households for each TAZ that closely match the household marginal values. This section shows a comparison between the marginal values shown in the above section and the synthesized population. Households by size in the household marginal file and in the population synthesis output PopGen.bin file are shown below.

Table 38 Persons Per Household in Input HH Marginal File

nty	r HH	r HH	r HH	r HH	r HH	er HH	l HH
ham	09	49	66	97	8	6	345
nge	73	64	5	2	4	8	56
e	68	172	18	81	97	04	640
ls	650	185	69	70	39	28	441

Table 39 Persons Per Household in Population Synthesis Output

nty	r HH	r HH	r HH	r HH	r HH	er HH	l HH
ham	20	13	13	12	3	3	334
nge	76	91	5	0	9	2	53
e	11	396	55	56	28	72	618

ls	707	600	23	98	60	17	405

This comparison shows that for the three core counties, the synthesized households are within thirty six households of the marginal targets. Within the distribution of households by size, more households are synthesized for one, two, and three person households and fewer for four, five, and six plus households. This results in a difference in population between the marginal values and the synthesized population of 2,129 persons out of 1,263,074 persons in the household marginal file. However, the household marginal file population was higher than the census SF1 household input file used to create the marginal file by 1,354 persons. The final synthesized population for the three core counties is 775 persons lower than the census SF1 household population reported. This is summarized in the following table showing population rather than households.

nty	) SF1 DP1 Observed Target	by size table input to marginal creation	marginal file input to population synthesis	ulation synthesis output	erence: Observed target – Synthesis
nam	466	452	457	930	
nge	244	245	534	338	
e	010	002	083	677	
ls	1,720	1,699	3,074	0,945	

3.5 Employment Synthesizer

The employment synthesis process was developed and used to assign employment by type and earning level to TAZs.

3.6 Area Type

3.6.1 Area Types in TRMv5

The TAZ area types in TRMv5 are recorded in the field, “ATYPE”, in the Socio-Economic (SE) data file. They are calculated when running “TRM SE Check and Post-processing Tool” based on Equation 1.

$$LUD_i = \frac{DWELLUNIT_i + Stud\_ON_i + \dfrac{\sum_j TotalHH_j}{\sum_j TotalEmp_j} \times TotalEmp_i}{Area_i} \qquad (1)$$

If $LUD_i \geq 2000$, Area Type for TAZ i is urban,

If $150 \leq LUD_i < 2000$, Area Type for TAZ i is suburban,

If $LUD_i < 150$, Area Type for TAZ i is rural.

Where,

LUD_i is the Land Use Density for TAZ i,

$Area_i$ is the area (unit: square miles) for TAZ i,

$TotalHH_j$ is the Total Household (field "HH" in the SE file) for TAZ j,

$\sum_j TotalHH_j$ is the Total Household for the entire region,

$TotalEmp_j$ is the Total Employment (fields "IND"+ "RET"+ "HWY"+ "OFF"+ "SER"+ "SPUNIV"+ "SPSC"+ "SPAIR"+ "SPHOSP" in the SE file) for TAZ j, and

$\sum_j TotalEmp_j$ is the Total Employment for the entire region.

TAZ area types are used to determine the terminal time in TRMv5. In general, the trip origin terminal times are 2 min, 1 min and 1 min for urban, suburban and rural TAZs, respectively. The trip destination terminal times are 2 min, 2 min and 1 min. Some TAZs are identified as parking restriction TAZs, and they have higher trip origin and destination terminal times.

TAZ area types are also used in model specifications in TRMv5. Area type related variables, such as urban dummy variable, suburban dummy variable and rural dummy variables were tested in Trip Production Models, Destination Choice Models and Non-motorized Models. Some of them are included in the final model specifications after testing. In detail, they are Trip Production Models for HBW and WBNH Workers, and Non-motorized Models for HBW, HBShop and NHNW.

Link area types in TRMv5 are recorded in the field, "AreaType", in the highway network. The area type values were entered by network coders manually based on personal judgment, therefore many of them are not consistent with the TAZ area types. Fortunately, link area types in the field of "AreaType" were not actually used in TRMv5. "AreaType" appeared in the "CapacityFactor.bin" file in the folder of "Input\Parameters\", which is a lookup table to find the factor to convert peak hour capacity to AM peak, PM peak and off-peak period capacity based on facility type and area type. However, the factors are always 3.50 for peak periods and 7.14 for the off-peak period, so "AreaType" would not change any lookup results. It was also believed that "AreaType" was used to determine which bus speed equation should be used for a link. There are 9 bus speed categories, and they are designed for each combination of area type (urban, suburban and rural) and facility type group (freeway, arterial and local). However, the bus speed category for a link was obtained from the facility lookup table in TRMv5. Therefore, it is determined by the link attributes, such as number of lanes, posted speed, median/left turn lane, signal density and special, but not by area type.

3.6.2 Area Types in other models

Area Types in five other models have been reviewed to help our work to define new area types. Table 3-24 shows the summary.

Table 3-38 Summary of Area Types for Different Models

	Area Type	DESCRIPTION	How to determine the area type
Florida Southeast Regional Planning Model VI (SERPM6)	1	CBD	Pre-defined
	2	High Density (non-CBD)	Calculated based on population density and employment density
	3	Medium Density (non-CBD)	
	4	Low Density (non-CBD)	
	5	Very Low Density (non-CBD)	
Atlanta Regional Commission (ARC) Travel Demand Model	1	CBD / Very High Density Urban	Calculated based on population density and employment density
	2	High Density Urban	
	3	Medium Density Urban	
	4	Low Density Urban	
	5	Suburban	
	6	Exurban	
	7	Rural	
New York Best Practice Model (NYBPM)	11 area types		Based on a classification table (the row is the population density, and the column is the employment density)
Dallas-Fort Worth Regional Travel Model (DFWRTM)	1	Central Business District	Calculated based on population density and employment density
	2	Outer Business District	
	3	Urban Residential	
	4	Suburban Residential	
	5	Rural	
Southern California Association of Governments (SCAG) Regional Transportation Model	1	Core	Based on development density (population and employment density) and land use characteristics
	2	Central Business District	
	3	Urban Business District	
	4	Urban	
	5	Suburban	
	6	Rural	
	7	Mountain	

Florida Southeast Regional Planning Model VI (SERPM6)

A revised “dynamic” area type was coded on the networks. The area types shown on TAZ layer DBF file are for display purposes. The process extracts the existing area types from the network primarily to identify CBD areas. It then calculates the activity density based area types for all the non-CBD areas using following equation.

$$ADEN(I) = \left[POP(I) + B * \frac{EMP(I)}{AREA(I)}\right] = PDEN(I) + B * EDEN(I)$$

Where ADEN(I) is the activity density in zone I, POP(I) is the population in zone I, EMP(I) is the total employment in zone I, AREA(I) is the total “usable” area of zone I in acres, PDEN(I) is the population density in zone I, EDEN(I) is the employment density in zone I, and B is the regional population to employment ratio.

Three types of exception areas (water, parks, and roadway rights-of-way) were excluded to define the “usable” areas. The new area type for each of the subject links is based on zonal activity densities of TAZs with an influence area of one mile of distance from the link middle point. The population and employment of all TAZs within a one mile radius are accumulated to define this new density based area type. All these calculations are done in Cube-Voyager scripts. Users do not need to code any area types other than the CBD area that is determined from the existing area types. The new density based area types (SATx) are shown in Table 3-25.

Table 3-39 Area Types for Florida Southeast Regional Planning Model VI

Area Type (SATx)	DESCRIPTION	ADEN/Acre Range
SAT1 (Existing AT1-CBD)	CBD	Existing CBD (not variable)
SAT2 (Comparable to AT2-Fringe)	High Density (non-CBD)	More than 49.6
SAT3 (Comparable to AT4-OBD)	Medium Density (non-CBD)	>22.9 & <=49.6
SAT4 (Comparable to AT3-Residential)	Low Density (non-CBD)	>3.1 & <=22.9
SAT5 (Comparable to AT5-Rural)	Very Low Density (non-CBD)	>=0 & <=3.1

Atlanta Regional Commission (ARC) Travel Demand

An area type procedure calculates a floating zone population and employment density for each TAZ, assigns an area type to each TAZ based on the densities, determines the nearest TAZ to each link in the network, and assigns the associated TAZ area types to links. “Floating zone” means that sums of population, employment, and acres for all zones within a specified airline distance of the current zone are used to assign an area type to the zone.

New York Best Practice Model (BPM)

For the BPM, the project team developed an approach that defines Area Type in terms of a general measure of the development character of sub-areas, based on the density of both residential and employment development in each zone and its vicinity. The Area Type program in the BPM “buffers” the population and employment data in a .75 mile area of each zone centroid and includes in the calculation of densities, effectively "smoothing" the area type classification. As shown in Table 3-26, the BPM procedures determine in which of the ten ranges of both population and employment densities a particular area belongs, and based on this two-way consideration, assigns one of the eleven distinct Area Type classifications to each zone. In forecasting applications, this approach automatically adjusts Area Type with future year socio-economic data zonal forecasts, allowing for changes in development scale and mix to be reflected in the BPM, both, in the behavioral models that incorporate Area Type as an explanatory variable, an in capacity estimates of highway network links.

Table 3-40 Area Types for New York Best Practice Model

Population Density per Mile Greater than	Employment Density per Square Greater than									
	0	100	500	1,800	3,375	6,800	10,000	22,250	48,800	211,000
0	11	10	8	8	4	4	3	3	2	1
300	10	10	8	8	4	4	3	3	2	1
1,000	9	9	9	8	4	7	3	3	2	1
4,675	9	9	9	8	4	7	3	3	2	1
9,600	6	6	6	6	4	7	3	3	2	1
14,500	6	6	6	6	4	7	3	3	2	1
20,000	6	6	6	6	6	6	3	3	2	1
30,000	5	5	5	5	5	5	3	3	2	1
70,000	5	5	5	5	5	5	5	3	2	1
80,000	5	5	5	5	5	5	5	5	2	1

Dallas-Fort Worth Regional Travel Model (DFWRTM)

The model has 4,874 Travel Survey Zones (TSZ), and they are aggregated into 720 Regional Area Analysis (RAA) zones. Area type is defined by the activity density at the RAA level. It is assumed that, within each RAA, the area type remains constant across TSZs. The activity density is defined as follows:

$$ADEN_i = (POP_i + B * EMP_i) / AREA_i$$

Where ADENi is the activity density for RAA i; POPi is the population of RAA i; EMPi is the total employment of RAA i; AREAi is the total area of RAA i; and B is the regional population to employment (P/E) ratio. The area type is then defined in Table 3-27.

Table 3-41 Area Types for Dallas-Fort Worth Regional Travel Model

Area Type	Description	Activity Density Range (Per Acre)
1	Central Business District	>125
2	Outer Business District	30-125
3	Urban Residential	7.5-30

4	Suburban Residential	1.8-7.5
5	Rural	<1.8

It should be noted that there are approximately 100 RAAs whose area types are adjusted after the activity density is calculated. The main reason for this adjustment is to keep an RAA's area type consistent with the surrounding RAAs.

Southern California Association of Governments (SCAG) Regional Transportation Model

Area type (AT) used in the highway networks were prepared based on development density (population and employment density) and land use characteristics.

3.6.3 Adopted Formula for Land Use Density in TRMv6

In the review of area types in other models, only two models (Florida Southeast Regional Planning Model VI and Southern California Association of Governments Regional Transportation Model) documented the formulas they used. These two formulas are actually the same, and they are close to the formula used in TRMv5. TRMv5 used dwelling unit and household instead of population. It was recommended to use population in TRMv6 to be consistent with formulas used in other areas. In general population is more consistent across geography than households, and people are always single units, but households can vary by size. Two zones with the same number of households could have different numbers of people, and population better captures the difference of activity densities between these two zones. So it was suggested to use population instead of number of household in TRMv6 to quantify the density of activities. It was recommended to use the land use density and employment density equations shown in Equations 2 and 3.

$$LUD_i = \frac{POP_i + Stud\_ON_i + \frac{\sum_j TotalPOP_j}{\sum_j TotalEmp_j} \times TotalEmp_i}{Area_i} \qquad (2)$$

$$EmpD_i = \frac{TotalEmp_i}{Area_i} \qquad (3)$$

Where,

$$TotalPOP_j = POP_j + Stud\_ON_j$$

$$TotalEmp_j = IND_j + RET_j + HWY_j + OFF_j + SER_j + SPUNIV_j + SPSC_j + SPAIR_j + SPHOSP_j$$

LUD_i is the Land Use Density for TAZ i, and

$Area_i$ is the area (unit: square mile) for TAZ i,

3.6.4 Suggested Area Types in TRMv6

It is expected that area types will be used in TRMv6 to define link facility types, determine the terminal times, and work as dummy variables in the model specifications. The literature review showed that most other models have at least five area types. Area types were studied to determine if more area types (the current TRMv5 has only three area types) are needed, and what would be appropriate thresholds.

Equation 2 was used to calculate land use densities based on the 2010 and 2035 SE data from TRMv5, and color-coded maps were plotted to determine what thresholds would yield reasonable area types across the region. The judgment of “reasonable” is based on local knowledge. The histogram distribution of land use density was also studied to help the determination of thresholds, but regarded as much less important.

After trying different values, two final options were presented as listed in Table 3-28.

Table 3-42 Suggested Area Types in TRMv6

	Option 1		Option 2 (Recommended)	
Number of Area Types	5		4	
Thresholds of Area Types (persons per square mile)	1 Rural	>0 and <=600	1 Rural	>0 and <=600
	2 Suburb	>600 and <=3,600	2 Suburb	>600 and <=3,600
	3 Urban Low	>3,600 and <=10,000	3 Urban	>3,600 and <=35,000
	4 Urban High	>10,000 and <35,000	4 CBD	>35,000
	5 CBD	>35,000		

Table 3-28 shows that the only difference between these two options is that Area Types three and four in Option 1 cover the same land use density range of Area Type three in Option 2. In addition, the name “CBD” could probably be changed to Very High Density Area, because some TAZs outside of downtown areas could also fall into this category, such as the three major university campuses (NCSU, UNC and DUKE) and Crabtree Valley Mall.

It was recommended to use Option 2 for TRMv6, based on the following reasons:

- Based on the maps, it seems that there are no major differences for facilities in “Urban Low” and “Urban High”, therefore a single “Urban” seems sufficient for the purpose of defining the link facility types.
- The maps show that “Urban Low” and “Urban High” TAZs are well mixed so that the area type changes very frequently back and forth between “Urban Low” and “Urban High” from one TAZ to another.

It was decided to have four area types: CBD, Urban, Suburban, and Rural. Equations 2 and 3 were used to calculate land use and employment densities based on the 2010 and 2040 (preliminary) SE data from TRMv5, and color-coded maps were plotted to suggest what thresholds would yield reasonable area types across the region. The histogram distribution of land use density was also studied to help the determination of thresholds, but regarded as much less important. After different values were tested, the thresholds listed in Table 3-29 below were recommended,

Table 3-43 Suggested Area Types in TRMv6

Area Types and Density Thresholds	4 Rural (Low Density)	LUD >0 and <=700
	3 Suburb (Mid-low Density)	LUD >700 and <=4,000
	2 Urban Low (Mid-high Density)	LUD >4,000 and <=35,000 and EmpD < = 14,500
	1 CBD/HDRC (High Density)	LUD >35,000 **OR** EmpD > 14,500

Both the downtown areas and major university campuses (NCSU, UNC and DUKE) outside of downtown areas fall into the high density category, and DUKE campus even has the higher density than that of the downtown. So High-Density Regional Center (HDRC) is introduced to represent the high density areas outside downtown and used together with “CBD” as the name for this high density category.

Figure 3-9 shows the 2010 area types. CBD/HDRC, Urban, Suburban, and Rural areas are represented by red, blue, yellow and green colors respectively in the figure. Besides Raleigh downtown, Durham downtown, Chapel Hill/UNC, NCSU and Duke, many other small TAZs are classified as “CBD/HDRC”, and many small suburban TAZs are surrounded by urban areas. This area fragmentation is consistent with the area types that were defined and used in urban and regional planning. For example, a small park in the downtown should be classified as CBD and a small open space in urban areas should be classified as Urban as well. To solve this area fragmentation issue, a smoothing procedure is introduced in the next section.

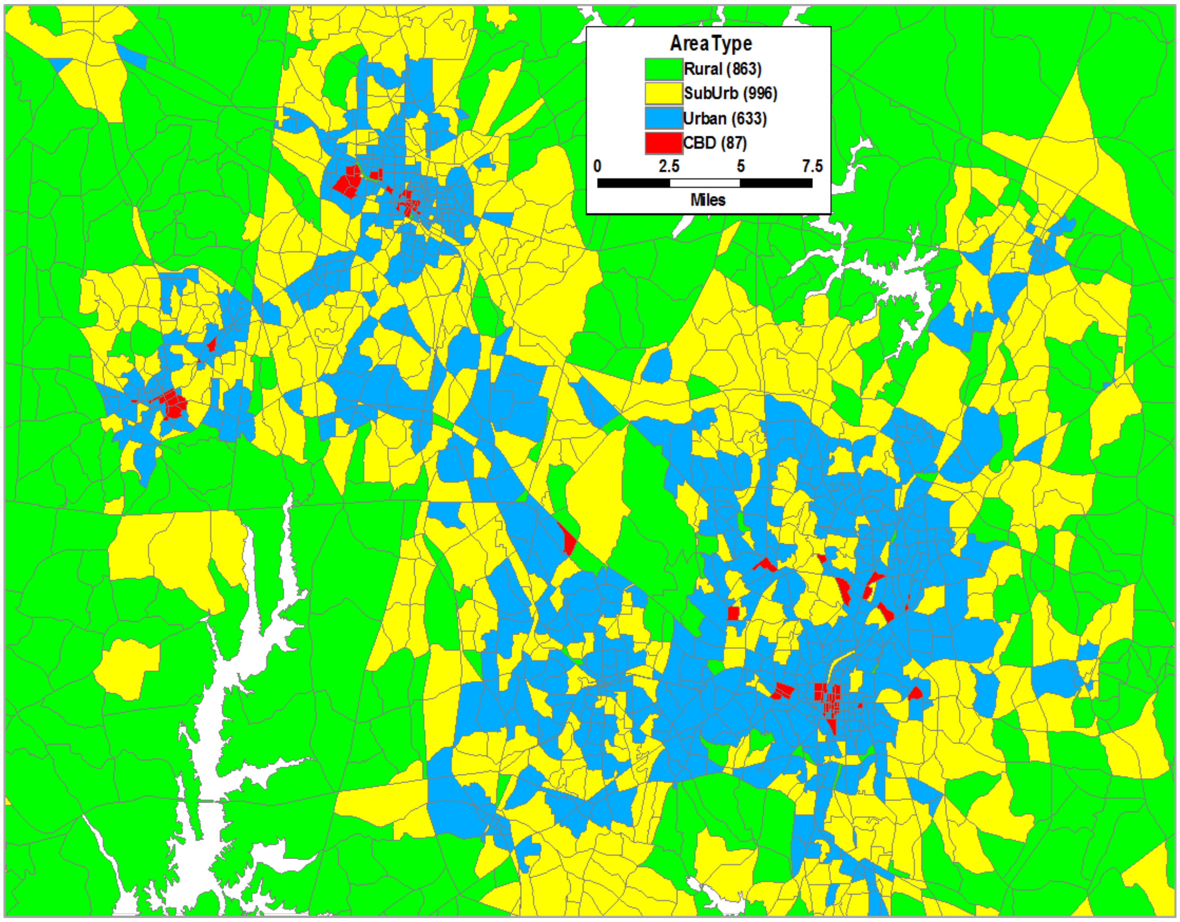


Figure 3-9 2010 Area Types (without smoothing)

3.6.5 Area Type Smoothing

A commonly used smoothing method is the GIS-based floating density process, which selects zone centroids one by one, creates the fixed distance buffer around each zone centroid using GIS, and calculates the zonal density within its buffer instead of within its zonal boundary. Using different distances to create buffers will create different area types. Buffer sizes of 0.25, 0.4 and 0.5 mile were used in the test to see which may result in relatively reasonable area types. Figure 3-10 shows Transportation Analysis Zones (TAZs) and 0.25 and 0.5 mile buffers around centroids in the TRM. The left part of Figure 3-10 shows the zoomed-in view of downtown Durham while the right part shows the zoom-out view with red and black cycles representing 0.25 and 0.5 mile buffers respectively. If a buffer fully falls into a large TAZ, the area type of the TAZ is only determined by its zonal density. In other words, this smoothing method has no impact on large TAZs in rural and suburban areas. This is generally acceptable, because the study focuses on the area type fragmentation of small TAZs in the urban area.

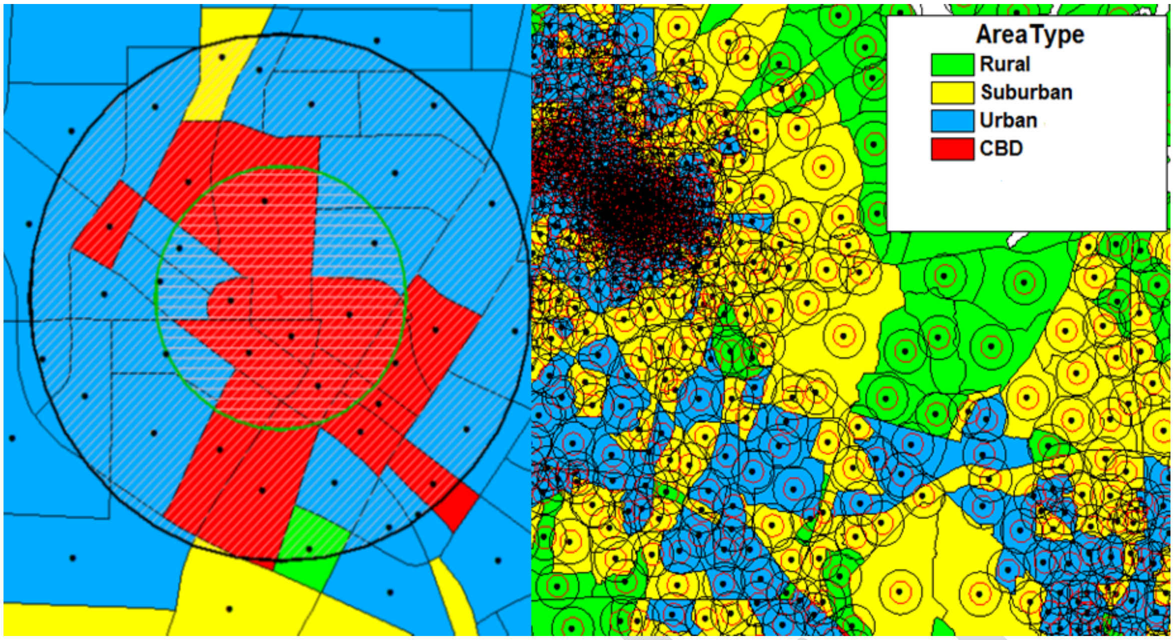


Figure 3-10 Transportation Analysis Zone (TAZ) and Centroid Buffers

The smoothing method is a two-step process. The first step is to create a buffer for each centroid and calculate the area share of the TAZs with a part in the buffer. The output of the first step is a table with at least three data fields, including centroid IDs, IDs of TAZs with a part in the centroid buffer, and percentage of a TAZ area in the buffer. The second step uses the output table, and employment and population of TAZs as inputs to calculate the land use density of each buffer. The calculation assumes that each TAZ has equal employment and population distributed equally over all its area. In other words, the density of each buffer is calculated by summing up all related zonal densities weighted by area percentages. Two GISDK scripts were developed with one is for each step. The first step takes a longer time in TransCAD, and it is not necessary to calculate the table when the TAZ system is not changed, so it was suggested to incorporate only the script of the second step together with the area percentage table into the TRM. The calculated buffer density is called the "smoothed density" and can be used to determine the smoothed area type based on the thresholds defined in Table 3-29.

Among three fixed distance buffers (0.25, 0.4 and 0.5 mile buffers), the 0.5 mile buffers result in relatively reasonable area types, which tend be less fragmented, to be unbroken, and to be contiguous areas for CBD/HDRC and urban areas. Therefore, the value of 0.5 mile was chosen to be used in the area type smoothing in TRMv6.

Figure 3-11 displays the 2010 smoothed area types. CBD/HDRC, Urban, Suburban, and Rural areas are represented by red, blue, yellow and green colors respectively in the figure. There are only four CBD/HDRC areas for 2010; Raleigh downtown, Durham downtown, Chapel Hill/UNC, and Duke. The stylized nature of the area type groupings found in Figure 3-11 for 2010 is much clearer than that found in Figure 3-9 before the smoothing process. The geographic areas by type which resulted from "smoothed" density are less interrupted by other area types, and smoothed area types tend be unbroken and contiguous areas. From a model application perspective, contiguous geographic areas with the same area type are visually appealing and more reasonable.

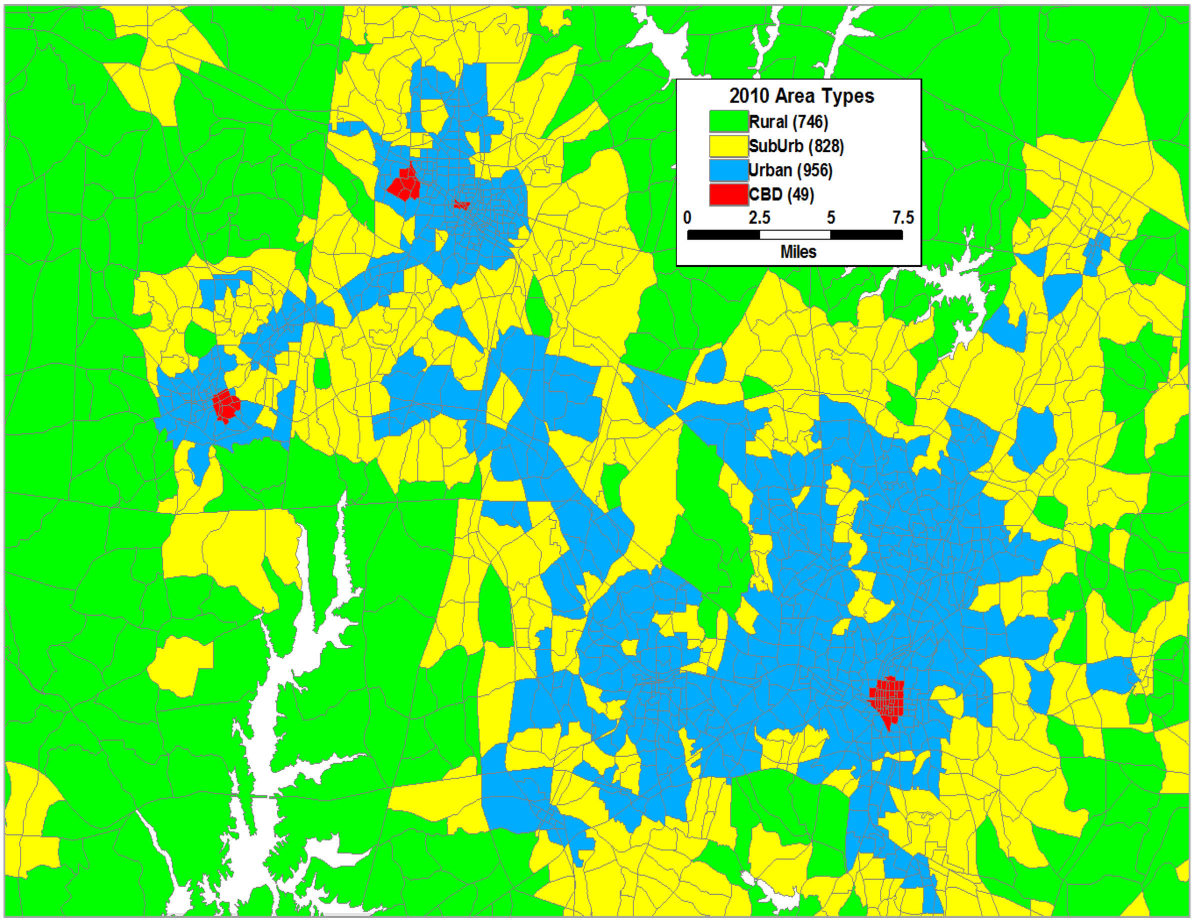


Figure 3-11 2010 Area Types with Smoothing

Figure 3-12 shows the 2010 Census urbanized area against the 2010 smoothed areas of CBD/HDRC, urban and suburban. These two layers fit each other well except in the RTP area between DCHC MPO and CAMPO MPO. This is because RTP is an employment area and the census urbanized area is defined mainly by using population density while the TRM area type takes account of not only population density but also employment density as shown in Table 3-29 and Equations 1-2.

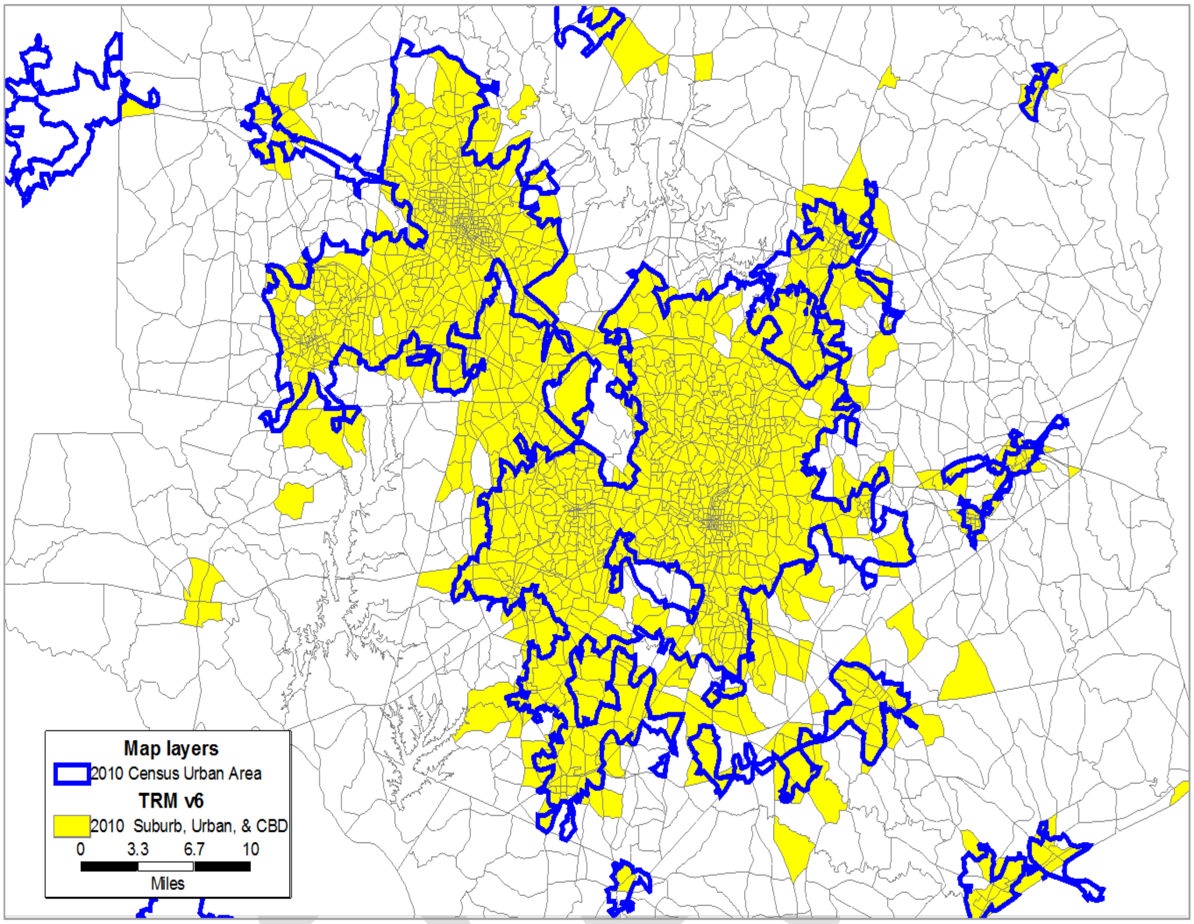


Figure 3-12 2010 TRM vs. Census Urbanized Area

Overall this smoothing method looks reasonable and generates an acceptable area type result. So it was recommended to implement this method in TRMv6.

4 Trip Generation

4.1 Introduction

4.1.1 Trip Production Models

Trip production models estimate trip ends for a typical weekday for three person types: working adults, non-working adults, and children. Multinomial logit-type discrete choice models are utilized to estimate the probability each traveler makes one or more trips of a particular trip purpose on an average weekday based on the demographic attributes of the traveler and his/her household as well as the local or regional geographic characteristics. The trip production models take this form:

$$p_{x,y}(n) = \frac{e^{U_{x,y}(n)}}{\sum \quad e^{U_{x,y}(n)}}$$

Where:

$p_{x,y}(n) = probability\ of\ a\ person\ of\ type\ x\ making\ n\ trips\ of\ purpose\ y, n = 0,1,2,\ldots$

$U_{x,y}(n) = utility\ of\ n\ trips\ for\ person\ type\ x\ and\ purpose\ y$

These probabilities are then used to calculate the effective net trip rate per person by person type and by trip purpose, which is in turn used to calculate the overall trip rate for the household by purpose, and summed to the TAZ level by five socioeconomic strata. The five socioeconomic strata are as follows:

- Households with no vehicles;
- Low income households with at least one vehicle;
- Low medium and high medium households with fewer vehicles than workers, but with at least one vehicle;
- Low medium and high medium households with vehicles equal to or more than workers; and
- High-income households with at least one vehicle.

For trip production model estimation, the data format is one record for each individual member in a household. Each record includes the number of trips made for a particular purpose by an individual respondent on the survey day, along with various demographic and geographic characteristics of the respondent and his/her household. Essentially, the model will predict the probability a person makes zero, one, two, or three, or more trips a day by trip purpose. The zero-trip option is chosen as the reference choice, and by definition it has a zero-value utility and the coefficients estimated for all the variables of other choice options are relative to this reference choice.

Motorized and non-motorized trips are not differentiated at the trip generation stage; therefore, both motorized and non-motorized trip records are included in the dataset for model estimation. To better explain non-motorized trip making behavior, inclusion of non-motorized specific variables in the sub-models was attempted wherever they demonstrated statistical significance. These variables mainly include Land Use Mix and Average Block Size where Land Use Mix = ((2*(Population + Employment) - abs(Population-Employment))/acre, and Average Block Size = Average Street Block Perimeter [miles].

4.1.2 Attraction Models

Trip attractions are calculated to forma basis for calculating the shares of attractions in each stratum. The modeled attraction values are not used in trip distribution, only the shares. The models are linear regression models with the number of attractions depending upon population, employment, or enrolled k12 students as appropriate to the trip purpose.

4.1.3 Attraction Share Models

Attraction share models are used to allocate trip attractions to strata one through five. The models are designed to be sensitive to accessibility and socio-economic characteristics of households. The constants could be expected to be related to the regional proportion of households in each stratum. Accessibility to transit could be expected to be more important for strata one, two, and three. Highway accessibility could be expected to be more important to strata four and five.

4.2 Model Estimation

4.2.1 Home Based Work (HBW)

The home based work (HBW) trip purpose is only estimated for workers, as would be expected.

4.2.1.1 Home Based Work Production Model

Home Based Work (HBW) trips are trips made with one end at the home and the other end at the workplace. Trip production models are trip frequency choice models that estimate the probability of a worker making one, two, or three plus work trips. Models were estimated using the 2006 household survey data including non-motorized specific variables not previously included.

Household Survey Data Summary

Table 4-1 summarizes the number of worker trip records available from the 2006 Household Travel Survey for estimating trip frequency choice models for workers.

Table 4-1 HBW Household Survey Data

HBW Trip Records	Workers
0 Trips	1864
1	1415
2	2339
3	101
4+	132
Total	**5463**

Model Estimation

Table 4-2 shows HBW production model coefficients and t-statistics for workers. For workers with three or more HBW trips, the daily average rate of HBW trips is 3.68. Some variables with low t-statistics were retained in the models to maintain consistency and to have reasonable variables in the models. Workers in zero car households have less chance to make three or more HBW trips, so it is retained in the estimation. Additionally, some coefficients were removed due to incorrect sign or no way to explain it.

Table 4-2 HBW Workers Person Type Production Model

Variable	1 Trip		2 Trips		3+ Trips (Avg. 3.68)	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-0.937	-4.08	0.049	0.39	-1.91	-12.27
Other adults dummy	-0.369	-4.12	-	-	-	-
Child dummy	-	-	-0.448	-7.85	-0.276	-2.01
Cars >= workers dummy	0.473	2.69	-	-	-	-
CBD & Urban area	0.157	2.1	0.231	3.52	0.248	1.67
Inc2 + Inc3 dummy	0.384	2.39	0.251	1.96	0.273	2.0
Inc4 dummy	0.565	3.49	0.311	2.49	-	-
ZeroCarHH	0.447	1.33	-	-	-1.42	-1.4
Avg. block size (miles)	-	-	-	-	-0.584	-2.28
Rho-squared:	0.136					

4.2.1.2 Home Based Work Attractions Model

TAZs were grouped into 40 districts which exhibit similar zonal characteristics, as there is great variation at the TAZ level. Then attraction trips and socioeconomic variables were aggregated to the district level. For home-based work trips, the directly related variable is the total employment. A linear regression model was estimated with total employment as the independent variable.

Table 4-3 HBW Attractions

Variable	Coefficient	t-statistic

Total employment	1.117	32.223
Rho-squared:	0.982	

4.2.1.3 Home Based Work Attraction Share Model

Trip attraction share models are designed as a share model to estimate the probability that an attraction would be in one of five socioeconomic strata:

- Strata 1 – Households with no automobiles (all income levels),
- Strata 2 – Low income households;
- Strata 3 – Low medium and high medium income households with fewer vehicles than workers, but with some automobiles;
- Strata 4 – Low medium and high medium income households with cars equal to or more than workers, or
- Strata 5 – High income households (with automobiles).

Strata 2 was kept and used as the reference and this should be taken into consideration with the interpretation of the model coefficients. The results of the trip attraction share models are shown in Table 4-5.

Table 4-4 HBW Trip Attraction Share Model

	Strata 1		**Strata 3**		**Strata 4**		**Strata 5**	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-1.77	-10.88	-0.85	-7.51	1.56	12.88	1.72	14.83
Highway accessibility					0.0641	3.62	0.107	6.31
Walk to transit accessibility	0.334	3.77	0.21	3.32				
Rho-squared:	0.385							

4.2.1.4 Home Based Work Calibrated Models

Worker Trip Productions

Table 4-5 HBW worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips (Avg. 3.68)

Constant	-0.89	0.125	-1.89
Other adults dummy	-0.369	-	-
Child dummy	-	-0.448	-0.276
Cars >= workers dummy	0.473	-	-
CBD & Urban area	0.157	0.231	0.248
Inc2 + Inc3 dummy	0.384	0.251	0.273
Inc4 dummy	0.565	0.311	-
ZeroCarHH	0.447	-	-1.42
Avg. block size (miles)	-	-	-0.584

Trip Attractions

Table 4-6 HBW attraction model after calibration

Variable	Coefficient
Total employment	1.08349

Attraction Share

Table 4-7 HBW attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-1.25	-0.68	1.23	0.78
Highway accessibility	-	-	0.0641	0.107
Walk to transit accessibility	0.334	0.21	-	-

4.2.2 Home Based Shopping (HBSh)

4.2.2.1 Home Based Shop Production Model

Home Based Shop (HBSh) Trips are trips made with one end at the home and the other end at a retail establishment. Trip production models were estimated using the 2006 Household Travel Survey data.

Household Survey Data Summary

Table 4-5 summarizes the number of person trip records available from the 2006 Household Travel Survey for estimation for each trip frequency choice for workers, non-working adults and children.

Table 4-8 HBSh Household Survey Data

HBSh Trip Records	Workers	Non-Working Adults	Children
0 Trips	3739	1027	1892
1	883	324	227
2	667	443	396
3+	174	133	34
Total	**5463**	**1927**	**2351**

Model Estimation

Table 4-9, Table 4-10, and Table 4-11 show production model coefficients and t-statistics for workers, non-workers and children, respectively. For workers with three or more HBSh trips, the daily average rate of HBSh trips is 3.43. For the non-working adults with three or more HBSh trips, the daily average rate of HBSh trips is 3.70. For children with two or more HBSh trips, the daily average rate of HBSh trips is 2.21.

Table 4-9 HBSh Workers Person Type Production Model

Variable	1 Trip (No. of records = 940)		2 Trips (No. of records = 711)		3+ Trips (Avg. 3.431) (No. of records = 188)	
	Coefficient	**t-statistic**	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-1.171	-12.79	-1.694	-16.38	-2.990	-16.05
Inc1 dummy	-0.361	-2.16	-	-	-	-
Number of children	-0.140	-3.48	-0.126	-2.80	-0.243	-2.68
Number of other adults	-0.292	-4.86	-0.157	-2.48	-0.277	-2.30
Empl. accessibility	22.200	2.77	31.600	3.57	59.400	3.88
ZeroCarHH	-0.515	-1.00	-1.116	-2.04	-1.605	-1.43

Rho-squared: 0.345 Adjusted Rho-squared: 0.343

Table 4-10 HBSh Non-Workers Person Type Production Model

Variable	1 Trip (No. of records = 341)		2 Trips (No. of records = 462)		3+ Trips (Avg. 3.701) (No. of records = 142)	
	Coefficient	**t-statistic**	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-1.054	-4.50	-0.432	-3.82	-1.562	-4.71
Inc1 dummy	-0.230	-1.15	-0.296	-1.71	-0.751	-2.34
Inc4 dummy	0.207	1.43	0.262	2.04	0.550	2.77
Cars >= workers dummy	0.441	1.59	-	-	0.635	1.35
Number of other adults	-0.583	-5.83	-0.494	-5.83	-0.893	-5.48
Avg. block size - Area	0.258	1.99	0.192	1.50	-0.546	-1.61
Rho-squared:	0.194		Adjusted Rho-squared:		0.188	

Table 4-11 HBSh Children Person Type Production Model

Variable	1 Trip (No. of records = 228)		2+ Trips (Avg. 2.210) (No. of records = 232)	
	Coefficient	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-2.713	-4.17	-1.621	-1.47
Inc2 dummy	1.050	2.29	-	-
Inc3 dummy	1.280	2.83	0.342	2.02
Inc4 dummy	1.070	2.43	-	-
Number of Working adults	-0.297	-2.33	-0.405	-2.60
Number of Non-Working adults	-	-	0.115	0.73
ZeroCarHH	-0.225	-1.65	-0.225	-1.65
Rho-squared:	0.434	Adjusted Rho-squared:		0.430

4.2.2.2 Home Based Shop Attraction Share Model

Trip attraction share models are designed as a share model to estimate the probability that an attraction would be in one of five socioeconomic strata:

- Strata 1 – Households with no automobiles (all income levels),
- Strata 2 – Low income households;
- Strata 3 – Low medium and high medium income households with fewer vehicles than workers, but with some automobiles;
- Strata 4 – Low medium and high medium income households with cars equal to or more than workers, or
- Strata 5 – High income households (with automobiles).

Strata 2 was kept and used as the reference and this should be taken into consideration with the interpretation of the model coefficients. The results of the trip attraction share models are shown in Table 4-1.

Table 4-12 HBSh Trip Attraction Share Model

	Strata 1		**Strata 3**		**Strata 4**		**Strata 5**	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-1.410	-11.47	-1.970	-11.99	0.948	8.14	0.872	7.64
Highway accessibility					0.107	6.12	0.145	8.63
Walk to transit accessibility	0.408	4.27						
Drive to transit accessibility			0.519	3.66			0.140	3.29

Rho-squared: 0.343 Adjusted Rho-squared: 0.342

4.2.2.3 Home Based Shop Calibrated Models

Worker Trip Productions

Table 4-13 HBSh worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips (Avg. 3.457)
Constant	-1.171	1.694	-2.99
Inc1 dummy	-0.361	-	-
Number of children	-0.14	-0.126	-0.243
Number of other adults	0.292	-0.157	-0.277
Empl. accessibility	22.2	31.6	59.4
ZeroCarHH	-0.515	-1.116	-1.605

Non-Worker Trip Productions

Table 4-14 HBSh non-worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips (Avg. 3.701)
Constant	-1.054	-0.432	-1.562
Inc1 dummy	-0.230	-0.296	-0.751
Inc4 dummy	0.207	0.262	0.550
Cars >= workers dummy	0.441	-	0.635
Number of other adults	-0.583	-0.494	-0.893
Avg. block size - Area	0.258	0.192	-0.546

Children Trip Productions

Table 4-15 HBSh children production model coefficients after calibration

Variable	1 Trip	2 Trips (Avg. 2.21)
Constant	-2.713	-1.621
Inc2 dummy	1.050	-
Inc3 dummy	1.280	0.342
Inc4 dummy	1.070	-
Number of Working adults	-0.297	-0.405
Number of Non-Working adults	-	0.115
ZeroCarHH	-0.225	-0.225

Trip Attractions

Table 4-16 HBSh attraction model after calibration

Variable	Coefficient
Retail employment	6.36318

Attraction Share

Table 4-17 HBSh attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-0.95	-1.9	0.425	-0.45
Highway accessibility	-	-	0.124	0.193
Walk to transit accessibility	0.443	-	-	-
Drive to transit accessibility	-	0.473	-	-

4.2.3 Home Based K12 School (HBK12)

Home based K12 (HBK12) school trips are trips made between home and school for study or other activities by children and by adults transporting children to/from school.

4.2.3.1 Home Based School Production Model

Household Survey Data Summary

Table 4-6 summarizes the number of person trip records available from the 2006 Household Travel Survey for estimation for each trip frequency choice for workers, non-working adults and children.

Table 4-18 HBSch Household Survey Data

HBSch Trip Records	Workers	Non-Working Adults	Children
0 Trips	4967	1953	860
1	272	36	344
2	147	53	1086
3	37	15	27
4+	40	25	35
Total	**5463**	**2082**	**2352**

Model Estimation

Table 4-19 HBSch Workers Person Type Production Model

	1 Trip		2 Trips (Avg. 2.55)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-7.7	-11.75	-6.22	-11.93
Non-worker adult dummy	-0.119	-0.7	-0.63	-2.89
Child dummy	4.4	11.35	3.53	12.19
Cars < workers dummy	-0.168	-0.51	-0.378	-1.01
Inc2 dummy	1.13	2.08	0.455	0.98
Inc3 dummy	1.28	2.36	0.245	0.52
Inc4 dummy	1.4	2.65	0.712	1.6
Employment accessibility	4.51E-06	2.85	3.64E-06	2.14

Rho-squared: 0.743

Table 4-20 HBSch Non-Workers Person Type Production Model

	1+ Trip (Avg. 2.396)	
Variable	**Coeff.**	**t-stat**
Constant	-3.72	-16.16
Num. of workers	0.93	6.46
Num. of children	0.801	10.34
Inc1 dummy	-1.69	-4.28
Inc2 dummy	-1.24	-4.47
Inc3 dummy	-1.1	-3.94

Rho-squared: 0.786

Table 4-21 HBSch Children Person Type Production Model

	1 Trip	2+ Trips (Avg. 2.08)

Variable	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-0.57	-5.03	0.221	2.63
Non-worker adult dummy	-0.803	-5.26	-0.627	-6.21
Num. of other children	0.0917	1.2	0.29	5.58
Zero car dummy	-	-	1.65	4.15
Inc1 dummy	-0.514	-1.64	-0.06	-0.3
Inc2 dummy	-0.58	-2.89	-0.63	-0.29
Inc3	-0.484	-2.71	-0.276	-2.24

Rho-squared: 0.115

4.2.3.2 Home Based School Trip Attractions

TAZs were grouped into 40 districts which exhibit similar zonal characteristics, as there is great variation at the TAZ level. Then attraction trips and socioeconomic variables were aggregated to the district level. For home-based school trips, the directly related variable is the school enrollment. A linear regression model was estimated with school enrollment as the independent variable.

Table 4-22 HBSch Attractions

Variable	Coefficient	t-statistic
School enrollment	2.53	23.705

R^2: 0.967

4.2.3.3 Home Based School Attraction Share Model

Trip attraction share models are designed as a share model to estimate the probability that an attraction would be in one of five socioeconomic strata:

- Strata 1 – Households with no automobiles (all income levels),
- Strata 2 – Low income households;
- Strata 3 – Low medium and high medium income households with fewer vehicles than workers, but with some automobiles;
- Strata 4 – Low medium and high medium income households with cars equal to or more than workers, or
- Strata 5 – High income households (with automobiles).

Strata 2 was kept and used as the reference and this should be taken into consideration with the interpretation of the model coefficients. The results of the trip attraction share models are shown in Table 4-11.

Table 4-23 HBSch Trip Attraction Share Model

	Strata 1		Strata 3		Strata 4		Strata 5	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-0.886	-5.58	-1.47	-4.22	1.24	7.21	1.85	11.53
Highway accessibility			0.0821	1.57	0.101	3.8	0.133	5.32
Walk to transit accessibility	0.349	1.65						

Rho-squared: 0.421

4.2.3.4 Home Based School Calibrated Models

Worker Trip Productions

Table 4-24 HBSch worker production model coefficients after calibration

Variable	1 Trip	2+ Trips (Avg. 2.55)
Constant	-7.82	-6.21
Non-worker adult dummy	-0.107	-0.623
Child dummy	4.4	3.53
Cars < workers dummy	-0.186	-0.383
Inc2 dummy	1.12	0.444
Inc3 dummy	1.3	0.245
Inc4 dummy	1.41	0.712
Emp. Accessibility	5.84 E-5	4.14 E-5

Non-Worker Trip Productions

Table 4-25 HBSch non-worker production model coefficients after calibration

Variable	1+ Trip (Avg. 2.396)
Constant	-3.67
Number of workers	0.93
Num. of children	0.801
Inc1 dummy	-1.69
Inc2 dummy	-1.24
Inc3 dummy	-1.1

Children Trip Productions

Table 4-26 HBSch children production model coefficients after calibration

Variable	1 Trip	2+ Trips (Avg. 2.08)
Constant	-0.43	0.34
Non-worker adult dummy	-0.802	-0.627
Num. of other children	0.092	0.29
Zero car dummy	-	2.55
Inc1 dummy	-0.514	-0.48
Inc2 dummy	-0.58	-0.062
Inc3 dummy	-0.484	-0.276

Trip Attractions

Table 4-27 HBSch attraction model after calibration

Variable	Coefficient
Total employment	2.343

Attraction Share

Table 4-28 HBSch attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-0.63	-1.66	0.71	0.58
Highway accessibility	-	0.0821	0.101	0.133
Walk to transit accessibility	0.349	-	-	-

4.2.4 Home Based Other (HBO)

4.2.4.1 Home Based Other Production Model

Home based other (HBO) trips are any trips with an end at home except for work, shopping, K12 school, and university student trips. They typically include social – recreational and personal business trips. Trip production models were estimated using the 2006 Household Travel Survey data.

Household Survey Data Summary

Table 4-6 summarizes the number of person trip records available from the 2006 Household Travel Survey for estimation for each trip frequency choice for workers, non-working adults and children.

Table 4-29 HBO Household Survey Data

HBO Trip Records	**Workers**	**Non-Working Adults**	**Children**
0 Trips	3003	711	1113
1	987	292	336
2	896	551	675
3	273	139	99
4+	300	223	123
Total	**5459**	**1916**	**2346**

Model Estimation

Table 4-7, Table 4-8, and Table 4-9 show production model coefficients and t-statistics for workers, non-workers and children, respectively. For workers with four or more HBO trips, the daily average rate of HBO trips is 4.68. For the non-working adults with four or more HBO trips, the daily average rate of HBO trips is 4.75. For children with three or more HBO trips, the daily average rate of HBO trips is 3.85.

Table 4-30 HBO Workers Person Type Production Model

	1 Trip		2 Trips		3 Trips		4+ Trips (Avg. 4.677)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-1.035	-12.62	-1.213	-16.04	-2.218	-17.61	-2.525	-28.74
Num. of children	0.144	3.85	0.213	5.68	0.283	4.83	0.323	5.87
Num. other adult	-0.193	-3.50	-0.123	-2.20	-0.336	-3.28	-	-
Pop & emp access.	0.891	0.95	3.510	4.14	4.080	3.45	4.030	3.41
Zero car HH	-	-	-0.407	-1.77	-1.194	-1.770	-0.991	-1.390

Rho-squared: 0.225 Adjusted Rho-squared: 0.223

Table 4-31 HBO Non-Workers Person Type Production Model

	1 Trip		2 Trips		3 Trips		4+ Trips (Avg. 4.745)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-0.405	-3.79	0.056	-0.07	-2.086	-4.57	-3.106	-4.42
Num. other adult	-0. 436	-3.53	-0.186	-2.10	-0.496	-2.83	-0.292	-2.25
Num. work adults	-0.322	-2.32	-0.202	-1.90	-0.422	-2.11	-0.108	-0.71
Inc3&Inc4 dummy	0.461	3.19	0.234	2.03	0.555	2.84	0.293	1.86
Num. of children	-	-	-	-	0.278	2.94	0.276	3.77
Cars >= workers	-	-	-	-	0.908	1.89	2.230	3.09

Rho-squared: 0.111 Adjusted Rho-squared: 0.105

Table 4-32 HBO Children Person Type Production Model

	1 Trip		2 Trips		3+ Trips (Avg. 3.854)	
Variable	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-1.771	-4.03	-0.625	-1.61	-1.998	-3.90
Inc1 dummy	-0.870	-2.72	-0.561	-2.57	-0.843	-2.19
Cars >= workers	0.675	1.17	0.487	1.01	0.692	1.08
Avg. block size – area	-	-	-0.737	-4.59	-0.622	-2.52
Zero car HH	-0.846	-1.52	-0.846	-1.52	-0.846	-1.52

Rho-squared: 0.134 Adjusted Rho-squared: 0.131

4.2.4.2 Home Based Other Attraction Share Model

Trip attraction share models are designed as a share model to estimate the probability that an attraction would be in one of five socioeconomic strata:

- Strata 1 – Households with no automobiles (all income levels),
- Strata 2 – Low income households;
- Strata 3 – Low medium and high medium income households with fewer vehicles than workers, but with some automobiles;
- Strata 4 – Low medium and high medium income households with cars equal to or more than workers, or
- Strata 5 – High income households (with automobiles).

Strata 2 was kept and used as the reference and this should be taken into consideration with the interpretation of the model coefficients. The results of the trip attraction share models are shown in Table 4-10.

Table 4-33 HBO Trip Attraction Share Model

	Strata 1		Strata 3		Strata 4		Strata 5	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-2.110	-20.00	-1.980	-17.73	0.948	11.83	0.818	10.59
Highway accessibility					0.099	7.75	0.171	13.97
Walk to transit accessibility	0.711	11.92	0.197	2.06				
Drive to transit accessibility			0.464	3.64				

Rho-squared:	0.355	Adjusted Rho-squared:	0.355

4.2.4.3 Home Based Other Calibrated Models

Worker Trip Productions

Table 4-34 HBO worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3 Trips	4+ Trips (Avg. 4.699)
Constant	-1.035	-1.213	-2.218	-2.525
Num. of children	0.144	0.213	0.283	0.323
Num. other adult	-0.193	-0.123	-0.336	-
Pop & emp access.	0.0891	0.351	0.408	0.403
Zero car HH		-0.407	-1.194	-0.991

Non-Worker Trip Productions

Table 4-35 HBO non-worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips	4+ Trips (Avg. 4.745)
Constant	-0.405	0.056	-2.086	-3.106
Num. other adult	-0.436	-0.186	-0.496	-0.292
Num. work adults	-0.322	-0.202	-0.422	-0.108
Inc3&Inc4 dummy	0.461	0.234	0.555	0.293
Num. of children	-	-	-	0.276
Cars >= workers	-	-	0.908	2.23

Children Trip Productions

Table 4-36 HBO children production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips (Avg. 3.854)
Constant	-2.713	-1.621	-1.998
Inc1 dummy	-0.87	-0.561	-0.843
Cars >= workers	1.280	0.342	0.692
Avg. block size – area	1.070	-	-0.622
Zero car HH	-0.297	-0.405	-0.846

Trip Attractions

Table 4-37 HBO attraction model after calibration

Variable	Coefficient
Households	1.6865
Service Low Rate Employment	1.4297
Service High Rate Employment	6.7018

Attraction Share

Table 4-38 HBO attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-1.525	-1.81	0.6	-0.15
Highway accessibility	-	-	0.099	0.171
Walk to transit accessibility	0.711	0.197	-	-
Drive to transit accessibility	-	0.464	-	-

4.2.5 Non Home Based Non-work (NHNW)

Non-home based non-work (NHNW) trips neither begin nor end at home or work place, they occur in the middle of trip chains. This trip purpose and Work-Based Non-Home (WBNH) trip purpose compose Non-Home-Based (NHB) trips. The estimation is based on the 2006 Household Travel Survey data.

Table 4-11 shows the summary of data used to estimate the NHNW model for workers and the model results.

Table 4-39 NHNW Household Survey Data

NHNW Trip Records	Workers	Non-Working Adults	Children
0 Trips	3921	1170	1498
1	956	350	468
2	504	260	387
3	244	302	
4+	243		
Total	**5868**	**2082**	**2353**

Table 4-40 NHNW Workers Person Type Production Model

	1 Trip		2 Trips		3 Trips		4+ Trips (Avg. 5.005)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-1.24	-17.46	-1.8	-19.48	-2.65	-20.42	-2.77	-20.91
Num. of children	0.112	3.02	0.091	1.87	0.116	1.75	0.191	2.99
Num. other adult	-0.239	-4.09	-0.303	-3.85	-0.191	-1.8	-0.138	-1.38
Zero car HH	-0.557	-1.54*	-1.46	-2.02	-0.674	-0.93	-0.633	-0.87

Rho-squared: 0.357 Adjusted Rho-squared: 0.355

* Insignificant at the 90% confidence level

According to the results above, the number of other adults in a household is negatively associated with the probability of a worker to make NHNW trips. This indicates that the non-working adults in a household can make the NHNW trips, which reduces the probability for the working adult to take such trips. The number of children is positively associated with the probability of a worker to make

NHNW trips, which is because children increase the needs for a worker to make NHNW trips. Other potential factors have been tested in the estimate model, such as auto ownership (CarsGEWorkers) and location (Urban/Suburban/Rural), etc., and they are insignificantly related to the NHNW trips by workers. ZeroCarHH was added into the estimation model because it reflects the behavior of no-car households regarding making NHNW trips, and makes the estimation results much closer to the observed data.

Table 4-41 NHNW Non-Workers Person Type Production Model

	1 Trip		2 Trips		3+ Trips (Avg. 3.821)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-0.603	-4.5	-0.791	-5.31	-0.598	-4.13
HHStrata1	-0. 516	-1.83	-1.17	-2.96	-1.06	-2.93
HHStrata2	-0.324	-1.83	-0.686	-3.14	-0.425	-2.21
Num. other adult	-0.47	-4.97	-0.452	-4.26	-0.568	-5.39
Num. of children	0.128	1.82	-	-	0.174	2.42
Land Use Mix	-0.0123	-1.48	-0.0115	-1.22*	-0.02	-2.01

Rho-squared: 0.177 Adjusted Rho-squared: 0.171

* Insignificant at the 90% confidence level

Both household strata 1 and 2 are negatively associated with the probability of a non-working adult to make NHNW trips, which indicates that no-car households and low-income households are less likely to add NHNW trips to their trip chains. The number of other adults in a household is negatively associated with the probability of a non-working adult to make NHNW trips, which indicates that the number of other adults in a household decreases the likelihood of a non-worker to make NHNW trips. The number of children is positively associated with the probability of a non-working adult to make NHNW trips, which is because children increase the needs of NHNW trips. “Land Use Mix” is negatively associated with the probability of a non-working adult to make NHNW trips, which is probably because a household with better accessibility in their neighborhood can meet most needs by short home-based trips and is less likely to take NHNW trips.

Table 4-42 NHNW Children Person Type Production Model

	1 Trip		2+ Trips (Avg. 2.592)	
Variable	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-0.569	-2.19	-0.197	-0.68

HHStrata1	-1.83	-3.03	-2.92	-2.86
HHStrata2	-0.802	-2.85	-0.638	-2.27
HHStrata3	-0.659	-1.33	-0.11	-0.24
HHStrata4	-0.288	-2.43	-0.322	-2.49
Num. other adult	-0.215	-1.75	-0.501	-3.62

Rho-squared: 0.186 Adjusted Rho-squared: 0.182

The number of other adults in a household is negatively associated with the probability of a child to make NHNW trips, which is probably because 1) NHNW trips are more likely to be completed by an adult when there are more adults in the household; 2) children are more likely to stay home with one of the adults. The household strata 1 to 4 are included in the estimation model, while strata 5 (high income households with auto) is used as the reference group and its effects are reflected in the constants. The household strata 1 to 4 are negatively associated with the probability of a child to make NHNW trips, which indicates that strata 1 to 4 make fewer trips than strata 5. And the lower strata make fewer trips than the higher strata.

4.2.5.1 Non-Home based Non-Work (NHNW) Trip Attractions

Linear regression model without constant is used to estimate the zonal attraction for NHNW trips. The number of trips attracted to a TAZ and the employment and population information in the attraction TAZ are aggregated to 40 districts. The regression models are estimated based on the 40 records.

Table 4-43 NHNW Attractions

Variable	Coefficient	t-statistic
Population	0.3671	7.4522
Total employment	0.6593	8.1617

Rho-squared: 0.962

Both total population and total employment by zone are significantly related to zonal attractions. The R-squared value of 0.962 shows the model explains most of the variation in the attractions.

4.2.5.2 Non-Home Non-Work (NHNW) Attraction Share

Multinomial logit model is employed for this task. Multiple tests were conducted by using different strata as the reference group. The final results are shown in the tables below, with Strata 2 fixed as the reference group. Highway accessibility, walk to transit accessibility, and drive to transit accessibility are the variables. The coefficients for the accessibility variables are “forced” to be non-negative in the estimation.

Table 4-44 NHNW Attraction Share

	Strata 1		Strata 3		Strata 4		Strata 5	
Variable	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Constant	-2.14	-14.45	-2.56	-7.28	0.755	6.33	0.735	6.51
Highway accessibility			0.124	2.41	0.138	7.75	0.188	11.42
Walk to transit accessibility	0.654	6.91	0.556	3.84			0.0921	1.7
Rho-squared:	0.371				Adjusted Rho-squared:		0.37	

4.2.5.3 Non-Home Non-Work Calibrated Models

Worker Trip Productions

Table 4-45 NHNW worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3 Trips	4+ Trips (Avg. 5.005)
Constant	-1.285	-1.776	-2.647	-2.809
Number of other adults	-0.239	-0.303	-0.191	-0.138
Number of children	0.112	0.091	0.116	0.191
No cars	-0.6684	-1.752	-0.8088	-0.7596

Non-Worker Trip Productions

Table 4-46 NHNW non-worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3+ Trips (Avg. 3.831)
Constant	-0.6201	-0.725	-0.5755
HH Strata 1	-0.516	-1.17	-1.06
HH Strata 2	-0.324	-0.686	-0.425
Num. of other adults	-0.47	-0.452	-0.568
Num. of children	0.128		0.174
Land use mix	-0.0123	-0.0115	-0.02

Children Trip Productions

Table 4-47 NHNW child production model coefficients after calibration

Variable	1 Trip	2+ Trips (Avg. 2.592)
Constant	-0.4165	-0.0405
HH Strata 1	-1.9581	-3.1244
HH Strata 2	-1.2431	-0.9889
HH Strata 3	-1.5157	-0.253
HH Strata 4	-0.36288	-0.4057
Number of adults	-0.215	-0.501

Trip Attractions

Table 4-48 NHNW attraction model after calibration

Variable	Coefficient
Population	0.3485
Total employment	0.6260

Attraction Share

Table 4-49 NHNW attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-1.67	-2.57	0.38	-0.21
Highway accessibility		0.124	0.138	0.188
Walk to transit accessibility	0.654	0.556		0.0921

4.2.6 Work Based Non Home (WBNH)

Like home-based work trips, only working adults make work place based trips. Most of the work place based non-home (WBNH) trips are shopping, personal/family business, going to lunch, and picking up or dropping off kids at school. However, unlike home-based trip making where the trip production end is home and socioeconomic characteristics of trip makers at the production end can be relatively easy to obtain from the home-based demographic forecasting model, the production end of a WBNH trip is the work place and there are no sub-models in the TRM forecasting SE characteristics of trip makers at work places. It also appears to be challenging to develop such models since people can change work places easily in the model, as indicated by the trip distribution model, and therefore zonal socioeconomic characteristics of trip makers change accordingly.

An effective approach is to utilize the results from the HBW trip attraction share model. The HBW trip attraction share model predicts household stratification percentages of working adults in attraction end TAZs for HBW trips. HBW attraction end TAZs – work places - are just the production end TAZs for work place based non-home trips. That being said, it is recognized that while this method covers the vast majority of the cases, it does not cover all. For example, if a person takes his child to school from home and then goes to his work place in the morning, his household stratification is not counted in the household stratification shares predicted by the HBW attraction share model, since he did not make a HBW trip. Therefore, it is assumed that the part the HBW attraction share model does not predict has the same share distribution as the HBW part.

WBNH trips are produced by working adults at the work zone and have non-home destinations. So the purpose of such trips often involves meetings out of the office, lunch, picking up kids, shopping, personal errands, etc. Table 4-15 shows the summary of data used to estimate the WBNH model and model results.

Table 4-50 WBNH Household Survey Data

WBNH Trip Records	Workers
0 Trips	356 1 106
1	9
2	732
3	280
4+	226
Total	586 8

Table 4-51 Worker Person Type Production Model

	1 Trip		2 Trips		3 Trips		4+ Trips (Avg. 4.438)	
Variable	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Constant	-1.25	-20.05	-1.69	-23.46	-2.75	-25.21	-3.18	-25.78
Work end empl. Accessibility (millions)	5.65	4.03	8.23	5.3	11.4	5.24	14.7	6.6
HHStrata1	-0.434	-1.39*	-1.29	-2.47	-1.76	-1.74	-8.17	-0.29
HHStrata2	-0.401	-2.5	-0.66	-3.18	-1.65	-3.22	-0.78	-1.97
HHStrata3	-0.848	-3.11	-0.513	-1.87	-0.75	-1.61*	-0.71	-1.36*
HHStrata4	-0.221	-2.92	-0.254	-2.87	-0.178	-1.35	-	-

Rho-squared: 0.297 Adjusted Rho-squared: 0.295

* Insignificant at the 90% confidence level

Unlike home-based trips, work-based non-home (WBNH) trips cannot be estimated by directly using the socioeconomic characteristics of trip makers at the home zones, since WBNH trips are produced at the work zones. To estimate the production for this trip purpose, the results of HBW trip attraction share model were used. The HBW trip attraction share model predicted household stratification percentages of working adults in attraction end TAZs for HBW trips. HBW attraction end TAZs are the “work places” TAZs. The household strata 1 to 5 at the HBW attraction end TAZs were used to estimate the production of work zone based trips.

The household strata 1 to 4 are included in the estimation model, while strata 5 (high income households with auto) is used as the reference group and its effects are reflected in the constants. The household strata 1 to 4 are negatively associated with the probability of a worker to make WBNH trips, which indicates that strata 1 to 4 make fewer trips than strata 5. And generally speaking, more trips are made by higher strata groups.

Work-end employment accessibility (in million) is positively associated with the probability of a worker to make WBNH trips, which indicates that a worker is more likely to take WBNH trips when accessibility at the work zone is better. Other potential factors have been tested, such as “Urban” variable (if a TAZ is in the urban area), and they are insignificantly related to the WBNH trips by workers.

4.2.6.1 Work Based Non-Home (WBNH) Trip Attractions

Linear regression model without constant is used to estimate the zonal attraction for WBNH trips. The number of trips attracted to a TAZ and the employment and population information in the attraction TAZ are aggregated to 40 districts. The regression models are estimated based on the 40 records.

Variable	Coefficient	t-statistic
Total employment	0.6741	24.0

R^2: 0.937

Total employment by zone is significantly related to zonal attractions. The R-squared value of 0.937 shows the model explains most of the variation in the attractions.

4.2.6.2 Work Based Non-Home (WBNH) Attraction Share

Multinomial logit model is employed for this task. Multiple tests were conducted by using different strata as the reference group. The final results are shown in the tables below, with Strata 2 fixed as the reference group. Highway accessibility, walk to transit accessibility, and drive to transit accessibility are the variables. The coefficients for the accessibility variables are “forced” to be non-negative in the estimation.

Table 4-52 WBNH Attraction Share

	Strata 1		Strata 3		Strata 4		Strata 5	
Variable	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Constant	-2.28	-7.2	-1.48	-3.12	1.33	6.31	1.37	6.82
Highway accessibility			0.0563	0.84*	0.124	4.15	0.194	6.82
Walk to transit accessibility	0.487	2.47	0.717	3.95			0.255	2.38
Drive to transit accessibility					0.285	2.55	0.139	1.14*
Rho-squared:	0.451				Adjusted Rho-squared:		0.449	

* Insignificant at the 90% confidence level

4.2.6.3 Work-Based Non-Home Calibrated Models

Worker Trip Productions

Table 4-53 WBNH worker production model coefficients after calibration

Variable	1 Trip	2 Trips	3 Trips	4+ Trips (Avg. 4.438)
Constant	-1.1482	-1.5	-2.51	-2.854
Work end empl. Accessibility (millions)	5.65	5.23	11.4	14.7
HH Strata 1	-0.41881	-1.24485	-1.6984	-7.88405
HH Strata 2	-0.39699	-0.6534	-1.6335	-0.7722
HH Strata 3	-0.9328	-0.5643	-0.825	-0.781
HH Strata 4	-0.18785	-0.21082	-0.1335	

Trip Attractions

Table 4-54 WBNH attraction model after calibration

Variable	Coefficient
Total employment	0.716217

Attraction Share

Table 4-55 WBNH attraction share model after calibration

	Strata 1	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.
Constant	-1.86	-1.38	1.021	0.45
Highway accessibility		0.563	0.124	0.194
Walk to transit accessibility	0.487	0.717		0.255
Drive to transit accessibility			0.285	0.139

4.3 Model Calibration

Model parameters were adjusted for each trip purpose to improve model performance compared to observed values. Production models were adjusted until total trips for each trip purpose were within one percent of observed trips and trips by strata were within ten percent of observed trips by strata. Comparisons are provided below for the calibrated production models by trip purpose. First total trips by purpose estimated by the model are compared to observed trips.

Table 4-56 After Calibration Results - Trip Rate Comparisons

	Estimated	Observed	% Difference
Work trips per worker			%
K-12 trips per child			%
Shopping trips per retail empl.			%
Total trips per person*			%
Total trips per household			%

4.4 Model Validation

5 Time of Day and Peak Spreading

5.1 Peak Spreading Model

Peak Spreading is a phenomenon where the proportion of traffic demand decreases in the most severely congested part of a peak period when travel conditions deteriorate and the decreased proportion moves outward to the shoulders of the most severely congested part. Peak spreading causes the peak-period travel demand profile to be flatter and wider over time, as shown in Figure 5-1 below. Peak spreading can be a result of reactive responses of travelers to deteriorated traffic conditions. However, implementation of policies such as flextime work schedules and temporal/dynamic road pricing can encourage peak spreading, if implemented appropriately. In either way, peak spreading leads to a more efficient use of urban roadway networks during the peak period. Failure to take peak spreading into account can result in overestimation of forecasted traffic volumes in the peak hour (and thus underestimation of average speeds) and an underestimation of forecasted traffic volumes in the shoulder periods (and thus an overestimation of average speeds), which can lead to problematic subsequent analysis such as air quality analysis for conformity requirements and capital investment analysis for new projects.

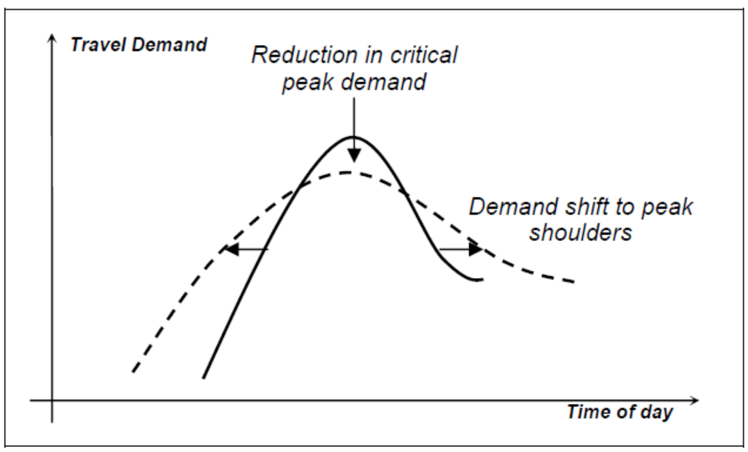


Figure 5-1 Demand Change in Peak Spreading

Three modeling techniques were used to develop peak spreading models for the Triangle Region, which were intended to be sensitive to congestion. These techniques were; discrete choice modeling, peaking factor diversion curves, and trip matrix reduction. Developing models using the first two techniques relies heavily on local household travel survey data, while the last one needs effective matrix adjustment procedures. The discrete choice modeling technique was used to develop a set of peak hour versus shoulder choice models; however, no satisfactory models were achieved. The peaking factor diversion curves derived from the survey data reveal that there was no substantial region-wide peak spreading phenomena back in 2006 when the survey was conducted, which means the survey data do not support the development of peak spreading models for the study area. The idea of using an OD Matrix Estimation procedure in the trip matrix reduction process was later developed, which automatically constrains the trip matrix to peak hour highway network capacity. The approach worked well according to preliminary testing. Based on the tests done on a couple of highway network scenarios of the study area, the results showed the method has great potential to handle peak spreading in large congested networks. Further research could be conducted in the future along this line to optimize parameters in the method to improve convergence in shorter run time.

5.2 Time of Day Factors

The time-of-day analysis used for TRMv6 was based on the 2006 Household Survey (2006HHS), which was re-weighted and re-expanded to 2010. The input file is "2006HIS_Data_All_Persons_Apr02_2014.xlsx".

In TRMv6, time-of-day analysis is used to:

- Generate person trip PK/OP factors, which are used to disaggregate trip generation output to create peak and off-peak person trip tables for the destination choice model. The person trip PK/OP factors are used in the sheet "PK_Factor" in the destination choice input file '\Input\Parameters\DChoice.xlsx'.
- Generate vehicle trip directional time-of-day factors, which are used to disaggregate mode choice output (the auto part only) to create vehicle trip tables for different model time periods (AM peak, PM peak, midday and night), before the highway assignment. Each of the AM peak and PM peak periods are further divided into three sub-periods to facilitate the peak hour analysis. The vehicle trip diurnal direction split factors are used in 'Input\Parameters\HourlyFactor.bin'.

The definitions of time periods used in TRMv6 are shown in Table 5-1.

Table 5-1 Definition of Time Periods in TRMv6

Time Period	Sub-period	Definition
AM peak	Shoulder 1	[6:00, 7:30)
	Peak hour	[7:30, 8:30]
	Shoulder 2	(8:30, 10:00]
PM peak	Shoulder 1	[15:30, 17:00)
	Peak hour	[17:00, 18:00]
	Shoulder 2	(18:00, 19:30]
Midday		(10:00, 15:30)
Night		[0:00, 6:00) and (19:30, 24:00)

Notes: "(" or ")" means exclusive, and "[" or "]" means inclusive. For example, [6:00, 7:30) means from 6:00 (inclusive) to 7:30 (exclusive).

Compared to the similar time-of-day analysis conducted for TRMv5, the analysis for TRMv6 uses 2010 trip weights instead of 2005 trip weights, and it excludes trips that were made by university students from the four major universities (NCSU, UNC, DUKE and NCCU). Therefore, the results are slightly different from what were used for TRMv5.

5.2.1 2. Person Trip PK/OP Factors

Person trip PK/OP factors were calculated by trip purpose for peak (AM peak and PM peak combined) and off peak periods. Person trip PK/OP factor for the peak is calculated as the weighted number of trips in peak period divided by the weighted number of daily trips. A person trip is regarded as a trip in the peak period if its trip mid-point (in terms of time) is in a peak period (either AM peak or PM peak periods). Person trip PK/OP factor for the off peak is simply one minus the person trip PK/OP factor for peak. The results are shown in Table 5-2.

Table 5-2 Person Trip PK/OP Factors

	Number of Trip Records		Weighed Trips		Weighted Percentage	
	Peak [AM+PM]	Off Peak	Peak [AM+PM]	Off Peak	Peak [AM+PM]	Off Peak
HBW	5,229	1,599	694,386	230,664	75.06%	24.94%
HBShop	2,586	2,806	371,805	404,657	47.88%	52.12%
HBK12	2,157	661	326,056	105,954	75.47%	24.53%
HBO	6,370	4,497	950,161	682,292	58.20%	41.80%
WBNH	1,981	2,257	267,716	285,522	48.39%	51.61%
NHNW	3,150	4,015	445,092	572,533	43.74%	56.26%
All	21,473	15,835	3,055,216	2,281,622	57.25%	42.75%

Notes:
- Only internal to internal trips made by residents are considered in the calculation
- Trips made by university students from the four major universities (4UStudOff=1) are excluded from the calculation.

5.2.2 Vehicle Trip Directional Time-of-day Factors

Vehicle trip directional time-of-day factors were calculated by direction by trip purpose for eight time sub-periods (as shown in Table 5-1). A trip is classified into each of the eight sub-periods based on the time mid-point of the trip: if a trip’s time mid-point falls in the window for a time sub-period, it is classified as a trip in that time sub-period.

In case more sub-periods will be needed in the midday or night time periods in the future, the vehicle trip directional time-of-day analysis started with eleven sub-periods. This analysis and complete details of deriving the vehicle time of day factors can be found in “Time of Day analysis TRMv602092015.doc.” Only the final TRMv6 vehicle directional time of day factors are presented here for the eight time of day periods which were aggregated from the eleven time period analysis.

For home based trip purposes, i.e., HBW, HBShop, HBK12, HBO and HBU, the trips are further separated into “from home” trips and “to home” trips. For the WBNH trip purpose, the trips are further separated into “from work” trips and “to work” trips. For a loop trip that goes from home to home or goes from work to work, it was considered as a “from home” trip or a “from work” trip.

Only trips that meet all the following conditions were considered in the analysis:

- Internal to internal trips made by residents
- Trips that were made by the general population; not made by university students from the four major universities (4UStudOff=1)

- Trips that were made by Mode=1 (driver-auto/van/truck), Mode=2 (passenger-auto/van/truck), Mode=3 (motorcycle) or Mode=8 (Motorized moped/scooter).

For each trip record, the weighted number of vehicle trips was calculated as the weighted number of person trips divided by the total number of persons with whom the respondent was traveling (including the respondent).

The weighted numbers of vehicle trips in each time period and in each direction for each trip purpose were divided by the total weighted number of vehicle trips for each trip purpose. These percentages are the vehicle trip directional time-of-day factors.

The time sub-periods for the time period definitions for TRMv6 are shown in Table 5-3, and they are used in the “HourlyFactor.bin” file in the folder “Input\Parameters\”. Some numbers in Table 5-3 were adjusted to make sure the sum equals 50.0000 or 100.0000 after rounding.

Table 5-3 Vehicle Trip Directional Time-of-day Factors for TRMv6, Unit: %

Time Period	Time Window	HBW		HBShop		HBK12		HBO	
		From Home	To Home	From Home	To Home	From Home	To Home	From Home	To Home
AM Peak	6:00 to 7:30	14.4021	0.4721	2.0464	0.3201	15.4758	2.6853	3.3988	0.9847
	7:30 to 8:30	14.1800	0.4417	1.8447	0.4997	16.9100	6.1784	5.5128	1.1249
	8:30 to 10:00	8.7507	0.4195	3.5143	1.6160	5.9663	3.7179	8.2602	2.9946
PM Peak	15:30 to 17:00	1.3991	10.9384	3.9701	6.3147	2.7870	10.5378	4.4820	6.7972
	17:00 to 18:00	0.7309	14.2893	4.9806	4.9782	0.8295	4.1821	3.6705	5.7085
	18:00 to 19:30	0.7735	8.0401	9.0706	7.6711	0.5224	1.8008	6.1281	5.5163
Midday	10:00 to 15:30	6.7440	9.3046	21.0130	18.7011	7.2638	18.5529	15.3686	14.5283
Night	0:00 to 6:00 and 19:30 to 24:00	3.0197	6.0943	3.5603	9.8991	0.2452	2.3448	3.1790	12.3455
Daily		50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000

6 Trip Distribution

6.1 Introduction

Trip distribution models in the TRM are destination choice models. These predict the probability that trips for each stratum from a home zone will be attracted to another zone based on the attributes of the zone and cost of traveling to it. For each trip purpose, models are estimated for each of five socioeconomic strata: Strata 1 are households with no car(s), Strata 2 are low income households with car(s), Strata 3 are medium income households with fewer cars than workers, Strata 4 are medium income households with more cars than workers, and Strata 5 are high income households with car(s).

Destination choice models for the general population were estimated daily for six trip purposes, and the five household strata for a total of thirty models. The models are estimated using trip records in the household travel survey, zonal attributes, and the cost of travel from one zone to another.

The form of the model is shown below:

$$Trips_{ij}^{s,p} = Productions_i^{s,p} * \frac{exp(V_{ij}^{s,p})}{\sum_{j \in Zones} \quad exp(V_{ij}^{s,p})}$$

This says that for each trip purpose *p* trips between zones *i* and *j* for each stratum *s* are a portion of the productions at zone *i* where the portion equals exp(V) at zone *j* divided by the sum of exp(V) for all zones *j* where V is the observed destination choice utility of travel from zone *i* to zone *j*.

$$V_{ij}^{s,p} = S_j + \alpha_{s,p} t_{ij}^{s,p} + \theta_{s,p} d_{ij}^{s,p}$$

The *V* term is made up of a size component (*S*), and of measures of the difficulty of traveling between *i* and *j* shown here as time (*t*) and distance (*d*). Note that distance is highly correlated with time and during model estimation it was decided to use the time variable for the destination choice models. This choice was made because distance does not (typically) vary by levels of service from one alternative to another. The size term (*S*) is typically employment or population.

6.2 Data Preparation

TRMv6 uses a destination choice model, instead of a traditional gravity model, in trip distribution. To estimate the parameters in the destination choice models, estimation files have to be generated based on 2006 household survey (HHS2006). Such files must include, for each observed trip, the impedance and socio-economic variables for the actual attraction, TAZ and all other potential attraction TAZs. In theory, all internal TAZs in TRMv6 are potential choices. To make the estimation file manageable, only a sample of these TAZs is selected. TRMv6 uses the same sampling method as in TRMv5. This file details the procedure to select the sample TAZs, and how the impedances and socio-economic variables are calculated. Matlab was used in this data preparation work.

6.2.1 Sampling procedure

This section explains in detail how the sampling method is implemented in TRMv6.

(1) Selection weight and selection probability

The goal of the sampling method is to select a representative sample set of the choices (TAZs) available for each trip in HHS2006. The probability of each TAZ being selected depends on the attractiveness (i.e., attraction or employment) and the accessibility (i.e., distance from the production TAZ). The process to calculate the selection weight and selection probability is as follows.

For each trip record whose production TAZ is i in HHS2006, calculate the selection weight of destination TAZ j (for all 2857 internal TAZs in TRMv6) using the following formula,

$$W_{ij}^{p} = A_{j}^{p} \times e^{\left(-2\times\frac{D_{ij}}{D_{avg}^{p}}\right)} \tag{1}$$

Where,

W_{ij}^{p} is the selection weight of attraction TAZ j for a trip whose production TAZ is i for trip purpose p;

A_{j}^{p} is the trip attractions for the studied trip purpose p in TAZ j. For example, for a HBW trip record in HHS2006, A_{j}^{p} is the HBW attractions in TAZ j. The attraction values are provided from the trip generation model. They have been normalized to trip productions. Please notice that on-campus university students are not considered when calculating the attractions, and the HBK12 attractions include the school bus trips;

D_{ij} is the highway distance from production TAZ i to attraction TAZ j. The highway distance is from the distance matrix of AMLOV2.mtx (based on the Oct. 16, 2013 network skim); and

D_{avg}^{p} is the regional average trip distance for the studied trip purpose p based on HHS2006. Table 6-1 listed the D_{avg}^{p} values. These values are weighted average.

$$P_{ij}^{p} = \frac{W_{ij}^{p}}{\sum_{k=1}^{N} W_{ik}^{p}} \tag{2}$$

Where,

P_{ij}^{p} is the selection probability of attraction TAZ j for a trip whose production TAZ is i for trip purpose p; and

N is the total number of internal TAZs in TRMv6, which is 2857.

Table 6-1 Average trip distance for each trip purpose

Trip purpose	D_{avg}^{p} (miles)
HBW	11.175
HBShop	6.083
HBK12	4.824
HBO	6.520
WBNH	6.835
NHNW	5.836

(2) Selection process

In this step, 19 TAZs are selected randomly with replacement (i.e. a TAZ can be selected several times) based on the calculated selection probabilityP_{ij}^{p}. In detail, for each trip record in HHS2006, the cumulative weights of all attraction TAZs (all 2857 internal TAZs) are calculated first. Each attraction TAZ then has a low limit and a high limit – the low limit is the sum of the weights before this attraction TAZ and the high limit is the low limit plus the weight of this attraction TAZ. Matlab is used to generate a random number uniformly distributed between 0 and the sum of all weights (for all 2857 internal TAZs). If an attraction TAZ's low limit is less than or equal to the random number and its high limit is greater than the random number, this TAZ is selected into the sample set. Such process is repeated until 19 TAZs are selected. The actual attraction TAZ is also selected into the sample set by default, so the final sample size is 20.

(3) Selection frequency

For the actual attraction TAZ and 19 selected TAZs, count the number of times a TAZ was selected, which is defined as selection frequency F_j. Since the TAZs are selected with replacement, some TAZs might have F_j greater than 1. Obviously, the range of F_j is from 1 to 20.

(4) Correction factor

Since only a subset of all the potential TAZs is used in model estimation, it is necessary to account for the possible bias introduced by the sampling of TAZs (Ben-Akiva and Lerman, 1985[1]). The correction factors are calculated as,

$$CF_{ij} = -ln\left(\frac{P_{ij}}{\frac{F_{ij}}{n}}\right) \tag{3}$$

Where,
CF_{ij} is the correction factor of attraction TAZ j for a trip whose production TAZ is i;
P_{ij} is the selection probability of attraction TAZ j for a trip whose production TAZ is i;
F_{ij} is the selection frequency of attraction TAZ j for a trip whose production TAZ is i;
n is the number of selected TAZs, which is 20 in this case.

These correction factors are only used in the model estimation as a linear term (more like a constant term) in the utility function for each selected TAZ. They are not a part of the true model, and will not be used in the model application.

If $\frac{F_{ij}}{n}$ is equal to the selection probability P_{ij}, the correction factor would be equal to 0. However, if a TAZ is selected more frequently than the selection probability suggests, this TAZ would have a positive correction factor, and consequently a lower base utility in the utility function.

It is possible for P_{ij} to be 0 in Equation (3), which will lead to CF value of infinity. Based on the selection process described in step (2), a TAZ with selection probability P_{ij} of 0 will never be selected into the

[1] Ben-Akiva M. and Lerman S. (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge.

sample set. However, the actual attraction TAZ, which is also in the sample set, could have a selection probability of 0. For a certain trip purpose, this will happen if the trip generation model shows that a TAZ has no attractions, but the HHS2006 shows that some respondents claimed that they used that TAZ as the attraction TAZ. That is to say, the inconsistency in the model and the survey data makes infinity CF values possible. Table 6-2 summarizes the values of the correction factors.

Table 6-2 Summary of correction factors

	Min	Max	Number of Infinity values	Number of total records
HBW	-1.2770	14.3305	28	6,830
HBShop	-1.1464	18.6829	289	5,393
HBK12	-1.2835	16.1188	865	2,819
HBO	-1.2842	19.5448	73	10,866
WBNH	-1.2940	19.1815	28	4,238
NHNW	-1.4550	22.1641	0	7,166

In the distributed estimation files, all the infinity values have been replaced with 99. It was suggested to ignore the records with correction factor of 99, since such records only account for a small portion of total records (except for HBK12).

6.2.2 Estimation file structure

There were 6 estimation files, with one for each trip purpose: HBW, HBShop, HBK12, HBO, WBNH and NHNW. The estimation files were created based on the HHS2006. Only internal to internal (I-I) trips made by residents in the model area were considered. The estimation files included intrazonal trips, and trips in all modes (including Mode=97 and 99). The HBK12 trips made by taking school buses were not considered since such trips are removed before trip distribution. The trips made by the university students in the four major universities (NCSU, UNC-Chapel Hill, DUKE and NCCU) were also removed since they are modeled separately from the general population in TRMv6. The number of records in each estimation file can be found in Table 6-2. The structure of the estimation files is shown in Table 6-3.

Table 6-3 Destination choice model estimation file structure

Column	Variable	Description
1	Trip_ID	Trip ID in HHS2006
2	Weight	Weight in HHS2006 (weighting and expansion factor)
3	Choice	Equal to 1: the TAZ the respondent selected is the first TAZ.
4	P_TAZ	Production TAZ ID
5	A_TAZ	Attraction TAZ ID
6	Strata	Household strata of the respondent
7	PK	PK trip (=1) or OP trip (=0)
8	TAZ1	First TAZ option: always the actual TAZ the respondent selected, so always equals A_TAZ.
9	CF1	Correction factor for TAZ1. Should be included in the utility function for TAZ1 (like a constant term) in the model estimation.
10	NMD1	Non-motorized distance from P_TAZ to TAZ1
11	MCT1	Motorized composite time from P_TAZ to TAZ1. Please refer to Section 3 for more details.
12	MLS1	Motorized logsum from P_TAZ to TAZ1 (from initial calibrated mode choice model). **<u>Note</u>**: for HBK12, this column is Enrollment1, which is the enrollment in TAZ1 (=ENROLLMENT in the SE file).
13	HWY1	Highway distance between P_TAZ and TAZ1 (based on the distance from AMLOV2.mtx and OPLOV2.mtx)
14	HH1	Households in TAZ1 (=HH in the SE file)
15	POP_HH1	Population in households in TAZ1 (=HH_POP in the SE file)
16	POP_Total1	Total population in TAZ1 (=HH_POP+Stud_GQ+Other_NonInst_GQ in the SE file)
17	Retail1	Retail employment in TAZ1 (=Retail in the SE file)
18	NonRet1	Non-retail employment in TAZ1 (=Industry+Office+Service_RateLow +Service_Ratehigh in the SE file)
19	Industry1	Industry employment in TAZ1 (=Industry in the SE file)
20	Office1	Office employment in TAZ1 (=Office in the SE file)
21	Ser_RateL1	Service_RateLow employment in TAZ1 (=Service_RateLow in the SE file)
22	Ser_RateH1	Service_RateHigh employment in TAZ1 (=Service_RateHigh in the SE file)
23	LUM1	Land use mix in TAZ1
24	PathD1	Non-motorized path density in TAZ1 (unit: mile/mile^2)
25	CBD1	CBD dummy variable of TAZ1
26	Urban1	Urban dummy variable of TAZ1
27	Suburb1	Suburban dummy variable of TAZ1
28	Rural1	Rural dummy variable of TAZ1
29-427		Similar to columns 8-28, for TAZ2 to TAZ20

6.2.3 Explanation of variables

(1) NMD

NMD is the Non-Motorized Distance between P_TAZ and an attraction TAZ. It was prepared following the same method as in TRMv5.

(2) MCT

MCT is the Motorized Composite Time between P_TAZ and an attraction TAZ. It was prepared following the same method as in TRMv5 based on the skim files created on Oct. 16, 2013. The transit shares by trip purpose, strata and time period (PK or OP) are required in the calculation.

(3) MLS

MLS is the Motorized LogSum between P_TAZ and an attraction TAZ. The values are based on the initial calibrated mode choice models. Table 6-4 summarizes the values of MLS by trip purpose and time period.

Table 6-4 Summary of the motorized logsum

		Min	Max	Average
HBW		-8.790	8.878	-1.494
		-8.831	21.226	-1.367
HBShop		-3.286	0.948	-0.325
		-3.304	1.125	-0.358
HBO		-3.236	1.326	-0.177
		-3.342	1.816	-0.307
WBNH		-7.043	15.123	-0.837
		-7.037	10.616	-1.232
NHNW		-6.837	2.025	-1.030
		-6.890	0.770	-1.153

(4) LUM

LUM is the Land Use Mix, and the formula is

$$LUM = \frac{2 * (People + Jobs) - abs(People - Jobs)}{Area\ in\ acre}$$

"People" in the above formula is equal to HH_POP+Stud_GQ+Other_NonInst_GQ from the SE file. "Jobs" is equal to Retail+Industry+Office+Service_RateLow+Service_Ratehigh from the SE file.

6.2.4 Creation of Mode Choice Logsum Impedance Values

For TRM v6 the mode choice logsum value was tested for *t* in the destination choice model. The logsum value is a composite utility for all motorized modes available between *i* and *j* and thus allows for sensitivity to changes in transit and auto level of service characteristics. The formula for the mode choice logsum is shown below for zone *i* to zone *j* as the natural logarithm of the sum of the exponential function of mode choice utilities (*U*) for all modes from 1 to *n* for peak and off peak time periods.

$$t_{ij}^{s,p} = ln\left[\sum_{mode=1}^{n} exp(U_{ij}^{s,p,mode})\right]$$

The mode choice FORTRAN application program was modified to write out a table of logsum values by zone for peak and off peak periods for each trip purpose. For each i-zone (production zone) the utilities for all modes by access mode are calculated for all attraction zones and the exponential function is applied to the utility value. These values for all modes are added and the natural logarithm of the sum is calculated. Using this logsum value for the impedance in the destination choice utility has several desirable qualities. It is consistent with utilities used in the later mode choice step. The value is sensitive to levels of service for all modes by access mode in mode choice and each mode is represented in relation to others according to coefficients used in the mode choice model.

The logsum calculation program was created from the mode choice program code by removing all steps after calculation of the mode choice utilities. Then a section of code was added to write out a binary file ("LSHBW_PK.BIN" for example) that can be read by the subsequent destination choice program execution. The program uses the mode choice program control file information for simplicity and consistency between model steps. The model script copies the mode choice control file to a logsum control file with a name such as "lshbw.pk.ctl". While the source code for both the logsum program and the mode choice program are closely related, it is important to note that the logsum program does not include shadow prices calculated for parking capacity constraint. Thus parking constraint is not part of destination choice, because it is assumed that travelers will continue to go to places with limited parking though they may choose to carpool or take transit.

6.3 Model Estimation by Purpose

6.3.1 Home Based Work

HB Work Destination Choice 2013 Calibrated Model

The 2013 home based work high earning calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-5 HB Work High Earning Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.6	0	0.699	0.611	0.611
Hwy. Distance	0.239	0	0.122	0.343	0.199
Hwy. Dist. Sqr. Rt.	-1.55	0	-1.37	-2.12	-1.48
Hwy. Dist. Sqr.	-0.00727	0	-0.00153	-0.00495	-0.00368
Hwy. Dist. Cube	0	0	0	0.000015	0.000023
Empl. Accessibility	0	0	0	0.575	0.522
Retail accessibility	-0.786	0	-0.349	-0.558	-0.565
Industry	1	1	0.8607	1	1
Office	1	1	0.8607	1	1
Service rate high	1	1	0.8607	1	1
Service rate low	1	1	0.8607	1	1
Retail	1	1	1	1	1

Table 6-6 HB Work High Earning Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.6	0	0.699	0.611	0.611
Hwy. Distance	0.219	0	0.102	0.309	0.164
Hwy. Dist. Sqr. Rt.	-1.55	0	-1.37	-2.12	-1.48
Hwy. Dist. Sqr.	-0.00727	0	-0.00153	-0.00495	-0.00368
Hwy. Dist. Cube	0	0	0	0.000015	0.000023
Industry	1	1	0.8607	1	1
Office	1	1	0.8607	1	1
Service rate high	1	1	0.8607	1	1
Service rate low	1	1	0.8607	1	1
Retail	1	1	1	1	1

The 2013 home based work low earning calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-7 HB Work Low Earning Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.6	0.6	0.699	0.7	0.7
Hwy. Distance	0.229	0.0286	0.112	0.0591	0.096
Hwy. Dist. Sqr. Rt.	-1.55	-0.924	-1.37	-1.3	-1.45
Hwy. Dist. Sqr.	-0.00727	-0.00015	-0.00153	-0.00489	-0.0011
Hwy. Dist. Cube	0	0	0	0	0
Empl. Accessibility	0	0	0	0	0
Retail accessibility	-0.786	-0.498	-0.349	-0.587	-0.0722
Industry	1	1	0.8607	0.829	1
Office	1	1	0.8607	0.829	1
Service rate high	1	1	0.8607	0.829	1
Service rate low	1	1	0.8607	0.829	1
Retail	1	1	1	1	1

Table 6-8 HB Work Low Earning Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.6	0.6	0.699	0.7	0.7
Hwy. Distance	0.15	0.01	0.04	0.01	0.03
Hwy. Dist. Sqr. Rt.	-1.65	-1.13	-1.47	-1.5	-1.65
Hwy. Dist. Sqr.	-0.00727	-0.001	-0.00153	-0.0015	-0.0021
Hwy. Dist. Cube	0	0	0	0	0
Industry	1	1	0.8607	1	1
Office	1	1	0.8607	1	1
Service rate high	1	1	0.8607	1	1
Service rate low	1	1	0.8607	1	1
Retail	1	1	1	1	1

6.3.2 Home Based Shopping

Model Estimation

Model Calibration

The comparison of model trip length to calibration targets is presented below. The performance target for trip distribution is to match trip length in minutes and distance in miles by plus or minus five percent.

For the peak period the initial modeled travel time matched the observed very closely and the coincidence ratio was high, as shown in Table 6-1. However, the initial modeled average trip distance for the peak period, shown in Table 6-2, was not within plus or minus five percent.

Table 6-9 Peak Period Observed Versus Initial Modeled Average Trip Time

Observed Average Trip Time (minutes)	Modeled Average Trip Time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
12.492	12.517	0.2%	0.80	-0.66

Table 6-10 Peak Observed Versus Initial Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
5.707	5.298	-7.2%	0.82	-0.66

Based on these comparisons, adjustments were made to the highway distance coefficients for the peak period. The performance of the feedback model, after calibration of the highway distance coefficients, was within the targets of the observed average travel time and average travel distance. The results of calibrating the highway distance coefficient on the average travel time and average travel distance are shown in Table 6-3 and Table 6-4, respectively.

Table 6-11 Peak Period Observed Versus Calibrated Modeled Average Trip Time

Observed Average Trip Time (minutes)	Modeled Average Trip Time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
12.492	12.762	2.2%	0.80	-0.60

Table 6-12 Peak Observed Versus Calibrated Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
5.707	5.454	-4.4%	0.81	-0.60

For the off peak the initial modeled time and initial modeled distance were compared to observed and checked for compliance within the plus or minus five per cent of target threshold. Table 6-5 shows the comparison of the off peak observed average trip time versus the initial modeled average trip time. Table 6-6 shows the comparison of the off peak observed average trip distance versus the initial modeled average trip distance.

Table 6-13 Off Peak Observed Versus Initial Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
12.652	12.602	-0.2%	0.80	-0.44

Table 6-14 Off Peak Observed Versus Initial Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
6.428	6.075	-5.5%	0.80	-0.44

For the off peak period the initial modeled travel time matched the observed very closely and the coincidence ratio was high, as shown in Table 6-5. However, the initial modeled average trip distance for the off peak period, shown in Table 6-6, was not within plus or minus five percent.

Based on these comparisons, adjustments were made to the HBShop highway distance coefficients for the off peak period. The performance of the feedback model, after calibration of the highway distance coefficients, was within the targets of the observed average travel time and average travel distance. The results of calibrating the highway distance coefficient on the average travel time and average travel distance in the off peak period are shown in Table 6-7 and Table 6-8, respectively.

Table 6-15 Off Peak Observed Versus Calibrated Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
12.652	12.823	1.5%	0.80	-0.41

Table 6-16 Off Peak Observed Versus Calibrated Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
6.428	6.246	-2.8%	0.80	-0.41

Percent intra-zonal trips were also compared and the results are shown in Table 6-9.

Table 6-17 Observed Versus Modeled Intra-zonal Trips

Time Period	Observed % intra-zonal	Modeled % intra-zonal	Modeled – Observed
Peak	4.93%	2.78%	-2.15%
Off peak	2.15%	1.96%	-0.19%

HB Shop Destination Choice 2013 Calibrated Model

The 2013 home based shop calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-18 HB Shop Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.998	0.992	0.999	0.969	0.969
Hwy. Distance	-0.6	-0.6	-0.6	-0.6	-0.6

Retail Emp.	1	1	1	1	1

Table 6-19 HB Shop Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.998	0.992	0.999	0.969	0.969
Hwy. Distance	-0.41	-0.41	-0.41	-0.41	-0.41
Retail Emp.	1	1	1	1	1

6.3.3 Home Based K12 School

The HBk12 trip purpose includes trips made by children going to school and adults in the household if they are transporting/escorting children to school. Trip distribution for the HBk12 trip purpose needs to be treated differently than other trip purposes, because for most children and their parents, the school location is chosen for the children and household by the school district in which they reside in the case of public schools. In the case of private schools, parents may choose between schools, but this is still a small portion of all school students. In the TRM so far, no distinction has been drawn between public and private schools, and all students are treated as public school students (though they may go to a private school in a TAZ based on its enrollment).

In TRMv5 HBk12 trip distribution is a function of school enrollment and highway distance to school locations.

In TRMv5 it was noted that for a significant number of trip records (20% overall), the trip recorded does not have an attraction in a TAZ with school enrollment. This could be due to geocoding errors for the survey trip records, geocoding errors in the school enrollment data, or incorrectly identifying a trip as HBk12. For TRMv6 new TAZs were defined requiring developing a new set of school enrollment values by TAZ. DCHC staff checked the locations of school enrollment for TAZs in the DCHC area. Coordinates and 2010 enrollment were obtained for public schools in Wake County from the ORED lab at ITRE. The need to complete TRMv6 model development prevented further improvements in the geocoding of school locations in the survey data. A visual check was made to compare the Wake County school enrollment provided by the ORED lab with the TAZ enrollment numbers in Wake County, and it does appear that some improvements can be made to the enrollment listed for TAZs in order to improve model application. CAMPO staff has reviewed school location information and updated the enrollment by TAZ in the SE data files.

The table below updates the number of trips available for HBk12 destination choice model estimation for TRMv6.

Table 6-20 Summary of the number of HBk12 trip records

Strata	Total number of trips	Number of trips going to TAZs without school enrollment (CF1=99)	Percent of CF1=99	Number of trips going to TAZs with school enrollment(CF1<>99)
Strata 1	14	2	14%	12
Strata 2	85	26	30%	59
Strata 3	36	17	47%	19
Strata 4	777	256	33%	521
Strata 5	1906	564	30%	1342
Total	2818	865	31%	1953

Model Estimation

To begin work estimating destination choice models for TRMv6, the TRMv5 model specification was estimated with the TRMv6 estimation data. In TRMv5 strata 1-3 were combined for estimation in order to have enough records to perform the estimation. This approach is continued for TRMv6. Note that even if all trip records are available for strata 1-3 there are not enough records to estimate models for each strata.

$$V_{ij}^{S,HBK12} = bHWYD * HWYD_{ij} + ln(Enrollment_j)$$

Where,
bHWYD is the parameter for highway distance,
$HWYD_{ij}$ is the highway distance from the production TAZ_i to TAZ_j, and
$Enrollment_j$ is the enrollment in TAZ_j

The results of the model estimation for strata 1-3 and strata 4 and 5 are shown below. The results are very similar to the results for TRMv5 (as might be expected, because the trips used for estimation, the highway distance and the school enrollments are similar).

Table 6-21 Model 1 HBk12 Destination Choice Model

	Strata 1		Strata 2		Strata 3		Strata 4		Strata 5	
Variable	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Hwy. Distance	-0.324	-9.97	-0.324	-9.97	-0.324	-9.97	-0.37	-21.68	-0.274	-36.03
Enrollment	1	Fixed	1	Fixed	1	Fixed	1	Fixed	1	Fixed
Rho-square	0.194		0.194		0.194		0.192		0.156	

It was suggested to test a county crossing dummy variable to reflect that the HBk12 school trips are unlikely to go from one county to another. This dummy variable was created by creating a lookup table of TAZ IDs and a county number after assigning a number between one and ten to each of the counties in the TRM study area. For each production and attraction TAZ (samples one through twenty), a VLOOKUP determined what the county number was. A relationship was then established to test whether the county number was the same (no crossing) returning zero, or not equal (county crossing occurred) returning one. This zero or one dummy variable was included in the model specification:

$$V_{ij}^{S,HBK12} = bHWYD * HWYD_{ij} + bCounty\ crossing\ dummy * County\ crossing\ dummy_{ij} + ln(Enrollment_j)$$

Where,
bHWYD is the parameter for highway distance,
$HWYD_{ij}$ is the highway distance from the production TAZ_i to TAZ_j , and
$Enrollment_j$ is the enrollment in TAZ_j
County crossing $dummy_{ij}$ is equal to zero if the county is the same for both i and j TAZs, and equal to one if the county is not the same for i and j TAZs.

The results for model estimation for Strata 1-3 and Strata 4 and Strata 5 are shown below. While the results show improved Rho-square values for all models and acceptable t-statistics for county crossing for Strata 4 and Strata 5, the t-statistic for Strata 1-3 is low.

Table 6-22 Model 2 HBk12 Destination Choice Model with County Crossing Variable

	Strata 1		Strata 2		Strata 3		Strata 4		Strata 5	
Variable	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Hwy. Distance	-0.302	-8.44	-0.302	-8.44	-0.302	-8.44	-0.346	-19.68	-0.252	-30.81
Enrollment	1	Fixed	1	Fixed	1	Fixed	1	Fixed	1	Fixed
County crossing	-0.841	-1.26	-0.841	-1.26	-0.841	-1.26	-2.63	-5.94	-1.03	-6.52
Rho-square	0.197		0.197		0.197		0.204		0.16	

Model Calibration

Model calibration was performed for peak and off-peak time periods. The daily model including the county crossing variable was applied using the script developed for the purpose for peak and off peak periods. First the daily trips in the schend.asc file are split into peak and off peak periods using the peak factor, which for HBk12 school is 0.755, meaning that seventy five percent of HBk12 school trips take place during the peak period. The model is then applied twice; first with the AMLOV.mtx, and second with the OPLOV.mtx. Note that the script used for calibration includes a step to remove trips made by off campus university students. For calibration, maximum iterations were set to 100 and the stop criteria was set to 0.05.

For the peak period, the highway distance coefficients were adjusted until the percent difference between modeled mean travel time and observed mean travel time was minimized and the percent difference between modeled mean travel distance and observed travel distance was minimized. The calibration also sought to maximize the coincidence ratio for the modeled and observed trip length frequency distributions for time and distance. The calibrated model is shown below.

Table 6-23 Peak Period HBk12 Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Hwy. Distance	-0.542	-0.542	-0.542	-0.586	-0.492

Enrollment	1	1	1	1	1
County crossing	-0.841	-0.841	-0.841	-2.63	-1.03

The results of comparing the modeled travel time and distance are shown below.

Table 6-24 Peak Period Observed Versus Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio
11.229	11.189	-0.4%	0.834

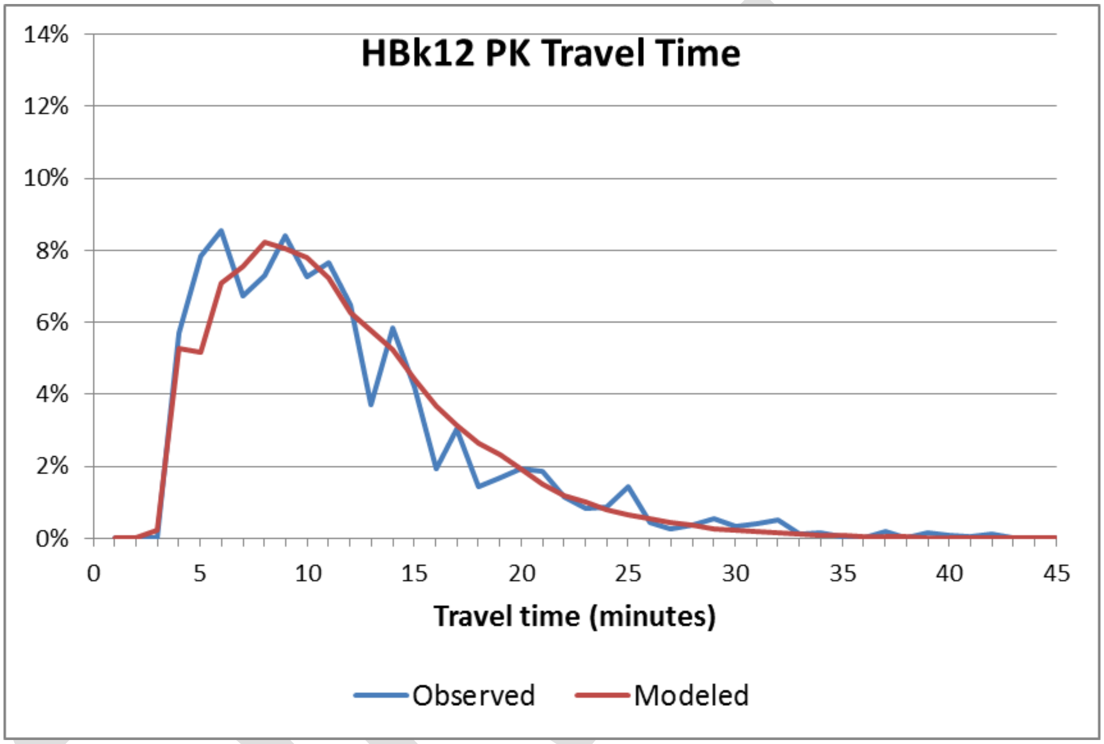
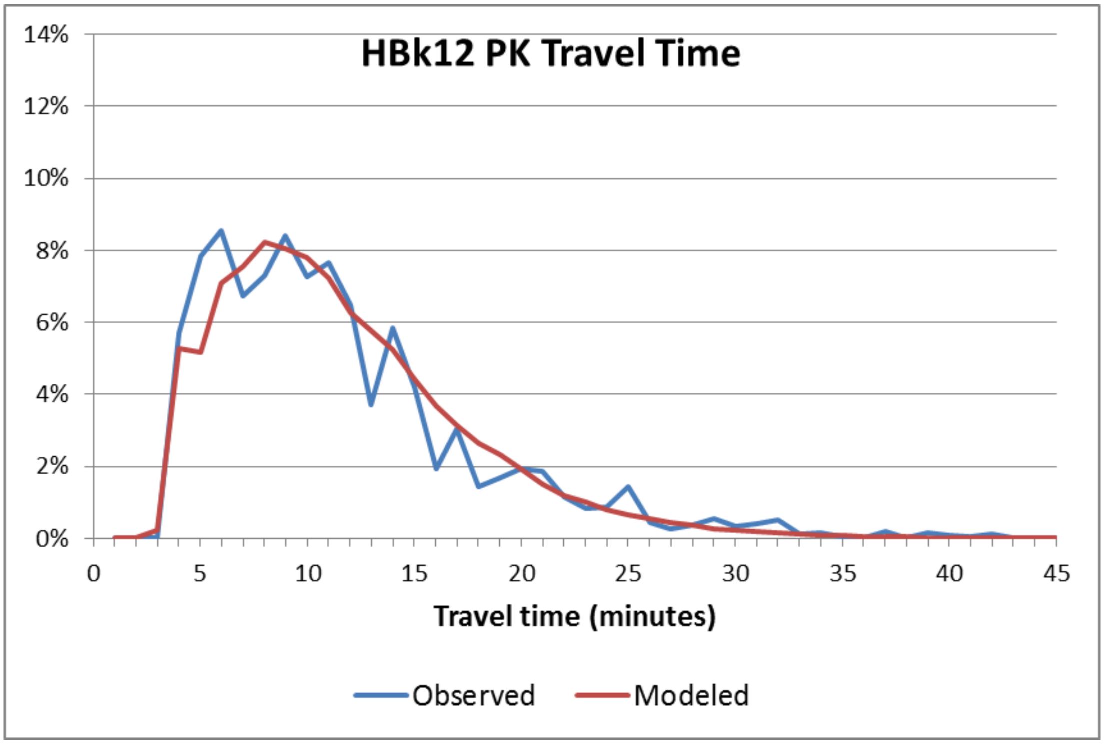


Table 6-25 Peak Observed Versus Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio
4.843	4.833	-0.2%	0.802



For the off peak period, the highway distance coefficients were adjusted until the percent difference between modeled mean travel time and observed mean travel time was minimized and the percent difference between modeled mean travel distance and observed travel distance was minimized. The calibration also sought to maximize the coincidence ratio for the modeled and observed trip length frequency distributions for time and distance. The calibrated model is shown below.

Table 6-26 Off Peak Period HBk12 Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Hwy. Distance	-0.562	-0.562	-0.562	-0.606	-0.512
Enrollment	1	1	1	1	1
County crossing	-0.841	-0.841	-0.841	-2.63	-1.03

The results of comparing the modeled travel time and distance are shown below.

Table 6-27 Off Peak Observed Versus Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio
10.226	10.267	0.4%	0.731

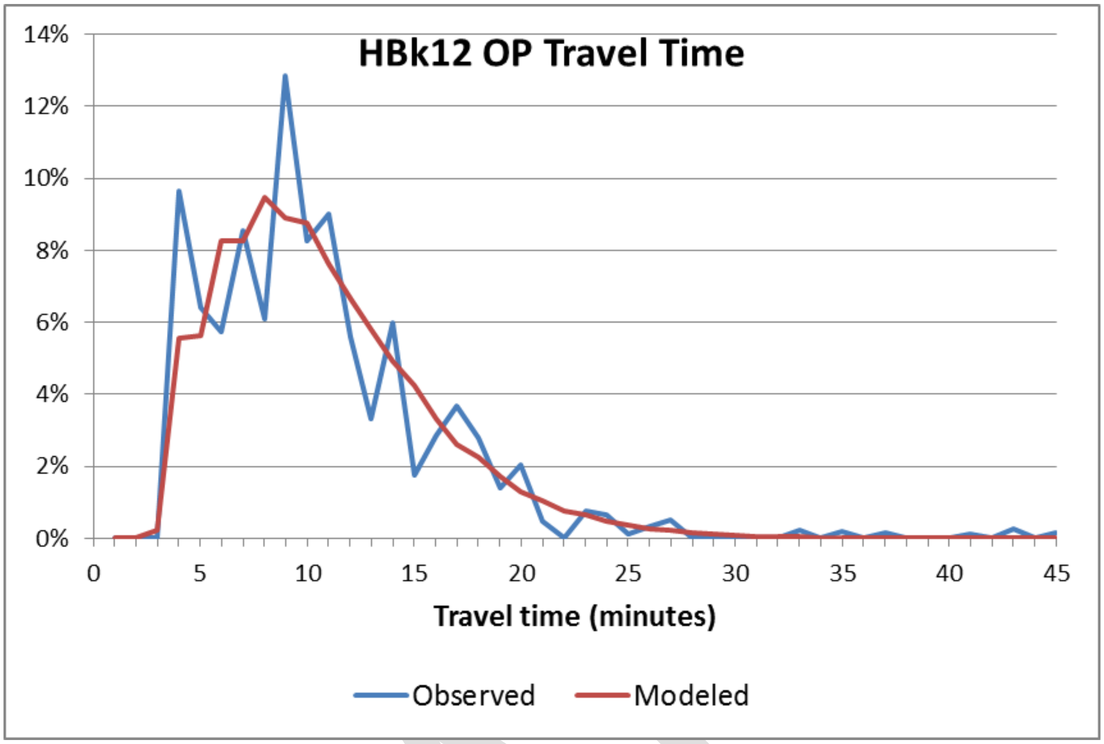
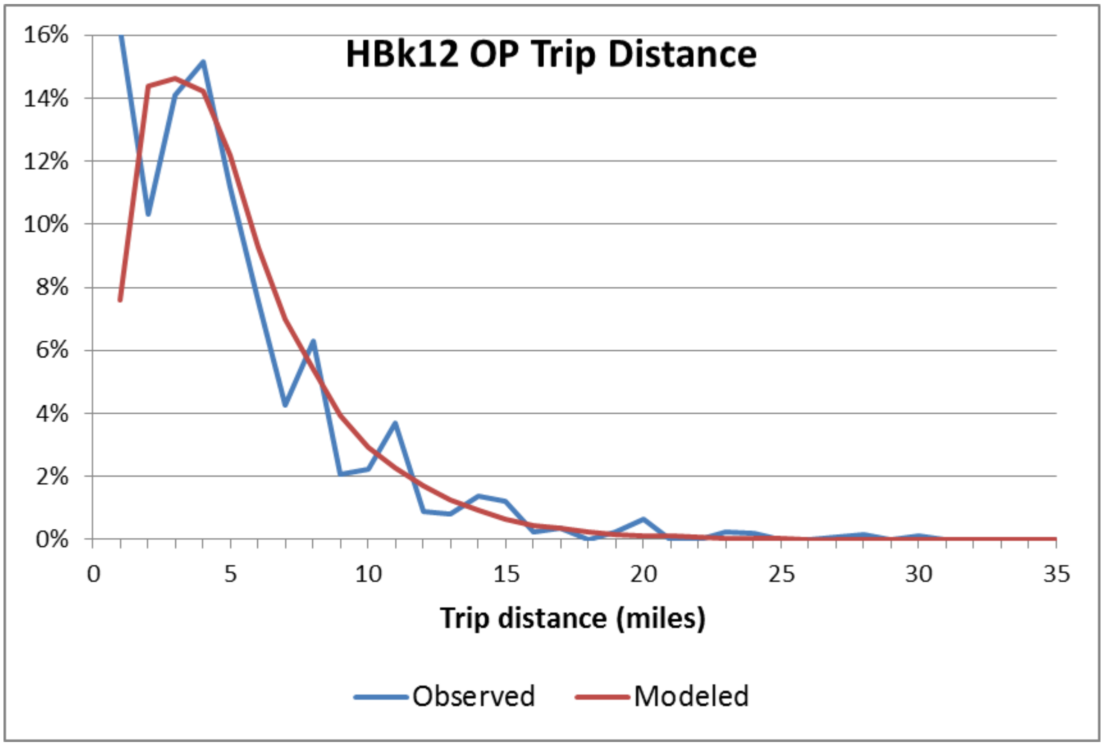


Table 6-28 Off Peak Observed Versus Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio
4.766	4.76	-0.1%	0.746



Additionally, a comparison was made of trip attractions with school enrollment in the SE data file. After examining two TAZs, there did not seem to be any particular problems. These are shown below. Generally speaking the destination choice output attractions match the input attractions by strata.

Table 6-29 TAZ 2 Chatham County: 476 Enrolled Students

Output/source	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5	Total
Trip Gen Output Attr	17	78	22	308	336	761
Dest Ch Attr PK	13	57	17	220	253	560
Dest Ch Attr OP	4	19	6	71	82	182
Dest Ch Tot Attr	17	76	23	291	335	742

Table 6-30 TAZ 1445 Wake County: 117 Enrolled Students

Output/source	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5	Total
Trip Gen Output Attr	5	13	5	79	85	187
Dest Ch Attr PK	4	10	4	60	65	142
Dest Ch Attr OP	1	3	1	19	21	46
Dest Ch Tot Attr	5	13	5	79	86	188

A comparison of the total input trips was made with the output trips. Trips are reduced by the off campus student trips, or about 3% of regional HBk12 school trips.

	Attractions
Input daily from trip generation	433,619
Output total daily from dest. ch.	421,383

Below are the destination choice total output trips by strata by time of day.

Time Period	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5	Total
Peak	5,603	23,420	8,558	129,151	151,302	318,035
Off peak	1,821	7,611	2,781	41,969	49,167	103,348
Total	7,424	31,031	11,339	171,110	200,469	421,383

HBk12 School Destination Choice 2013 Calibrated Model

The 2013 home based k12 school calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-31 HBk12 School Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Hwy. Distance	-0.542	-0.542	-0.542	-0.586	-0.492
County crossing	-0.841	-0.841	-0.841	-2.63	-1.03
Enrollment	1	1	1	1	1

Table 6-32 HBk12 School Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Hwy. Distance	-0.562	-0.562	-0.562	-0.606	-0.512
Enrollment	1	1	1	1	1

6.3.4 Home Based Other

Model Estimation

Model Calibration

The comparison of model trip length to calibration targets is presented below. The performance target for trip distribution is to match trip length in minutes and distance in miles by plus or minus five percent.

Comparisons between observed and modeled average travel time and average travel distance for the peak period are shown in Table 6-21 and Table 6-22. For the peak period the initial modeled travel time and initial modeled travel distance matched the observed closely and the coincidence ratios were high. The performance of the feedback model is within the targets of the observed average travel time and average travel distance. No adjustments to the highway distance coefficients for the peak period were suggested.

Table 6-33 Peak Period Observed Versus Initial Modeled Average Trip Time

Observed Average Trip Time (minutes)	Modeled Average Trip Time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
13.227	13.482	1.9%	0.77	-0.37

Table 6-34 Peak Observed Versus Initial Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
6.242	6.120	-2.0%	0.71	-0.37

For the off peak the initial modeled time and initial modeled distance were compared to observed, and checked for compliance within the plus or minus five per cent of target threshold. Table 6-23 shows the comparison of the off peak observed average trip time versus the initial modeled average trip time. Table 6-24 shows the comparison of the off peak observed average trip distance versus the initial modeled average trip distance.

Table 6-35 Off Peak Observed Versus Initial Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
13.113	13.807	5.3%	0.72	-0.282

Table 6-36 Off Peak Observed Versus Initial Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
6.923	7.186	3.8%	0.70	-0.282

For the off peak period the initial modeled travel time was not within plus or minus five percent of the observed, as shown in Table 6-23.

Based on these comparisons, adjustments were made to the HBO highway distance coefficients for the off peak period. The performance of the feedback model, after calibration of the highway distance coefficients, was within the targets of the observed average travel time and average travel distance. The results of calibrating the highway distance coefficient on the average travel time and average travel distance in the off peak period are shown in Table 6-25 and Table 6-26, respectively.

Table 6-37 Off Peak Observed Versus Calibrated Modeled Average Trip Time

Observed average trip time (minutes)	Modeled average trip time (minutes)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
13.113	13.618	3.9%	0.72	-0.292

Table 6-38 Off Peak Observed Versus Calibrated Modeled Average Trip Distance

Observed Average Trip Distance (miles)	Modeled Average Trip Distance (miles)	Per Cent Difference	Coincidence Ratio	Highway Distance Coefficient
6.923	7.036	1.6%	0.70	-0.292

Percent intra-zonal trips were also compared. These are shown in Table 6-27.

Table 6-39 Observed Versus Modeled Intra-zonal Trips

Time Period	Observed % intra-zonal	Modeled % intra-zonal	Modeled – Observed
Peak	12.02%	4.30%	-7.72%
Off peak	9.16%	3.16%	-6.00%

HB Other Destination Choice 2013 Calibrated Model

The 2013 home based other calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-40 HB Other Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.996	0.984	0.998	0.938	0.875
Hwy. Distance	-0.37	-0.37	-0.37	-0.37	-0.37
Service rate high	1.4219	2.6939	3.0957	2.8864	3.7434
Service rate low	1	1	1	1	1
Households	0.4658	1.1085	0.7581	1.2092	1.3338

Table 6-41 HB Other Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.996	0.984	0.998	0.938	0.875
Hwy. Distance	-0.292	-0.292	-0.292	-0.292	-0.292
Service rate high	1.4219	2.6939	3.0957	2.8864	3.7434
Service rate low	1	1	1	1	1
Households	0.4658	1.1085	0.7581	1.2092	1.3338

6.3.5 Non Home Non Work

Non Home Non Work Destination Choice 2013 Calibrated Model

The 2013 non home non work calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-42 Non Home Non Work Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0	0.9	0.9	0.9	0.9
Hwy. Distance	-0.4631	-0.23	-0.2499	-0.2321	-0.2594
Industry	0	0.0132	0.2894	0.0455	0.033
Office	0	0.034	0.1225	0.0314	0.0872
Service rate high	0.2592	0.0646	0.8668	0.2165	0.3296
Service rate low	0	0.0907	0	0.0416	0.0271
Retail	2.7183	2.7183	2.7183	2.7183	2.7183
HH population	0.0396	0.0898	0.0679	0.0837	0.088

Table 6-43 Non Home Non Work Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0	0.9	0.9	0.9	0.9
Hwy. Distance	-0.4697	-0.2332	-0.2535	-0.2354	-0.2631
Industry	0	0.0132	0.2894	0.0455	0.033
Office	0	0.034	0.1225	0.0314	0.0872
Service rate high	0.2592	0.0646	0.8668	0.2165	0.3296
Service rate low	0	0.0907	0	0.0416	0.0271
Retail	2.7183	2.7183	2.7183	2.7183	2.7183
HH population	0.0396	0.0898	0.0679	0.0837	0.088

6.3.6 Work Based Non Home

Work Based Non Home Destination Choice 2013 Calibrated Model

The 2013 work based non home calibrated destination choice models are shown below in Table 6-10 and Table 6-11.

Table 6-44 Work Based Non Home Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.14	0.9	0	0.9	0.9
Hwy. Distance	-0.2924	-0.1539	-0.2202	-0.1643	-0.1531
Industry	0	0.3465	0.0478	0.185	0.0284
Office	0	0.0889	0.0813	0.0488	0.0973
Service rate high	0.3499	0.36642	0.3642	0.323	0.5857
Service rate low	0	0.0813	0.1901	0.1013	0.0963
Retail	2.7183	2.7183	2.7183	2.7183	2.7183
HH population	0.0573	0.0944	0.1409	0.0813	0.0765

Table 6-45 Work Based Non Home Off Peak 2013 Destination Choice Calibrated Model

	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LogSum	0.14	0.9	0	0.9	0.9
Hwy. Distance	-0.68	-0.358	-0.512	-0.382	-0.356
Industry	0	0.3465	0.0478	0.185	0.0284
Office	0	0.0889	0.0813	0.0488	0.0973
Service rate high	0.3499	0.36642	0.3642	0.323	0.5857
Service rate low	0	0.0813	0.1901	0.1013	0.0963
Retail	2.7183	2.7183	2.7183	2.7183	2.7183
HH population	0.0573	0.0944	0.1409	0.0813	0.0765

6.4 Model Calibration

6.4.1 Trip Length Frequency Distributions – Peak and Off-Peak

6.4.2 Coincidence Ratios for Peak and Off-Peak Trip Length Frequencies by Trip Purpose

6.5 Model Application

6.6 Model Validation

6.6.1 Validation Data

6.6.2 Validation Test

6.6.3 Validation – Work Trip Distribution Volumes

6.6.3.1 TRMv6 2010 Work Trips Distribution vs. Estimated 2006-2010 CTPP

6.6.3.2 TRM v6 2013 Work Trips Distribution vs. Estimated 2009-2013 ACS Commuting Flows

6.6.4 Validation – Work Trip Attraction County Percent Share

6.6.4.1 Attraction County Percent Share vs. Estimated 2006-2010 CTPP

6.6.4.2 Attraction County Percent Share vs. Estimated 2009-2013 ACS Commuting Flows

6.6.5 Validation – Work Trip Resident Production County Percent Share

6.6.5.1 Resident Production County Percent Share vs. Estimated 2006-2010 CTPP

6.6.5.2 Resident Production County Percent Share vs. Estimated 2009-2013 ACS Commuting Flows

6.6.6 Validation – Work Trip Length in Minutes

7 Non-Motorized

7.1 Introduction

TRM v6 includes non-motorized models that were added to TRM v5 in order to make the model sensitive to changes in land use and infrastructure with regard to non-motorized travel (walk and bicycle). In the TRMv6 model non-motorized trips are separated from motorized trips after all trips are distributed. This allows non-motorized trips to be described by production and attraction zones and for trip tables to be constructed.

The non-motorized models are multinomial logit models that take the following form:

$$p_{x,non-motorized} = \frac{e^{U_{x,non-motorized}}}{e^{U_{x,non-motorized}} + e^{U_{x,motorized}}}$$

where:

$p_{x,non-motorized} = probability\ of\ a\ person\ of\ stratum\ x\ making\ non-motorized\ trips$
$U_{x,non-motorized} = utility\ of\ non-motorized\ trips\ for\ person\ stratum\ x,$ and
$U_{x,motorized} = utility\ of\ motorized\ trips\ for\ person\ stratum\ x.$

The variables used and models estimated are described in the next sections.

7.2 Data Preparation

7.2.1 Data Sources

To create data for model estimation, relevant data were extracted from the following four data sources and then processed:

1) 2006 Household Travel Survey Data

The survey data file used for this task is named “2006HIS_Data _All_Persons_Apr02_2014.xlsx”, which is stored on the TRM Server. The survey data has been weighted and expanded to the 2010 regional total number of households before use. Major data items used from the survey include:

a. Internal-to-internal trip records made by residents of the Triangle Region
b. Household characteristics, including HH size, income, SE strata, auto ownership, and number of workers

2) 2010 TAZ Socioeconomic Data

The SE data used here is revision #69 from the SVN repository for TRM v6, which was last updated on Feb. 06, 2014. Major data items used from the file include:

a. Zonal area type (CBD, urban, suburban, and rural)
b. Zonal population and employment densities (with further processing)

c. Zonal average block area
d. Non-motorized path length and density (with further processing)

3) 2006 Transit Onboard Survey

The transit onboard survey data file used is the Jan-06-2014 version from the TRM Server. This file is used for deriving composite travel times, and no individual trip records were used for non-motorized trip split model estimation. More details are provided in the Methodology section. Major data items used from the file include:

a. Expanded regional transit trips by trip purpose and household SE strata (with further processing)

4) 2010 Highway and Transit Skim Files

The highway and transit skim files used here were AMLOV2.mtx, OPLOV2.mtx, AML.mtx, AMP.mtx, OPL.mtx, and OPP.mtx. These files were generated on Oct. 16, 2013 and were stored on the TRM Server. Major data items used include:

a. TAZ-to-TAZ highway travel time and distance
b. TAZ-to-TAZ transit travel time (including in-vehicle travel time and waiting times) and fare

7.2.2 Methodology and Assumptions

1. Determination of eligible trip records to include for model estimation

According to the design of the TRM v6 model, only internal-to-internal trips made by the residents of the Triangle region should be used for non-motorized trip split model development. These trips are referred to as I-I-I trips. In addition, since student trips of the four major universities were modeled separately, corresponding student trips captured in the household survey were excluded. The attribute columns used to determine eligible trips in the survey data file are as follows:

- *Resident_II* = 1, indicating internal-internal trips made by residents only
- *If_4UStudOff* = 2 or 3, where 2 indicates trips made by students not in the four universities and 3 indicates non-student residents.

2. Classification of trip records based on travel modes used

Trips that used modes such as autos, transit, and school buses were classified as motorized trips, whereas trips made using bikes or by walk were classified as non-motorized trips. The column in the survey data file used for this classification is *Mode_AutoVehOccTNScB_TRMv6*.

3. Determination of trip production end and attraction end

The production and attraction ends of a trip were determined first in order for the zone-to-zone travel impedance to be assigned to the trip correctly, since at this step trips were still modeled in the PA format. For home-based trips, the home end TAZs were production TAZs and the other end TAZs were attraction TAZs. For work-based non-home (WBNH) trips, the TAZ where the workplace was located was the production end and the other end was the attraction TAZ. For non-home-based non-work (NHNW) trips, the origin end TAZs were production TAZs and the destination end TAZs were attraction TAZs. In the household survey data file used, production TAZs were stored in the *V6TAZ_ProductionEnd* column and attraction TAZs are in the *V6TAZ_AttractionEnd* column.

4. Classification of trips into peak and off-peak periods

The goal was to develop non-motorized trip split models stratified by time of day, so trip records for model estimation needed to be classified into the peak and off-peak periods. The peak period defined for the TRM model is from 6:00am to 10:00am and from 3:30pm to 7:30pm, and the off-peak period is the rest of the day. When a trip was made completely within one of the periods, it was easy to classify it. When a trip had its starting time in one period and ending time in another period, the classification was a little more complicated. The following rule was employed: If the mid-point of the travel time falls within either peak period, the trip was classified as a peak-period trip; otherwise, it was an off-peak trip. The column in the survey data file used for this purpose was *If_Peak_TRMv6*, which contains two values with 1 for peak and 0 for off-peak.

5. Derivation of non-motorized shortest distances

To obtain non-motorized shortest distances between TAZ centroids, freeways, expressways, and their associated ramps were excluded from the network as walking or biking on these facilities is prohibited in general. In the TRM v6 network, links with a Special value of 1, 2, 3, 5, 21, 22, 23, 24, 25, 41, 42, 43, 54, or 55 were excluded and only links with a value of 4, 6, 26, 31, or 99 were included.

Using the rule above, some segments of US 64 west of the merging/diverging point with US 1 in Cary were excluded due to their Special value of 5 (suburban freeway / expressway), as shown in Figure 1 below. This exclusion however causes a problem that TAZ 2166 no longer has connections to any other TAZs in the region and therefore in the resulting trip distance matrix all values in the row or column of TAZ 2166 are null. This problem was fixed later by relaxing the rule and including links with Special = 5 in the network. This fix was used for TAZ 2166 only and not applied to any other OD pairs.

All links were set to be bi-directional for non-motorized trips. Intra-zonal distance was calculated using 3 neighboring zones and factored by 0.5.

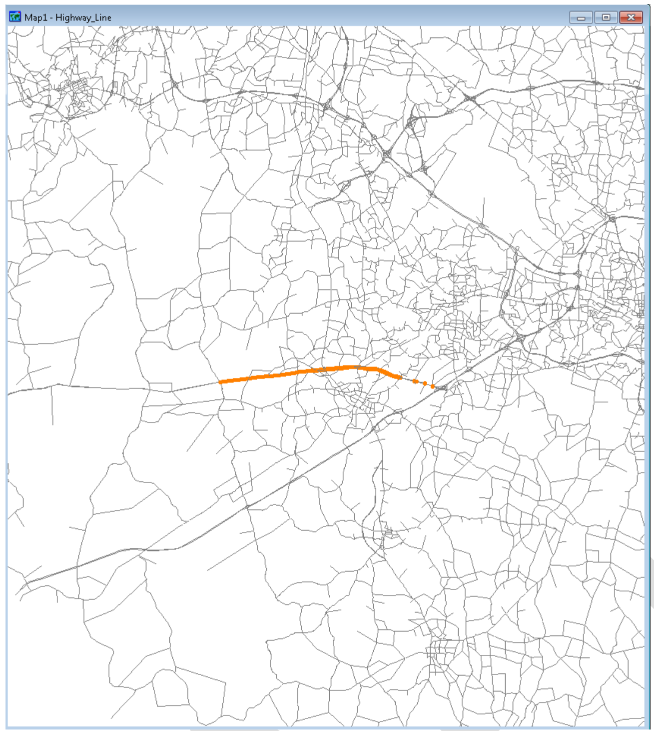


Figure 1 Segments of US 64 Classified as Suburban Freeway / Expressway
(Special = 5, highlighted in orange)

6. Calculation of composite motorized travel time

The composite motorized travel time integrates auto travel time and transit travel time for OD pairs where both the auto and transit modes are available. For OD pairs where transit is not an option, the composite motorized travel time simplifies to auto travel time. The composite time was calculated for the peak and off-peak periods separately.

Since transit is involved in the calculation of composite motorized travel time, and considering transit shares vary a bit among different household socioeconomic strata and for different trip purposes, calculation of composite motorized travel time is further stratified by trip purpose and household strata. To derive transit shares in motorized trips, auto (including school bus) trips from the 2006 household travel survey data and transit trips from the 2006 transit onboard survey were used, because there were too few transit trip observations (400+) in the household survey, while the onboard survey had more than 6,000 trip records.

Like the household travel survey, not all transit trip records in the onboard survey should be used. Specifically, only internal-to-internal trips made by residents of the Triangle region should be used, and trips made by students of the four universities should also be excluded. The columns in the transit onboard survey used for determining trip eligibility are *H_TAZ_TRM6*, *4UStudent*, *O_External*, and *D_External*. Specifically,

- *H_TAZ_TRM6* ≠ 9999
- *4UStudent* = 0 (general population)
- *O_External* = null

- *D_External* = null

Transit shares are calculated as the number of expanded transit trips divided by the sum of auto trips and transit trips, both expanded. Derived transit shares are shown in Table 7-1 and Table 7-2 for the peak and off-peak periods, respectively.

The definition of the peak and off-peak periods in the transit onboard survey differs slightly from the household travel survey. In the onboard survey, the peak periods are from 5:30am to 10:00am and 3:00pm to 7:00pm, compared with 6:00am to 10:00 am and 3:30pm to 7:30pm in the household survey.

Table 7-1 Peak Period Transit Shares by Trip Purpose and SE Strata

% Transit_PK	Strata_1	Strata_2	Strata_3	Strata_4	Strata_5	Total
HBW	41.1%	3.6%	6.5%	1.3%	0.6%	1.9%
HBShop	10.6%	0.8%	1.4%	0.0%	0.0%	0.3%
HBK12	1.0%	0.4%	0.4%	0.0%	0.0%	0.1%
HBO	12.7%	0.5%	1.4%	0.1%	0.0%	0.3%
WBNH	49.1%	1.3%	1.9%	0.2%	0.1%	0.5%
NHNW	18.5%	0.5%	0.4%	0.1%	0.0%	0.2%
Total	14.8%	1.2%	2.5%	0.4%	0.2%	0.6%

Table 7-2 Off-peak Period Transit Shares by Trip Purpose and SE Strata

% Transit_OP	Strata_1	Strata_2	Strata_3	Strata_4	Strata_5	Total
HBW	55.6%	4.3%	10.7%	1.2%	0.7%	2.8%
HBShop	5.5%	0.7%	2.7%	0.0%	0.0%	0.4%
HBK12	0.7%	0.4%	2.7%	0.1%	0.0%	0.2%
HBO	12.1%	0.8%	2.5%	0.1%	0.1%	0.5%
WBNH	43.8%	1.3%	2.9%	0.2%	0.3%	0.6%
NHNW	5.3%	0.6%	2.0%	0.1%	0.0%	0.2%
Total	11.3%	1.1%	4.6%	0.2%	0.2%	0.6%

After transit shares were obtained, the composite motorized travel time could be calculated. The time and distance skim matrices in AMLOV2.mtx and OPLOV2.mtx were used to calculate the auto mode (composite) travel time, while the walk access transit skim matrices in AML.mtx, AMP.mtx, OPL.mtx, and OPP.mtx were used for the transit mode.

Two sets of composite motorized travel time were computed; one with monetary travel cost incorporated and the other without as described below:

1) For composite motorized travel time without monetary cost incorporated

   a. Calculation of transit mode composite travel time:

$$CT_{trn} = IVT_{trn} + (T_{walk} + T_{init\ wait} + T_{xfer\ wait}) * 2$$

Where,
CT_{trn} is transit composite travel time in minutes;
IVT_{trn} is transit in-vehicle-travel time in minutes;
T_{walk} is access, transfer, and egress walk times in minutes;
$T_{init\ wait}$ is initial wait time in minutes;
$T_{xfer\ wait}$ is transfer wait time in minutes;
F_{trn} is transit fare in dollars; and
2 is a factor reflecting the perceived burden of out-of-vehicle travel time relative to in-vehicle travel time. A value of 2 means one minute of out-of-vehicle travel time (walk access, initial wait, and transfer wait times) equal to 2 minutes of in-vehicle travel time.

b. Calculation of composite motorized travel time:

- $CT_{motorized} = 1/(1/CT_{auto} + TrnShare/CT_{trn})$, if $CT_{trn} <> 0$;
- $CT_{motorized} = CT_{auto}$, if $CT_{trn} = 0$.

Where,
$CT_{motorized}$ is composite motorized travel time in minutes;
TrnShare is transit mode share, as shown in Tables 1 and 2.

2) For composite motorized travel time <u>with</u> monetary cost incorporated

a. Calculation of auto mode composite travel time uses the following formula:

$$CT_{auto} = TT_{auto} + TD_{auto} * 0.25 / 0.2$$

Where,
CT_{auto} is auto composite travel time in minutes;
TT_{hwy} is auto highway travel time in minutes;
TD_{hwy} is auto highway travel distance in miles;
0.25 is the auto operating cost in dollars per mile; and
0.2 is the value of time used in TRM with a unit of $/minute

b. Calculation of transit mode composite travel time uses the following formula:

$$CT_{trn} = IVT_{trn} + (T_{walk} + T_{init\ wait} + T_{xfer\ wait}) * 2 + F_{trn} / 0.2$$

Where,
F_{trn} is transit fare in dollars;
0.2 is the value of time used in TRM with a unit of $/minute; and
Other variables are the same as defined in section 1)-a above.

c. Calculation of the time-of-day motorized composite travel time is as follows:

- $CT_{motorized} = 1/(1/CT_{auto} + TrnShare/CT_{trn})$, if $CT_{trn} <> 0$;
- $CT_{motorized} = CT_{auto}$, if $CT_{trn} = 0$.

where all variables are the same as defined in section 1)-b above.

As a note, CT_{trn} for any OD pair with transit services available was calculated based on both local bus skims (AML.mtx for peak and OPL.mtx for off-peak) and express bus skims (AMP.mtx for peak and OPP.mtx for off-peak) and the lower value is chosen for CT_{trn}.

7. Calculation of average non-motorized travel speed and time

The average non-motorized travel speed was calculated for each trip purpose as a weighted average between the average bicycle speed and the average walk speed. The former was assumed to be 10 mph and the latter 3 mph. The bicycle and walk mode shares in all non-motorized trips in the 2006 household travel survey data are shown in Table 7-3 below.

Table 7-3 Bicycle and Walk Mode Shares in Non-motorized Trips

Trip Purpose	Bike Share	Walk Share	Total
HBW	26.56%	73.44%	100.0%
HBShop	10.84%	89.16%	100.0%
HBK12	3.98%	96.02%	100.0%
HBO	6.80%	93.20%	100.0%
WBNH	3.70%	96.30%	100.0%
NHNW	4.28%	95.72%	100.0%
Total	7.90%	92.10%	100.0%

The formulas used to calculate the average non-motorized travel speed and time are as follows:

$$TS_{nm} = TS_{bike} * BikeShare + TS_{walk} * WalkShare$$

$$TT_{nm} = D_{nm} / TS_{nm}$$

Where,
TS_{nm} is average travel speed of non-motorized modes in mph;
TS_{bike} is average bicycle travel speed in mph;
TS_{walk} is average walk speed in mph;
BikeShare is bicycle mode share in all non-motorized modes;
WalkShare is walk mode share in all non-motorized modes; and
D_{nm} is non-motorized TAZ to TAZ distance in miles.

8. Use of 15-mile or shorter trips only

Analysis of the household survey data has shown that as distance increases, the number of non-motorized trips drops rapidly. The relationship is shown in Table 7-4 and Table 7-5. Table 7-6 shows non-motorized trip shares in total trips by distance.

As indicated in Table 7-5, most (specifically, 89.4%) of the non-motorized trips are within a couple miles and those longer than 15 miles only account for about 0.77%. Broken down by trip purpose, the highest percentage of longer-than-15-mile trips is about 2% for WBNH. Therefore it is logical to use 15 miles as a threshold in the model so that trips longer than that are assumed to have no option of using the non-motorized modes. This constraint helps simplify the model without sacrificing much model accuracy. It also helps reduce the computational burden when applying the model.

Table 7-4 Number of Non-motorized Trips by Distance

Trip Length (miles)	Trip Purpose						Total
	HBW	HBShop	HBK12	HBO	WBNH	NHNW	
≤ 2	141	130	168	876	388	278	1981
(2, 5]	41	24	2	51	36	13	167
(5, 10]	6	5	0	3	3	6	23
(10, 15]	4	0	1	8	8	6	27
> 15	3	0	2	0	9	3	17
Total	195	159	173	938	444	306	2215

Table 7-5 Non-motorized Trip Distribution (%) by Distance

Trip Length (miles)	Trip Purpose						Total
	HBW	HBShop	HBK12	HBO	WBNH	NHNW	
≤ 2	72.31%	81.76%	97.11%	93.39%	87.39%	90.85%	89.4%
(2, 5]	21.03%	15.09%	1.16%	5.44%	8.11%	4.25%	7.54%
(5, 10]	3.08%	3.14%	0.00%	0.32%	0.68%	1.96%	1.04%
(10, 15]	2.05%	0.00%	0.58%	0.85%	1.80%	1.96%	1.22%
> 15	1.54%	0.00%	1.16%	0.00%	2.03%	0.98%	0.77%
Total	100%	100%	100%	100%	100%	100%	100%

Table 7-6 Non-motorized Trip Shares in Total Trips by Distance

Trip Length (miles)	Trip Purpose						Total
	HBW	HBShop	HBK12	HBO	WBNH	NHNW	
≤ 2	18.83%	9.52%	17.80%	30.23%	28.63%	11.57%	20.4%
(2, 5]	2.74%	1.31%	0.13%	1.50%	3.21%	0.57%	1.43%
(5, 10]	0.35%	0.37%	0.00%	0.12%	0.33%	0.42%	0.26%
(10, 15]	0.32%	0.00%	0.36%	0.75%	2.02%	1.11%	0.68%
> 15	0.18%	0.00%	1.92%	0.00%	1.97%	0.58%	0.43%
Total	2.86%	2.95%	4.44%	8.63%	10.48%	4.27%	5.77%

9. Notes on calculation of other variables

    1) Two sets of population densities were calculated: The first set includes household population (HH_POP) only and the second set includes not only household population (HH_POP), but also students and other people living in group quarters (i.e. HH_POP + Stud_GQ + Other_NonInst_GQ).

    2) Formula used for Land Use Mix (LUMix) Index calculation was exactly the same as used for TRM v5, which follows.

LUMix = (2 * (Population + Employees) – ABS(Population – Employees))/(Zonal Area in acres)

7.2.3 Data Dictionary

A dictionary explaining the data used for non-motorized trip split model estimation is shown in Table 7-7.

Table 7-7 Data Dictionary for Non-motorized Model Estimation

Field Heading	Description
Trip_ID	Trip ID, a combination of SAMPN, PERNO, and PLANO.
TripPurpose	1 - HBW | 2 - HBShop | 3 - HBK12 | 4 - HBO | 5 - WBNH | 6 - NHNW
Max15Miles	1, if the non-motorized distance of the trip is 15 miles long or shorter; otherwise, 0
IsPeak	1, if the trip is made in the peak periods; otherwise, 0
Mode	Travel mode used for the trip: 1 - non-motorized mode (including bike and walk); 2 - motorized mode (including auto, transit, school bus, and other motorized modes)
HHINC_1	1, if household income is "Low: <25K"; otherwise, 0
HHINC_2	1, if household income is "Med-Low: 25K - 50K"; otherwise, 0
HHINC_3	1, if household income is "Med-High: 50K - 75K"; otherwise, 0
HHINC_4	1, if household income is "High: >=75K"; otherwise, 0
HHSize	Household size
ZeroCar	Zero-car household dummy: 1 - yes; 0 - no
CarsLTWorkers	1, if household has cars but has fewer cars than workers in the HH; otherwise, 0
CarsGEWorkers	1, if household has cars equal to or more than workers in the HH; otherwise, 0
HHStrata_1	Household strata 1: zero car household
HHStrata_2	Household strata 2: low income (<=$24,999) household with car(s)
HHStrata_3	Household strata 3: medium income ($25,000 - $74,999) household with car(s) but car(s) fewer than worker(s)
HHStrata_4	Household strata 4: medium income ($25,000 - $74,999) household with car(s) greater than or equal to worker(s)
HHStrata_5	Household strata 5: high income (>=$75,000) household with car(s)
IsCBD_P	1, if production zone is of type CBD; otherwise, 0
IsCBD_A	1, if attraction zone is of type CBD; otherwise, 0
IsUrban_P	1, if production zone is of Urban type; otherwise, 0
IsUrban_A	1, if attraction zone is of Urban type; otherwise, 0
IsSuburb_P	1, if production zone is of Suburban type; otherwise, 0
IsSuburb_A	1, if attraction zone is of Suburban type; otherwise, 0
IsRural_P	1, if production zone is of Rural type; otherwise, 0
IsRural_A	1, if attraction zone is of Rural type; otherwise, 0
PopDen_GQ_P	Population density (persons per square mile) of production zone (HH population, students living in group quarters, and other people living in group quarters are all included)

PopDen_GQ_A	Population density (persons per square mile) of attraction zone (HH population, students living in group quarters, and other people living in group quarters are all included)
PopDen_noGQ_P	Population density (persons per square mile) of production zone (only HH population included)
PopDen_noGQ_A	Population density (persons per square mile) of attraction zone (only HH population included)
EmpDen_P	Employment density (employees per square mile) of production zone
EmpDen_A	Employment density (employees per square mile) of attraction zone
RetailEmpDen_P	Retail employment density (employees per square mile) of production zone
RetailEmpDen_A	Retail employment density (employees per square mile) of attraction zone
LUMix_P	Land use mix index of production zone
LUMix_A	Land use mix index of attraction zone
AvgBlockArea_P	Average block area (in square miles) of production zone
AvgBlockArea_A	Average block area (in square miles) of attraction zone
SidewalkDen_P	Sidewalk density (in miles per square mile) of production zone
SidewalkDen_A	Sidewalk density (in miles per square mile) of attraction zone
GreenwayDen_P	Greenway density (in miles per square mile) of production zone
GreenwayDen_A	Greenway density (in miles per square mile) of attraction zone
NMPathDen_P	Non-motorized path density (in miles per square mile) of production zone
NMPathDen_A	Non-motorized path density (in miles per square mile) of attraction zone
AutoTime	Travel time (in minutes) by auto mode from production zone to attraction zone (if the trip is made in peak period, the value is a peak value; otherwise, the value is of off-peak)
AutoDistance	Travel distance (in miles) by auto mode from production zone to attraction zone (if the trip is made in peak period, the value is a peak value; otherwise, the value is of off-peak)
TransitTime	Travel time (in minutes) by transit mode from production zone to attraction zone (if the trip is made in peak period, the value is a peak value; otherwise, the value is of off-peak)
TransitFare	Travel fare (in dollars) by transit mode from production zone to attraction zone (if the trip is made in peak period, the value is a peak value; otherwise, the value is of off-peak)
CompMotorTime_wCost	Composite motorized travel time (in minutes) with auto highway driving cost and transit fare included (converted via a value of time factor)
CompMotorTime_noCost	Composite motorized travel time (in minutes) without auto highway driving cost and transit fare included
NM_Dist	Non-motorized shortest distance (in miles) from production zone to attraction zone
NM_Time	Non-motorized travel time (in minutes) from production zone to attraction zone
DiffTime_wCost	Difference between non-motorized travel time (NM_Time) and cost-included composite motorized time (CompMotorTime_wCost), = NM_Time - CompMotorTime_wCost
DiffTime_noCost	Difference between non-motorized travel time (NM_Time) and cost-excluded composite motorized time (CompMotorTime_noCost), = NM_Time - CompMotorTime_noCost
TRMv6_Weight	TRM v6 weighting and expansion factor

7.3 Model Estimation

7.3.1 Home Based Work

Home Based Work (HBW) trips are trips made with one end at home and the other end at the workplace. The non-motorized trip split model is a probability model of binary choice, for the choice between non-motorized and motorized trips. The model is estimated using the 2006 Household Travel Survey data to include non-motorized specific variables and accessibilities by mode.

The following table summarizes the number HBW trip records available for non-motorized model estimation for TRMv6.

Table 7-8 HBW Trip Records Available for Non-motorized Model Estimation

HBW Trips	Records	Percent (%)
Motorized trips <= 15 miles	5,012	73.4%
Motorized trips > 15 miles	1,621	23.74%
Non-motorized trips <= 15 miles	192	2.81%
Non-motorized trips > 15 miles	3	0.04%
Total	6,828	100%

Motorized trips include auto and transit trips while non-motorized trips include walk and bike trips in general. HBW trips with travel distance greater than 15 miles were excluded from the model estimation based on the information in the table above.

7.3.1.1 Model Estimation

Based on the available survey records, BIOGEME 2.2 was used to estimate the binary choice model. Levels of uncertainty for each coefficient in the model are expressed as t-statistics. The 95 percent level of confidence was used to test for significance (t>1.96). A few coefficients with low t statistics were retained for consistency and because the variables were believed to make sense.

After testing many socio-economic, accessibility and non-motorized related variables, the following variables were selected.

- Composite Travel Time for motorized mode (without cost) including auto and transit travel time
- Non-motorized distance
- Non-motorized travel distance squared
- Zero car household
- Cars less than workers household

- Urban area type production zone
- Non-motorized path density for the attraction zone

The table below shows the estimation results.

Variable	Coefficient	T-statistic
Constant	-1.45	-5.95
Composite motorized time	0.181	3.81
Non-motorized distance	-1.73	-11.19
Non-motorized distance squared	0.0745	9.33
Non-motorized path density – attraction zone	0.0124	5.69
Cars less than workers household	0.78	2.88
Zero car household	1.62	5.1
Urban area – production zone	0.253	1.35
Rho square	0.85	

7.3.1.2 Calibration and validation

The following table shows numbers of trips, non-motorized trip percent from the survey, target non-motorized trips, modeled non-motorized trips after calibration and percent difference between the target non-motorized trips and modeled non-motorized trips. These are reported by household strata and time period.

HH Strata	Total trips	NM percent	Target NM trips	Modeled NM trips	% difference
Strata 1	20,407	24.5%	5,009	5,060	1.01%
Strata 2	46,241	3.8%	1,746	1,752	0.35%
Strata 3	30,669	8.9%	2,719	2,719	-0.01%
Strata 4	304,793	2.6%	7,870	7,948	1%
Strata 5	280,798	1.4%	3,895	3,899	0.08%
HH Strata	Total trips	NM percent	Target NM trips	Modeled NM trips	% difference
Strata 1	6,959	27.9%	1,940	1,936	-0.23%
Strata 2	16,586	2.6%	430	437	1.68%
Strata 3	10,981	8.4%	926	930	0.49%
Strata 4	101,968	4.2%	4,314	4,341	0.63%
Strata 5	73,301	1.7%	1,242	1,241	-0.02%

Calibration was performed by adjusting the constants in the utility functions to match the modeled non-motorized trips to the target non-motorized trips by strata and time period. Final model coefficients by household strata and time period are shown below in table ??.

HH Strata	Peak	Off Peak
Strata 1	2.461	2.519
Strata 2	-0.8918	-1.6168

Strata 3	0.664	0.1855
Strata 4	-1.102	-0.7975
Strata 5	-1.4355	-1.5037

The non-motorized trip share was compared to the taxi and non-motorized model share of the CTPP journey to work. In general the taxi and non-motorized mode share should be higher than the non-motorized HBW share. This comparison can give an idea of whether the non-motorized trip model is out of range, but the CTPP data is not exactly the same as the household survey data. The comparison in the table shows the shares to be fairly close which suggests the HBW non-motorized model is acceptable.

	Region	Durham	Orange	Wake
CTPP (Taxi+NM JTW share)	3.65%	4.41%	8.53%	3.18%
Model NM share	3.39%	4.54%	7.59%	3.14%

7.3.2 Home Based Shopping

7.3.2.1 Estimation

7.3.2.2 Calibration

Final calibrated models

The process for calibrating non-motorized trips follows that used for the initial calibration before applying the feedback model. The target for calibration is for the modeled non-motorized trip share to be within one percent of the observed share. As shown in Table 11 and Table 12, both the peak and off peak period non-motorized models appear to meet calibration targets.

Calibration results are shown below for peak and off peak periods.

Table 7-9 Peak Period Non-motorized Trip Share Compared to Observed Share

Strata	Observed %	Modeled %	Modeled – Observed
Strata 1	17.2%	19.9%	2.7%
Strata 2	16.7%	17.5%	0.8%
Strata 3	11.9%	11.1%	-0.8%
Strata 4	1.9%	1.7%	-0.1%
Strata 5	2.0%	1.9%	-0.1%
Total Peak	5.6%	5.4%	-0.2%

Table 7-10 Off-peak Non-motorized Trip Share Compared to Observed Share

Strata	Observed %	Modeled %	Modeled – Observed
Strata 1	15.1%	17.4%	2.4%
Strata 2	3.0%	3.2%	0.1%
Strata 3	8.8%	8.2%	-0.6%
Strata 4	1.8%	1.6%	-0.1%
Strata 5	1.9%	1.8%	-0.1%
Total Off Peak	3.2%	3.1%	-0.1%

Comparisons of trips modeled and observed are provided below using observed values used for model estimation and calibration.

Table 7-11 Comparison of Non-motorized Trips with Observed

Time Period	Observed non-motorized trips	Modeled non-motorized trips	% difference
Peak	20,670	20,670	0.0%
Off Peak	12,883	12,883	0.0%
Daily	33,553	33,553	0.0%

Table 7-12 Comparison of Motorized Modeled Trips with Observed

Time Period	Observed motorized trips	Modeled motorized trips	% difference
Peak	350,729	365,152	4.1%
Off Peak	391,332	407,029	4.0%
Daily	742,061	772,181	4.1%

Table 7-13 HBShop Modeled Motorized Trips by Strata

Strata	Peak	Off peak
Strata 1	19,567	21,943
Strata 2	44,186	56,428
Strata 3	8,350	9,385
Strata 4	172,531	187,975
Strata 5	120,518	131,298
Total	365,152	407,029

Quality Control (QC) Checks

Consistency of trips input and output from each step was checked.

Trips generated (output productions): 835,842[2]

Trips input to destination choice (after reduction for off campus students): 805,734[3]

Trips output from destination choice: 385,822 (pk) + 419,912 (op) = 805,734[4]

Trips output from non-motorized model: 365,152 + 20,670 + 407,029 + 12,883 = 805,734[5]

7.3.3 Home Based K12 School

The HBk12 trip purpose includes trips made by children going to school and adults in the household if they are transporting/escorting children to school. The HBk12 trip purpose is different from other purposes in that the trip from home to school is likely to take place in the AM peak and the trip from school back home is likely to take place in the off peak (mid-day) period. For this reason only a daily model for TRMv6 was estimated. This is consistent with the approach for TRMv5.

The table below shows the number of trips available for HBk12 non-motorized model estimation for TRMv6.

Peak			Off Peak			
Motorized	Non-motorized	Sum	Motorized	Non-motorized	Sum	All Day
2,047	110	2,157	598	63	661	2,818

After testing the TRMv5 model and several alternatives, a model to group all households with cars and compare to households without cars was developed, assuming that this is a key determinant of whether non-motorized trips are made to school. This model is presented below. Based on the results of estimating this model, this model was selected for the HBk12 non-motorized model for TRMv6.

Variable	Coefficient	t-Stat
Constant	-0.444	-2.13
Non-motorized – motorized time (no cost)	-0.0978	-11.63
Non-motorized path density, attraction zone	0.0176	3.31
Urban dummy, production & attraction zones	0.251	1.29
Strata 1	2.91	3.31
Rho square	0.795	Adj. 0.793

[2] Source: C:\TRMv6\2010\Output\tg.rep

[3] Source: C:\TRMv6\2010\Interim\tdshp.bin

[4] Source: C:\TRMv6\2010\Interim\tdshppk.mtx & tdshpop.mtx

[5] Source: C:\TRMv6\2010\Interim\M_shpPK_Per.mtx; M_shpOP_Per.mtx; NM_shpPK_Per.mtx; NM_shpOP_Per.mtx

Model Calibration

The process for calibrating the model proceeded as follows. Calibration targets were prepared for peak and off peak periods using the destination choice output total trips by time period by strata and observed non-motorized shares from the household survey data. Calibration adjustment factors were set equal to one for all strata as initial values. The non-motorized model was run and the non-motorized trips by strata were compared to targets. The calibration adjustment factors were adjusted and the model re-run until the modeled shares of non-motorized trips were within one percent of observed shares. The results are shown below.

Table 7-14Peak Observed Non-motorized Trips and Shares by Strata

Strata	Total trips	Non-Motorized Share	Non-Motorized Observed
Strata 1	5,603	38.8%	2,176
Strata 2	23,420	2.4%	557
Strata 3	8,558	11.3%	966
Strata 4	129,151	3.8%	4,876
Strata 5	151,302	4.9%	7,394
Total Peak	318,034	5%	15,969

Table 7-15 Peak Estimated and Observed Non-motorized Shares by Strata

Strata	Estimated %	Observed %	Modeled – Observed
Strata 1	38.8%	38.8%	0.0%
Strata 2	2.4%	2.4%	0.0%
Strata 3	11.3%	11.3%	0.0%
Strata 4	3.8%	3.8%	0.0%
Strata 5	4.9%	4.9%	0.0%
Total Peak	5%	5%	0.0%

Table 7-16 Off Peak Observed Non-motorized Trips and Shares by Strata

Strata	Total trips	Non-Motorized Share	Non-Motorized Observed
Strata 1	1,821	57.5%	1,047
Strata 2	7,611	12.8%	971
Strata 3	2,781	17.6%	488
Strata 4	41,969	6.5%	2,742
Strata 5	49,167	8.9%	4,394
Total Off Peak	103,349	9.3%	9,642

Table 7-17 Off Peak Estimated and Observed Non-motorized Shares by Strata

Strata	Observed %	Modeled %	Modeled – Observed
Strata 1	57.5%	57.2%	-0.4%
Strata 2	12.8%	12.7%	0.0%
Strata 3	17.6%	17.7	0.1%

Strata 4	6.5%	6.6%	0.0%
Strata 5	8.9%	8.9%	0.0%
Total Off Peak	9.3%	9.3%	0.0%

Table 7-18 Peak and Daily Estimated and Observed Total Trips

Time Period	Estimated non-motorized trips	Observed non-motorized trips	% difference
Peak	15,958	15,970	-0.1%
Off Peak	9,636	9,642	-0.1%
Daily	25,594	25,612	-0.1%

Table 7-19 Peak and Off Peak Calibration Adjustment Factors

Household Strata	Peak	Off Peak
Strata 1	-4.55	-10.5
Strata 2	2	-3.5
Strata 3	-2.75	-4.8
Strata 4	1.2	-0.45
Strata 5	-0.31	-2.41

7.3.4 Home Based Other

The process for calibrating non-motorized trips followed that used for the initial calibration before applying the feedback model. The target for calibration is for the modeled non-motorized trip share to be within one percent of the observed share. As shown in Table 7-20 and Table 7-21, the total peak and off peak period non-motorized models appear to meet calibration targets.

Table 7-20 Peak Period Non-motorized Trip Share Compared to Observed Share

Strata	Observed %	Modeled %	Modeled – Observed
Strata 1	25.9%	29.0%	3.1%
Strata 2	14.9%	14.3%	-0.6%
Strata 3	5.5%	5.1%	-0.3%
Strata 4	10.0%	9.6%	-0.4%
Strata 5	7.5%	7.2%	-0.3%
Total Peak	10.6%	10.2%	-0.2%

Table 7-21 Off-peak Non-motorized Trip Share Compared to Observed Share

Strata	Observed %	Modeled %	Modeled – Observed
Strata 1	18.0%	20.1%	2.2%
Strata 2	8.4%	8.1%	-0.3%
Strata 3	5.5%	5.2%	-0.3%
Strata 4	5.6%	5.4%	-0.2%
Strata 5	7.4%	7.2%	-0.3%
Total Off Peak	7.2%	7.0%	-0.2%

Comparisons of trips modeled and observed are provided below using observed values used for model estimation and calibration.

Table 7-22 Comparison of Non-motorized Modeled Trips with Observed

Time Period	Observed non-motorized trips	Modeled non-motorized trips	% difference
Peak	100,952	100,938	0.0%
Off Peak	49,696	49,756	0.1%
Daily	150,648	150,694	0.0%

Table 7-23 Comparison of Motorized Modeled Trips with Observed

Time Period	Observed motorized trips	Modeled motorized trips	% difference
Peak	853,984	884,503	3.6%
Off Peak	636,024	657,870	3.4%
Daily	1,490,008	1,542,373	3.5%

Table 7-24 HBO Modeled Motorized Trips by Strata

Strata	Peak	Off peak
Strata 1	32,323	26,127
Strata 2	120,202	92,597
Strata 3	24,116	17,305
Strata 4	401,789	302,061
Strata 5	306,073	219,780
Total	884,503	657,870

Quality Control (QC) Checks

Consistency of trips input and output from each step was checked.

Trips generated (output productions): 1,753,365[6]

Trips input to destination choice (after reduction for off campus students): 1,693,067[7]

Trips output from destination choice: 985,441 (pk) + 707,626 (op) = 1,693,067[8]

Trips output from non-motorized model: 884,503 + 657,870 + 100,938 + 49,756 = 1,693,067[9]

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[6] Source: C:\TRMv6\2010\Output\tg.rep

[7] Source: C:\TRMv6\2010\Interim\tdoth.bin

[8] Source: C:\TRMv6\2010\Interim\tdothpk.mtx & tdothop.mtx

[9] Source: C:\TRMv6\2010\Interim\M_othPK_Per.mtx; M_othOP_Per.mtx; NM_othPK_Per.mtx; NM_othOP_Per.mtx

7.3.5 Non Home Non Work

Estimated models for peak and off peak periods are shown in the tables below.

Table 7-25 Non Home Non Work Non-Motorized Peak

Variable	Coefficient	t-Stat
Constant	-2.31	-15.13
Non-motorized – motorized time (with cost)	-0.0535	-9.5
Strata 1	1.49	4.2
Strata 2	0.548	2.06
Strata 3	1.72	3.56
Land use mix, attraction	0.00357	1.72
Land use mix, production	0.00386	2.05
Non-motorized path density, attraction zone	0.0109	2.92
Non-motorized path density, production zone	0.00982	2.76
Rho square	0.797	

Table 7-26 Non Home Non Work Non-Motorized Off Peak

Variable	Coefficient	t-Stat
Constant	-2.06	-12.08
Non-motorized – motorized time (with cost)	-0.0611	-8.07
Strata 1	3.1	6.78
Land use mix, attraction zone	0.00512	1.78
Non-motorized path density, attraction zone	0.00904	1.99
Non-motorized path density, production zone	0.0032	0.63
Rho square	0.82	

7.3.6 Work Based Non Home

Estimated models for peak and off peak periods are shown in the tables below.

Table 7-27 Work Based Non Home Non-Motorized Peak

Variable	Coefficient	t-Stat
Constant	-0.931	-5.44
Non-motorized – motorized time (with cost)	-0.0711	-11.48
Strata 1	1.3	1.7
Strata 3	0.926	1.28
Strata 5	-0.284	-1.72
Land use mix, attraction	0.0102	5.49
Non-motorized path density, attraction zone	0.0105	3.25
Non-motorized path density, production zone	0.0108	3.38
Rho square	0.65	

Table 7-28 Work Based Non Home Non-Motorized Off Peak

Variable	Coefficient	t-Stat
Constant	-2.09	-9.0
Non-motorized – motorized time (with cost)	-0.036	-7.15
Strata 1	2.36	3.45
Strata 3 & 4	0.27	1.15
Land use mix, attraction zone	0.00795	5.04
Non-motorized path density, attraction zone	0.00851	2.16
Non-motorized path density, production zone	0.00619	1.86
Rho square	0.765	

8 Mode Choice

8.1 Introduction

The TRM v6 mode choice model has the same structure as the TRM v4 and TRM v5 mode choice models. Modifications were made to the model for TRM v5 to incorporate new parking price and capacity inputs, but these changed neither the model design nor the utility equation structure (described below). Mode choice utilities have been modified to apply values of time for each stratum based on stratum income (described below). There are twelve mode choice models with one for each trip purpose (home based work, home based shopping, home based K12 school, home based other, non-home non-work, and work based non-home for each time period: peak and off peak (university student mode choice models are described in the section on university student models). All the models use the nested logit form and details of the model form are described in the next section.

8.2 Model Description

The form of the model is a logit type model with the following form.

$$P_{g,i} = \frac{exp[U_{g,i}(x_{g,i})]}{\sum_{g,m} \quad exp[U_{g,m}(x_{g,m})]}$$

Where:

$P_{g,i}$ e probability of traveler from stratum g choosing mode *i*

$x_{g,i}$:he attributes of mode *i* that describe its attractiveness to stratum *g*

$U_{g,m}(x_{g,m})$ e utility of mode *m* for travelers in stratum *g*; and

$\sum_{g,m}$:ates the summation of utilities over all available alternatives.

The utility function for the mode alternatives is generally the following:

$$U_{g,m}(x_{g,m}) = a_m + b_m LOS_m + c_{g,m} SE_g + d_m TRIP$$

Where:

LOS_m esents variables describing levels-of-service provided by mode *m*

SE_g esents variables describing socio-economic characteristics of stratum g

TRIP esents variables describing characteristics of the trip (e.g. CBD trips)

b_m /ector of coefficients describing the importance of LOS_m variables

$c_{g,m}$ vector of coefficients describing the importance of each $SE_{g,m}$ characteristic of stratum *g* with respect to mode *m*

d_m vector of coefficients describing the importance of each TRIP characteristic with respect to mode *m*; and

a_m constant specific to mode m that captures the overall effect of any variables missing from the utility expression (comfort, safety or other).

The structure of the TRM mode choice model is a nested logit type with three nest levels. The first level calculates the probability of choosing auto or transit. The second nest level for auto trips calculates the probability of auto trips choosing to drive alone, carpool, or auto-intercept. The auto-intercept mode was added to TRM v4 to account for long auto trips that use a park and ride lot close to their destination and a short transit shuttle leg to complete their trips. This mode identifies park and ride lots (as TAZs) and destination zones (UNC campus zones) at the end of the transit leg of the trip. The second nest level for transit trips calculates the probability of transit trips using local bus transit, express bus transit, or urban rail. The urban rail mode is included for future forecasts, because no urban rail service exists yet in the region. The third nest level for auto trips calculates the probability of shared ride trips having two or three plus traveling together. The third nest level for transit calculates the probability of walking to transit, drive to park and ride lot to transit, or being dropped off at a transit stop (kiss and ride). This structure for the mode choice model is shown in Figure 8-1 below. [10]

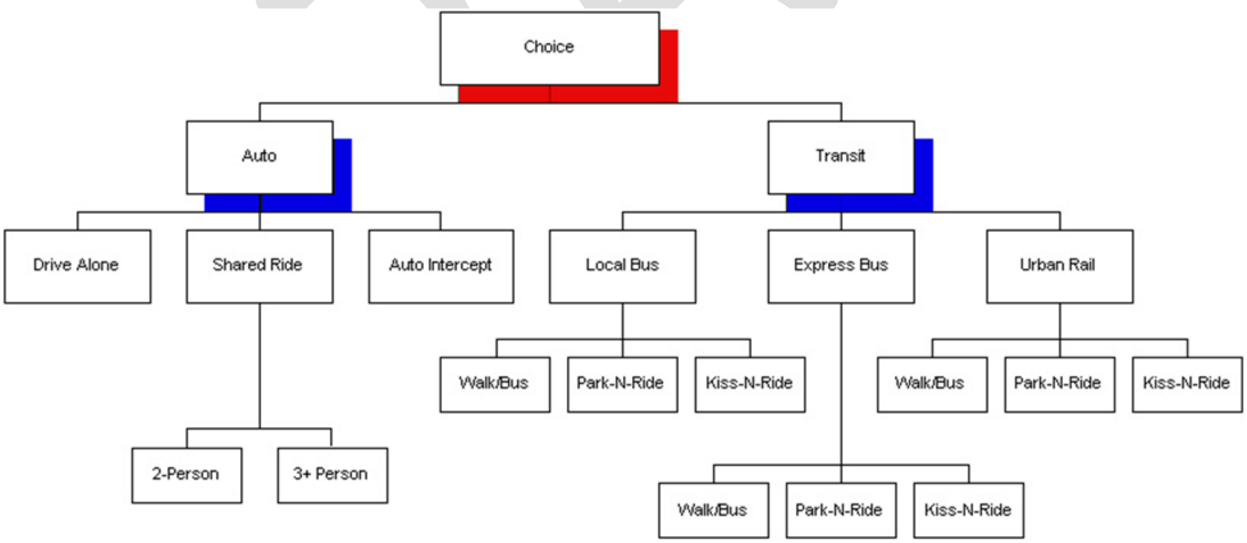


Figure 8-1 Mode choice model structure

[10] PB Americas, *Triangle Regional Model 2006 Documentation*, January, 2007, p. 47, 50.

8.2.1 Choice Sets and Modes

In addition to the modes described above which define the choice sets for each mode, the transit mode choice sets are further defined as follows. For walk to transit, the area of zones within one quarter mile of a transit stop are the short walk area (SW), and those within one quarter to one half mile of a transit stop are the long walk area (LW). People outside the long walk area can either ride in an auto and be dropped off at a transit stop known as kiss-n-ride (KR), or they can drive to a park and ride lot (DR). For selecting stops for kiss and ride the following rules are used: 1) all express bus and rail stops are chosen, 2) for local bus, only up to two stops directly connected to the TAZ centroid by walk access links are selected. A practical limit of 550 kiss and ride stops is applied due to memory limitations. Separate skims are generated for kiss and ride access to transit. The various combinations of mode of access to transit are:

t Walk to transit -> Short Walk from transit	-SW)
t Walk to transit -> Long Walk from transit	-LW)
; Walk to transit -> Short Walk from transit	-SW)
; Walk to transit -> Long Walk from transit	-LW)
n-ride to transit -> Short Walk from transit	-SW)
n-ride to transit -> Long Walk from transit	-LW)
e to transit -> Short Walk from transit	SW)
e to transit -> Long Walk from transit	LW)
t drive (no transit available)	TRN)

The portion of trips between zones for these access categories is calculated as shown below:

ent SW-SW	ent Short Walk at production * percent Short Walk at attraction
ent SW-LW	ent Short Walk at production * percent Long Walk at attraction
ent LW-SW	ent Long Walk at production * percent Short Walk at attraction
ent LW-LW	ent Long Walk at production * percent Long Walk at attraction
ent KW-SW	ent Kiss-n-ride at production * percent Short Walk at attraction
ent KW-LW	ent Kiss-n-ride at production * percent Long Walk at attraction
ent DR-SW	ent Drive at production * percent Short Walk at attraction

ent DR-LW ent Drive at production * percent Long Walk at attraction

ent NOTRN percent – all previous per cents

8.2.2 Parking Price

8.2.2.1 Parking Analysis Sub-Area

In order to enable testing various parking related policy scenarios, TRM v5 provided enhancements for parking cost and capacity constraint.

In 2009, stakeholders identified parking analysis sub-areas (PASA hereafter) to be used in TRM v5. These were augmented for TRMv6 by adding PASAs in downtown Carrboro and downtown Hillsborough.

In TRM v6 both parking cost and capacity constraints are applied only to peak time travel (both AM and PM peaks), not to off-peak.

8.2.2.2 Implementing Parking Cost

Parking price is implemented as a zonal average price for each PASA. This parking cost is applied as part of mode choice in the cost of auto travel. Parking cost can be set for each of three use types: work, university, and other. Parking price can also be set for each of three auto occupancies: single occupant, two person carpool, and three plus person carpool. Parking price is also implemented in trip distribution through use of the mode choice logsum value for impedance. The mode choice logsum is a composite value that includes level of service characteristics for all modes. Increasing parking price for a zone will make it less likely as a destination in the same relation as the coefficients used in mode choice.

8.2.3 Parking Capacity Constraint Analysis Module

8.2.3.1 Implementing Parking Capacity Constraint Module

Parking capacity constraint is implemented using a shadow price approach for each PASA. If demand for a particular use type exceeds capacity for a PASA, then an incremental shadow price starts to add to the parking cost until parking demand is less than the capacity. As the shadow price increases, carpooling becomes more likely and to a lesser extent transit becomes more likely in the same relation as the coefficients used in mode choice. For the UNC PASA the remote park and ride (auto intercept) can become more likely.

8.2.3.2 Parking Capacity

Theoretically, parking capacity by PASA should be developed from parking facility inventory information and facility usage information. However, while a relatively good inventory for the paid parking facilities is available, the information on free parking ‘facilities’ is not available. Complete information on parking facility usage (whether in current inventory or not) is not available. There is no information on the capacity constraint (how many spaces actually are short of demand), and especially traveler's behavior with respect to the capacity changes.

Besides parking inventory information, the observed 2006 auto vehicle trips attracted to each PASA, can be obtained from the 2006 HHS.

The TRM v5 capacity is temporarily developed based on the observed 2006 auto vehicle trips and the parking information associated with these trips (purpose, parking duration, parking cost paid, time of day). It is assumed the total number of auto vehicle trips attracted to each PASA is relatively reliable, despite the parking related information is not reliable (not well reported, can only be used as reference).

Parking capacity originally was developed by parking use: work, HBU and other. To simplify the procedure (reducing model run time), TRM v5 currently uses capacity by purpose (HBK12 is not applied with either parking cost or capacity constraint).

Table 5-1 is the parking capacity used in TRM v5. Please notice that a peak capacity of 20,000 is assigned to:

1) RDU. TRM v6 currently does not apply any parking cost or capacity constraint to it; and
2) ~~HBU trip is irrelevant to places outside of the four university campuses~~

Table 8-1 TRM v5-2010 Parking Capacity by Purpose and Parking Analysis Sub Area

PASA Name	Cap**HBW**	Cap**HBSH**	Cap**HBO**	Cap**HBU**	Cap**NHNW**	Cap**WBNH**
1: UNC	21,000	1,000	9,000	3,000	3,000	5,000
2: Duke	30,000	3,000	18,000	3,000	5,000	9,000
3: NCSU	19,000	3,000	7,000	7,000	5,000	7,000
4: NCCU	2,000	1,000	2,000	2,000	1,000	1,000
5: Chapel Hill CBD	3,000	1,000	2,000	20,000	1,000	1,000
6: Durham CBD	12,000	3,000	7,000	20,000	2,000	4,000
7: Raleigh CBD	45,000	17,000	24,000	20,000	6,000	14,000
8: RDU	20,000	20,000	20,000	20,000	20,000	20,000

8.2.4 Value of Time by Strata

The TRM v4 applied a coefficient for auto operating cost, transit fare, and parking cost equally to all five strata implying that all five strata have equal ability to pay based on household income. For version five household survey data was used to derive an average household income value for each stratum. These values are shown in Table 5-2 below (see technical memorandum for details of this calculation).

Table 8-2 Average annual household income and value of time by strata from HH survey

Strata	Average HH Income	Value of Time
Strata 1	$20,500	$3.42/hr
Strata 2	16,500	$2.75/hr
Strata 3	$48,000	$8.00/hr
Strata 4	$51,500	$8.58/hr
Strata 5	$105,000	$17.50/hr

A value of time (VOT) was computed as $VOT = annual\ HH\ income/2000\ work\ hours/3$. To derive values for coefficients for each stratum, the in vehicle time coefficient is divided by the value of time divided by 0.6. The values for auto operating cost, parking cost, and transit fare are shown below in Table 5-3.

Table 8-3 Mode choice cost coefficients calculated by strata from value of time

Strata	HBW	HBsh	HBk12	HBO	HBU	NHB
Strata 1	-0.00439	-0.00176	-0.00176	-0.00176	-0.00439	-0.00351
Strata 2	-0.00545	-0.00218	-0.00218	-0.00218	-0.00545	-0.00436
Strata 3	-0.00188	-0.00075	-0.00075	-0.00075	-0.00188	-0.00150
Strata 4	-0.00175	-0.000.70	-0.000.70	-0.000.70	-0.00175	-0.00140
Strata 5	-0.00086	-0.00034	-0.00034	-0.00034	-0.00086	-0.00069

8.2.5 Other Model Coefficients

Model coefficients for walk time and number of transfers were modified. The coefficient for walk time was changed from 2.0 times in-vehicle time to 2.5 times in-vehicle time, because it is usually thought that walking is more onerous than driving (or riding). A coefficient reflecting the reluctance of transit riders to transfer has been added that is worth eight minutes of in-vehicle time for each transfer.

8.3 Calibration Approach

8.3.1 Developing Calibration Targets

Data from the 2006 HHS and the 2006 transit on-board survey were combined to prepare the mode choice calibration targets by trip purpose and time period. The household survey was expanded to represent all households in the model region, and the auto trips were used to prepare the shares of single occupant auto, shared ride with two, shared ride with three and auto intercept trips. The household survey does not have enough sample households that use transit to represent all transit travel in the region (which is typical of small sample household surveys), so the transit on-board survey was expanded to represent all transit trips taken in the model region. These trips were used to prepare the shares of transit trips taken on local buses and express buses and for each by those who walk to transit, those who drive to a park and ride lot, and those who are dropped off at bus stops (there is no rail service in the model region in the base year). Alternative specific constants (ASC: constants for each mode by access mode) are adjusted until the model replicates the shares observed for each trip purpose by time period.

For TRMv6 the 2006 HHS data were re-expanded to the 2010 number of households (based on the 2010 census). The 2010 total number of motorized person trips including auto and transit (excluding school bus) is the sum of the expansion weight of all motorized trip records.

For TRMv6 students at the four major universities in the TRM region are modeled separately from the general population in university student models. To prepare calibration targets for the general population it is necessary to remove trips made by university students living off-campus (no on campus university students were included in the survey). For the purpose students attending UNC Chapel Hill, NC State University, Duke, and NC Central University were identified. The distribution of persons and trips by general population and university off campus students are shown in the table below.

	Resident Person		Resident Internal Person Trip	
Person Type	Person Records	**2010 Persons**	Trip Records	**2010 Person Trips**
General Population	10,023	1,489,930	38,393	5,538,060
University Off Campus Student	280	43,666	1,278	201,091
Total Population	**10,303**	**1,533,597**	**39,671**	**5,739,151**
General Population	97.3%	97.2%	96.8%	96.5%
University Off Campus Student	2.7%	2.8%	3.2%	3.5%
Total Population	**100%**	**100%**	**100%**	**100%**

In TRMv6 all college students not enrolled at the four major universities their trips to campus are modelled as HBO in the general population.

The total number of auto person trips are calculated by trip purpose, time of day by household strata. Then the percent shares of drive alone, shared ride two person, and shared ride three plus persons were calculated based on the 2006 HHS.

The 2006 transit on-board survey data were re-expanded to 2010 average weekday ridership. The sum of all the survey trip weights equals the total number of transit trips. The university students enrolled at the four major universities also had to be removed for preparing the general population trips. A special field was created to identify the major university students based on available information.

4UStudent	2010 Transit Trips	Sample Size
0: General population	33,947	3,312
1: University Off Campus Student	41,112	2,784
Total	**75,060**	**6,096**
Percent of Total		
0: General population	45%	54%
1: University Off Campus Student	55%	46%
Total	**100%**	**100%**

Similarly to the household survey data, the trips made to campus by students not enrolled at the major universities were classified as HBO trips in the general population.

The Work Based Non Home (WBNH) trip purpose transit access mode was updated to make the work end the production end and the other end the attraction end. Previously the origin of the trip was used for the production and the destination the attraction.

8.3.2 Calibration Results and Alternative Specific Constants

Calibrated mode choice constants for each trip purpose for each time period are shown below in Table 5-4 to Table 5-17.

Table 8-4 Mode choice calibration results and alternative specific constants for HBW PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	5.21508	21.91%	22.12%
	Strata 2	-0.61348	5.1%	5.1%
	Strata 3	0.58080	4.92%	4.92%
	Strata 4	-2.02779	1.3%	1.3%
	Strata 5	-2.67573	0.57%	0.57%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.27%	100%
	Strata 2	-0.61143	29.52%	29.52%
	Strata 3	-0.17059	44.73%	44.73%
	Strata 4	-1.32221	7.66%	7.66%

	Strata 5	-1.46265	5.9%	5.9%
Share of auto intercept trips among all motorized trips	**Strata 1**	-14.92	0.0%	0.0%
	Strata 2	-1.3662	0.32%	0.32%
	Strata 3	-1.77418	0.06%	0.06%
	Strata 4	-1.34623	0.15%	0.15%
	Strata 5	-1.8766	0.05%	0.05%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-1.26296	0.84%	0.84%
	Strata 2	-0.06531	43.64%	43.64%
	Strata 3	-0.36058	19.22%	19.22%
	Strata 4	-0.35881	20.17%	20.17%
	Strata 5	-0.31873	22.65%	22.65%
Share of drive access trips among all transit trips	**Strata 1**	-9.31470	4.02%	3.97%
	Strata 2	-3.44643	23.69%	23.68%
	Strata 3	-4.24018	13.25%	13.25%
	Strata 4	-3.32153	52.92%	52.92%
	Strata 5	-2.61983	61.96%	61.96%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-0.62193	1.48%	1.48%
	Strata 2	1.62882	82.18%	82.18%
	Strata 3	0.60477	37.02%	37.02%
	Strata 4	2.52633	96.73%	96.73%
	Strata 5	1.73283	87.2%	87.2%
Share of express transit trips among all transit trips	**All strata**	-0.16722	18.91%	18.9%

Table 8-5 Mode choice calibration results and alternative specific constants for HBW OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	14.59361	37.35%	37.2%
	Strata 2	0.44662	9.2%	9.17%
	Strata 3	2.44546	10.96%	10.94%
	Strata 4	-2.17898	1.21%	1.21%
	Strata 5	-2.59708	0.7%	0.7%
Share of shared ride trips among all auto trips	**Strata 1**	0	96.85%	100.0%
	Strata 2	-0.62686	23.87%	23.87%
	Strata 3	0.05676	55.4%	55.4%
	Strata 4	-1.40024	6.63%	6.63%
	Strata 5	-1.28556	7.98%	7.98%
Share of auto intercept trips among all motorized trips	**Strata 1**	0	0.0%	0.0%
	Strata 2	-0.03636	1.24%	1.24%
	Strata 3	-6.18363	0.0%	0.0%
	Strata 4	-1.46748	0.11%	0.11%

	Strata 5	-1.81478	0.05%	0.05%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-0.87691	3.29%	3.29%
	Strata 2	-0.62255	8.3%	8.3%
	Strata 3	-0.38064	18.08%	18.08%
	Strata 4	-0.42033	17.67%	17.67
	Strata 5	-0.40741	17.7%	17.7%
Share of drive access trips among all transit trips	**Strata 1**	-15.0	3.85%	47.45%
	Strata 2	-4.56373	13.41%	13.44%
	Strata 3	-7.24568	1.65%	1.66%
	Strata 4	-3.63442	58.12%	58.12%
	Strata 5	-3.50197	71.14%	71.14%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-2	0.0%	0.01%
	Strata 2	1.937	82.65%	82.65%
	Strata 3	0.34755	16.67%	16.67%
	Strata 4	3.07334	97.62%	97.62%
	Strata 5	3.02949	97.46%	97.46%
Share of express transit trips among all transit trips	**All strata**	-1.00754	5.23%	5.23%

Table 8-6 Mode choice calibration results and alternative specific constants for HBShop PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	-1.61998	2.52%	2.52%
	Strata 2	-2.51341	0.71%	0.71%
	Strata 3	-1.08729	1.48%	1.48%
	Strata 4	-6.53732	0.01%	0.01%
	Strata 5	-6.45161	0.01%	0.01%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.35%	100.0%
	Strata 2	-0.24746	44.74%	44.74%
	Strata 3	0.33841	78.34%	78.34%
	Strata 4	-0.08042	52.92%	52.92%
	Strata 5	0.0538	57.85%	57.85%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-15	0.44%	0.66%
	Strata 2	-0.05807	44.24%	44.24%
	Strata 3	0.23061	71.52%	71.52%
	Strata 4	-0.04878	45.17%	45.17%
	Strata 5	-0.1319	37.17%	37.17%

Table 8-7 Mode choice calibration results and alternative specific constants for HBShop OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	-1.52718	2.8%	2.81%
	Strata 2	-2.87786	0.64%	0.64%
	Strata 3	-1.052	1.54%	1.54%
	Strata 4	-6.67608	0.01%	0.01%
	Strata 5	-5.24954	0.03%	0.03%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.31%	100.0%
	Strata 2	-0.2052	43.63%	43.63%
	Strata 3	0.47081	79.43%	79.43%
	Strata 4	-0.19014	45.53%	45.53%
	Strata 5	-0.09382	49.82%	49.82%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-15.0	0.4%	1.24%
	Strata 2	-0.21627	29.83%	29.83%
	Strata 3	0.09562	59.42%	59.42%
	Strata 4	-0.14804	35.73%	35.73%
	Strata 5	-0.17749	33.07%	33.07%

Table 8-8 Mode choice calibration results and alternative specific constants for HBK12 PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	0.08331	4.18%	4.17%
	Strata 2	-1.4565	0.7%	0.7%
	Strata 3	-1.38763	0.55%	0.55%
	Strata 4	-6.80412	0.0%	0.0%
	Strata 5	-5.46588	0.01%	0.01%
Share of shared ride trips among all auto trips	**Strata 1**	0	96.92%	100.0%
	Strata 2	1.12129	89.42%	89.42%
	Strata 3	1.15487	92.38%	92.38%
	Strata 4	1.21652	91.12%	91.12%
	Strata 5	0.73534	83.07%	83.07%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-0.86948	3.15%	3.15%
	Strata 2	-0.19041	31.97%	31.97%
	Strata 3	0.06952	56.88%	56.88%
	Strata 4	-0.0363	46.41%	46.41%
	Strata 5	-0.13512	36.88%	36.88%

Table 8-9 Mode choice calibration results and alternative specific constants for HBK12 OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	1.66835	5.38%	5.37%
	Strata 2	-0.88105	1.18%	1.18%
	Strata 3	0.88696	3.59%	3.59%
	Strata 4	-3.23966	0.15%	0.15%
	Strata 5	-4.75391	0.02%	0.02%
Share of shared ride trips among all auto trips	**Strata 1**	0	86.45%	100.0%
	Strata 2	0.74245	85.99%	85.99%
	Strata 3	1.10227	92.15%	92.15%
	Strata 4	0.50709	75.94%	75.94%
	Strata 5	0.33563	71.56%	71.56%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-0.42095	15.67%	15.67%
	Strata 2	0.08705	58.58%	58.58%
	Strata 3	0.05748	55.71%	55.71%
	Strata 4	-0.11522	38.78%	38.78%
	Strata 5	-0.0538	44.67%	44.67%

Table 8-10 Mode choice calibration results and alternative specific constants for HBO PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	-0.70456	3.82%	3.83%
	Strata 2	-2.71682	0.49%	0.49%
	Strata 3	-1.75764	1.13%	1.13%
	Strata 4	-3.74443	0.13%	0.13%
	Strata 5	-4.56687	0.05%	0.05%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.85%	100.0%
	Strata 2	-0.00983	51.57%	51.57%
	Strata 3	0.48642	77.51%	77.51%
	Strata 4	0.06067	58.91%	58.91%
	Strata 5	0.26356	68.84%	68.84%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-1.02343	1.74%	1.74%
	Strata 2	-0.38557	17.76%	17.76%
	Strata 3	-0.03171	46.85%	46.85%
	Strata 4	-0.09918	40.25%	40.25%
	Strata 5	-0.0593	44.12%	44.12%
Share of drive access trips among all transit trips	**Strata 1**	-4.85104	5.2%	5.2%
	Strata 2	-3.65063	3.75%	3.75%
	Strata 3	-2.19838	31.2%	31.2%
	Strata 4	-3.58368	15.43%	15.43%
	Strata 5	-2.31488	33.56%	33.53%

Share of Park and Ride trips among all drive access trips	**Strata 1**	0.25521	34.67%	34.67%
	Strata 2	0.58878	52.38%*	52.38%
	Strata 3	0.57711	60.26%	60.26%
	Strata 4	1.32895	88.31%	88.31%
	Strata 5	0.19319	26.0%	26.0%
Share of express transit trips among all transit trips	**All strata**	-1.77618	3.97%	3.97%

* The observed number of trips is only 4

Table 8-11 Mode choice calibration results and alternative specific constants for HBO OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	-0.32106	5.95%	5.97%
	Strata 2	-2.16623	1.02%	1.03%
	Strata 3	-1.01734	1.85%	1.85%
	Strata 4	-4.26087	0.1%	0.1%
	Strata 5	-3.80306	0.09%	0.09%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.9%	100.0%
	Strata 2	-0.2092	40.75 %	40.75 %
	Strata 3	0.24102	65.87 %	65.87 %
	Strata 4	-0.07925	51.92 %	51.92 %
	Strata 5	-0.05353	52.38 %	52.38 %
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-14.28398	0.36%	0.32%
	Strata 2	-0.51253	11.76 %	11.76 %
	Strata 3	-0.1666	34.0%	34.0%
	Strata 4	-0.09856	40.33 %	40.33 %
	Strata 5	-0.15316	35.21%	35.21%
Share of drive access trips among all transit trips	**Strata 1**	-4.35043	8.02%	8.01%
	Strata 2	-2.20331	11.91%	11.91%
	Strata 3	-4.07348	5.78%	5.78%
	Strata 4	-2.5688	29.6%	29.6%
	Strata 5	-4.64924	12.83%	12.84%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-2.0	0.0%	0.02%
	Strata 2	-0.47528	2.83%	2.83%
	Strata 3	-1.4	0.0%*	0.12%
	Strata 4	1.09848	74.39 %	74.39 %

	Strata 5	1.72133	91.67 %	91.67 %
Share of express transit trips among all transit trips	**All strata**	-1.45344	1.98%	1.98%

* The observed number of Park and Ride trips is 0 and the observed number of Kiss and Ride trips is 12.

Table 8-12 Mode choice calibration results and alternative specific constants for WBNH PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	4.72287	23.92%	23.94%
	Strata 2	-2.27677	1.42%	1.42%
	Strata 3	-2.20898	1.72%	1.68%
	Strata 4	-3.65625	0.22%	0.22%
	Strata 5	-4.33892	0.1%	0.1%
Share of shared ride trips among all auto trips	**Strata 1**	0	91.88%	100.0%
	Strata 2	-0.56813	25.68%	25.68%
	Strata 3	-0.57187	25.62%	25.62%
	Strata 4	-1.15378	10.31%	10.31%
	Strata 5	-1.20087	9.17%	9.17%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-0.60677	8.26%	8.26%
	Strata 2	-0.71076	6.46%	6.46%
	Strata 3	-0.57677	9.74%	9.74%
	Strata 4	-0.35559	20.25%	20.25%
	Strata 5	-0.41726	16.7%	16.7%
Share of drive access trips among all transit trips	**Strata 1**	-8.23258	0.97%	1.02%
	Strata 2	-1.01893	36.68%	36.72%
	Strata 3	-2.88686	2.7%	3.11%
	Strata 4	-6.45533	2.83%	3.21%
	Strata 5	-4.2	0%	2.01%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-1.5	0.0%	0.06%
	Strata 2	-1.5	0%	0.05%
	Strata 3	-1.5	0%	0.06%
	Strata 4	3.66	100.0%	99.8%
	Strata 5	-1.5	0.0%	0.05%
Share of express transit trips among all transit trips	**All strata**	-1.06316	12.74%	12.82%

Table 8-13 Mode choice calibration results and alternative specific constants for WBNH OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	Strata 1	4.73792	25.07%	24.87%
	Strata 2	-2.38903	1.04%	1.04%
	Strata 3	-2.38486	1.41%	1.41%
	Strata 4	-3.50863	0.33%	0.33%
	Strata 5	-3.93195	0.2%	0.2%
Share of shared ride trips among all auto trips	Strata 1	0	93.43%	100.0%
	Strata 2	-0.92841	26.7%	26.7%
	Strata 3	-1.05425	12.01%	12.01%
	Strata 4	-1.10667	10.42%	10.42%
	Strata 5	-1.02547	12.13%	12.13%
Share of 3+ drive trips among all shared ride trips	Strata 1	-0.88776	7.04%	7.04%
	Strata 2	0.35249	79.31%	79.31%
	Strata 3	-0.57972	11.76%	11.76%
	Strata 4	-15	3.36%	3.59%
	Strata 5	-0.62925	9.69%	9.69%
Share of drive access trips among all transit trips	Strata 1	-7.61824	0.79%	0.8%
	Strata 2	-2.31693	14.57%	14.57%
	Strata 3	-7.12361	2.97%	2.97%
	Strata 4	-2.82973	7.69%	7.69%
	Strata 5	-6.17172	15.85%	15.85%
Share of Park and Ride trips among all drive access trips	Strata 1	-2	0.0%	0.01%
	Strata 2	1.44082	75.86%	75.86%
	Strata 3	5.16	100.0%	99.88%
	Strata 4	0.94013	56.52%	56.52%
	Strata 5	5.2	100.0%	99.84%
Share of express transit trips among all transit trips	All strata	-2.46922	1.73%	1.74%

Table 8-14 Mode choice calibration results and alternative specific constants for NHNW PK

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	Strata 1	-0.32541	5.28%	5.31%
	Strata 2	-2.96149	0.43%	0.44%
	Strata 3	-3.028	0.44%	0.44%
	Strata 4	-4.34302	0.14%	0.14%
	Strata 5	-5.25301	0.03%	0.03%
Share of shared ride trips among all auto trips	Strata 1	0	98.45%	100.0%
	Strata 2	-0.04697	48.77%	48.77%
	Strata 3	0.27978	67.65%	67.65%

	Strata 4	0.00536	54.07%	54.07%
	Strata 5	0.19056	61.52%	61.52%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-15.0	1.54%	2.2%
	Strata 2	-0.33245	21.63%	21.63%
	Strata 3	-0.08736	41.45%	41.45%
	Strata 4	-0.15098	35.59%	35.59%
	Strata 5	-0.21357	30.17%	30.17%
Share of drive access trips among all transit trips	**Strata 1**	-3.1882	5.98%	5.96%
	Strata 2	-2.41606	9.21%	9.2%
	Strata 3	-5.04752	19.57%	19.57%
	Strata 4	-1.68673	59.02%	59.02%
	Strata 5	-6.3	0%	0.19%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-2	0.0%	0.01%
	Strata 2	0.26343	22.73%	22.73%
	Strata 3	4.355	100%	99.98%
	Strata 4	1.82113	89.81%	89.81%
	Strata 5	-2.0	0%	0.01%
Share of express transit trips among all transit trips	**All strata**	-1.0068	4.06%	4.06%

Table 8-15 Mode choice calibration results and alternative specific constants for NHNW OP

		ASC	Observed	Modeled
Share of transit trips among all motorized trips	**Strata 1**	-1.9683	2.99%	3.02%
	Strata 2	-2.71153	0.62%	0.62%
	Strata 3	-1.83044	1.09%	1.09%
	Strata 4	-4.56308	0.06%	0.06%
	Strata 5	-5.03675	0.04%	0.04%
Share of shared ride trips among all auto trips	**Strata 1**	0	99.39%	100.0%
	Strata 2	-0.1431	42.52%	42.52%
	Strata 3	0.21536	64.3%	64.3%
	Strata 4	-0.17301	45.32%	45.32%
	Strata 5	-0.12894	46.43%	46.43%
Share of 3+ drive trips among all shared ride trips	**Strata 1**	-15	1.72%	5.67%
	Strata 2	-0.63648	8.37%	8.37%
	Strata 3	-0.16102	34.56%	34.56%
	Strata 4	-0.16777	34.15%	34.15%
	Strata 5	-0.23199	28.77%	28.77%
Share of drive access trips among all transit trips	**Strata 1**	-1.96367	6.47%	6.47%
	Strata 2	-1.4892	26.62%	26.62%
	Strata 3	-2.68231	8.09%	8.08%

	Strata 4	-10.61838	6.33%	6.33%
	Strata 5	-3.21613	5.56%	5.56%
Share of Park and Ride trips among all drive access trips	**Strata 1**	-1.5	0%	0.03%
	Strata 2	-1.5	0%	0.04%
	Strata 3	-1.5	0%	0.03%
	Strata 4	8.6	100.0%	100.0%
	Strata 5	-1.5	0%	0.03%
Share of express transit trips among all transit trips	**All strata**	-2.09753	0.23%	0.23%

9 Special Models

9.1 Commercial Vehicle Model

Commercial vehicle trips constitute a significant percentage of overall traffic volumes and have substantially different characteristics and driving forces than person trips. Therefore, the TRMv6 represents the generation and distribution of commercial vehicle trips through a separate submodel. Due to the nature of commercial vehicle trips, this submodel does not include a separate mode-choice step. Instead, trips by different categories of commercial vehicles are estimated in the trip-generation step.

In 2010, a survey of commercial vehicle trips was conducted in the Triangle region. The TRMv6 is the first version of the TRM to have its commercial-vehicle component estimated on the basis of data from a local commercial-vehicle survey. In contrast, the TRMv5 was created using commercial-vehicle survey data from the nearby Triad region of North Carolina. However, even the Triangle-region commercial-vehicle survey data had some significant limitations, as will be discussed below.

Data from the 2010 Triangle Region Commercial Vehicle Travel Survey are best suited for modeling trips that are internal to the Triangle region. However, many commercial-vehicle trips have only one end inside the model region, and many pass through the region without stopping. In the TRMv6, these commercial-vehicle trips with one or both ends outside of the Triangle region were modeled by interfacing with forecasts from the North Carolina Statewide Travel Model (NCSTM).

9.1.1 Trip Generation

9.1.1.1 Commercial Vehicle Classification

The TRM v5 commercial vehicle model classified commercial vehicles (CVs) into three categories: cars, pick-ups, and trucks. During the subsequent years of model application, it was determined that this classification scheme was not optimal and needed to be adjusted for the TRMv6. Specifically, the "trucks" class in the TRMv5 was too broad, including all trucks classified as FHWA vehicle classes five through thirteen. As the 2010 Triangle Region Commercial Vehicle Travel Survey revealed, single-unit trucks and multi-unit trucks behave differently in terms of the numbers and types of trips they make, which will be discussed in detail in Section 9.1.1.3**,** below. Also, it has been thought that, while cars and pickups that are used as commercial vehicles may show some different travel characteristics from one another, the difference may not be big enough to have them separated in the model. A review of a few other regional travel models in the U.S. included none in which these two types of commercial vehicles are considered separately from one another (more details are provided in Table 9-1). Therefore, a new commercial vehicle grouping scheme was created for the TRM v6.

In general there are two commonly-used types of vehicle classification schemes: weight-based and configuration-based.

Gross Vehicle Weight (GVW): GVW is the sum of the empty-vehicle weight and the weight of the vehicle's payload. GVW classification ratings are primarily used for air quality modeling purposes. GVW vehicle ratings cannot be directly observed or measured, and are therefore usually obtained through intercept surveys. Consequently, it is difficult to associate a vehicle of a certain GVW with a particular vehicle configuration, which means that it is also difficult to validate GVW classes against observed truck counts.

FHWA Vehicle Configuration: These classifications are primarily based on the physical appearance of a vehicle, especially the body type (e.g., automobile, single unit, combination tractor trailer, multiple trailers) and number of axles and/or tires. Using this scheme, the FHWA groups vehicles into thirteen categories, as shown in Figure 9-1. Classes 1 through 4 are passenger vehicles, including motorcycles, automobiles, and buses. Classes 5 through 13 are trucks, further subdivided by number of axles and number of units. Ground traffic count data are usually classified based on vehicle configuration, since vehicle configurations are easier to obtain than vehicle weights. Due to the importance of model validation against ground counts, vehicles were grouped by configuration rather than weight in the TRMv6. With respect to air quality modeling and analysis, the U.S. Environmental Protection Agency (EPA) provides guidance on the mapping of FHWA vehicle classes to MOBILE6 vehicle classes.[11]

Other regional models were reviewed as part of this model updating effort. It was found that most of them use the FHWA vehicle classification scheme, as shown in Table 9-1. Table 9-1 also shows a pattern where Classes 3 and below are usually grouped as light-duty commercial vehicles, Class 5 always as medium trucks, and Classes 8 and above as heavy trucks. Variations only existed in how Classes 6 and 7 were treated. Some regions treat them as medium trucks, while others treat them as heavy trucks. However, the differences in classification among the regions looked at are not huge and there are more similarities than differences.

The Triangle Regional Model Service Bureau (TRMSB) determined that the TRMv6 commercial vehicle model would use FHWA vehicle classes, grouped as follows:

- Light-duty commercial vehicles (Classes 2 and 3)
- Single-unit trucks (Classes 5 through 7)
- Multi-unit trucks (Classes 8 through 13)

[11] Emission Inventory Improvement Program (EIIP) document, *Use of Locality-Specific Transportation Data for the Development of Mobile Source Emission Inventories*, available at www.epa.gov/ttn/chief/eiip/techreport/volume04/. The Highway Performance Monitoring System (HPMS) vehicle types can be mapped to MOBILE5b vehicle types using Table 2-1 and the resulting MOBILE5 VMT mixes can be converted to MOBILE6 fractions using a methodology in Chapter 5 (Section 5.3.2) of the MOBILE6 User Guide.

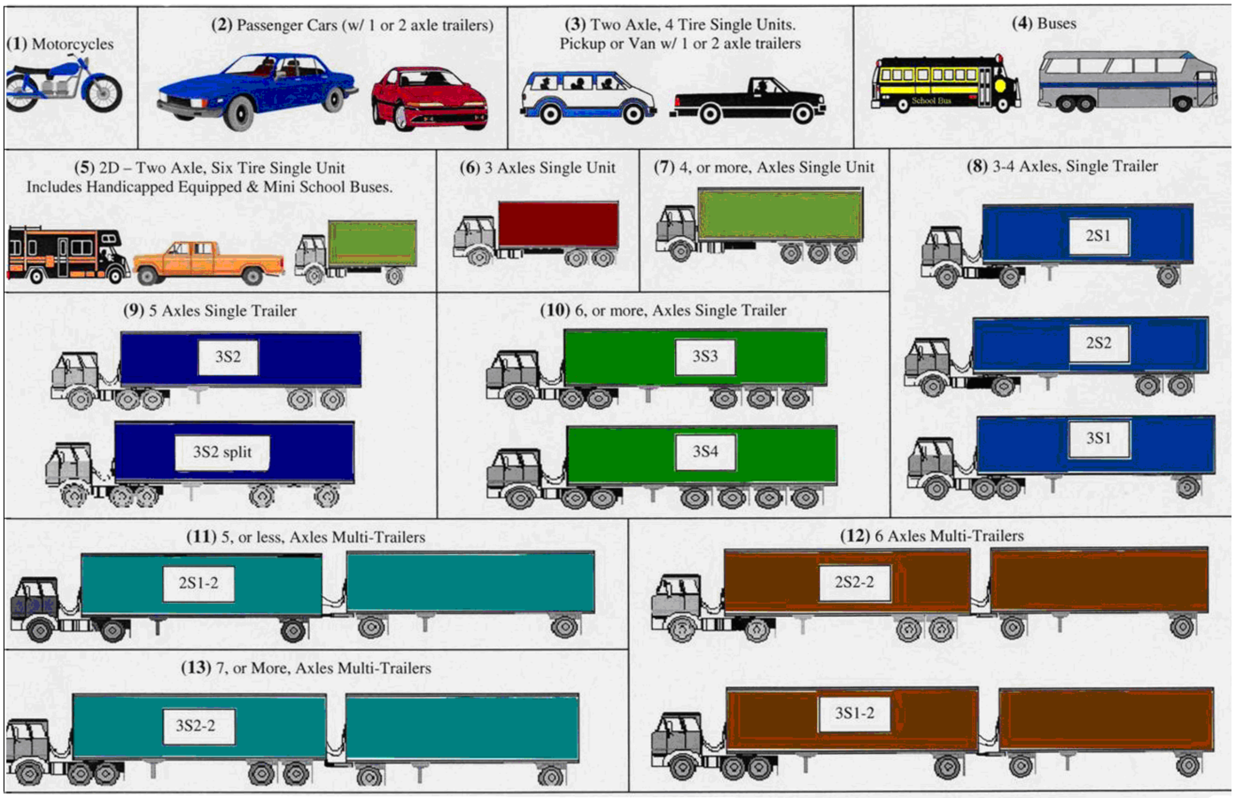


Figure 9-1 FHWA vehicle classifications

Table 9-1 Commercial vehicle grouping schemes used by other models (by FHWA class)

	Atlanta	Baltimore	Phoenix	Portland	Detroit	Philadelphia	Charlotte
Heavy trucks	F8 - F13	F6 – F13	F8 – F13	F6 – F13	F6 – F13	F6 – F13	F7 – F13, F4
Medium trucks	F4 - F7	F5	F5 – F7	F5	F5	F3, F5	F5 – F6
Light duty CVs	F2 - F3	F2 – F3	F-3 pickups	Not modeled	F2 – F3		F2 – F3

9.1.1.2 Survey Data Processing and Preparation for Model Development

A dataset for trip generation model estimation was prepared from the results of the 2010 commercial vehicle survey. Major data processing and preparation steps included:

1) Removing buses and trips made by buses from the survey data

In theory, person trips are captured in household travel surveys. Commercial vehicle travel models are mostly focused on modeling trips that deliver goods and/or services, for which reason buses and bus trips are usually not included in commercial vehicle models. In this regard, common industry practice was followed. Some statistics from the survey before and after removing buses are shown in Table 9-2.

Table 9-2 Survey statistics with buses included and excluded

Surveyed Item	Including Buses	Excluding Buses	Remark
# of Establishments	500	486	14 establishments made bus trips only
# of Vehicles	1,552	1,489	
# of Trips	4,877	4,557	

All statistics related to the commercial vehicle survey from here on refer to the set with buses removed, unless otherwise indicated.

2) Redefining trip purposes originally classified as “Other”

Trips were classified into three trip purposes in the original survey dataset: *Delivery of Goods*, *Delivery of Services*, and *Other*. The “Other” purpose (TPUR=7 in original survey data file) contained all trips that did not qualify as either delivery of goods or delivery of services. Out of 4,557 surveyed trips, 1,702 were classified as “Other,” accounting for 37.3% of the total, as shown in Table 9-3. A well-designed survey should minimize the number of observations in this category, as it is usually more difficult to analyze and model them, due to their high heterogeneity.

Table 9-3 Trip statistics by trip purpose from original survey dataset

Trip Purpose	# of Trips	Percentage
Delivery of Goods	1,411	31.0%
Delivery of Services	1,444	31.7%
Other	1,702	37.3%
Total	4,557	100%

Trips with a purpose of “Other” in the survey results were reclassified as having one of the following six purposes, which were then used in addition to the original Delivery of Goods and Delivery of Services purposes:

- Picking Up Goods
- Picking Up Supplies for Services
- Serving People
- Delivering/Retrieving Mail
- Return
- Other

In addition to redefining the purposes of trips that were originally designated as “Other,” the TRMSB also made corrections to several Delivery of Goods and Delivery of Services trips. The resultant new trip statistics are shown in Table 9-4.

Table 9-4 Trip statistics by refined trip purposes

Trip Purpose	# of Trips	Percentage
Delivery of Goods	1,416	31.1%
Delivery of Services	1,596	35.0%
Picking Up Goods	217	4.8%
Picking Up Supplies for Services	52	1.1%
Serving People	137	3.0%
Delivering/Retrieving Mail	75	1.6%
Return	789	17.3%
Other	275	6.0%
Total	4,557	100%

The trips whose purpose is still designated as "Other" include those made for short errands and/or personal business, such as going to restaurants for breakfast or lunch, banks for banking, gas stations for fueling, meetings, classes, and so on. This category also includes a few trips that did not well fit any of the other designated trip purposes, such as "bidding on a job," "vehicle maintenance," and "disposing of trash."

3) Classifying the first and last recorded trips made by each vehicle

Classifying the first and last recorded trips made by each vehicle is not directly related to trip-based model development. Instead, it is a way of better understanding the travel behavior of commercial vehicles. The first (i.e., starting) trip by each vehicle is classified into either of the following two categories, statistics on which are in Table 9-5:

- Start from the Establishment
- Start from Another Place

Table 9-5 Numbers of trips by starting place

Starting Place	# of Trips	Percentage
Start from the Establishment	757	87.7%
Start from Another Place	106	12.3%
Total	863	100%

To identify whether a vehicle's first trip started from the surveyed establishment it is associated with, the latitude and longitude of the starting place were compared with the establishment's coordinates, as recorded in the survey dataset. Only 338 trips from a vehicle's starting location out of a total of 863 (39.2%) were found to have starting-location coordinates that matched those of the surveyed establishment. This percentage was deemed unreasonably low, but there was not enough time to investigate the cause, and perhaps not enough additional data to find a solution, either. Therefore, it was then decided to also compare the name of each vehicle's starting place with the name of the establishment. An additional 419 start-from-the-establishment trips were identified in this manner, resulting in a final figure of 757 out of 863 (87.7%).

Classifying the last recorded trip by each vehicle was more complicated. Because the survey only recorded up to ten trips by each vehicle, the last recorded trip was not necessarily the last trip that the vehicle made on the survey day. Therefore, vehicles' recorded last trips are classified into "Last Trip of the Day" and "Not Last Trip of the Day" categories. Then, the "Last Trip of the Day" category was further divided into four sub-groups: "Return to the Establishment," "Return to the Starting Place," "Return to Another Place," and "With a Non-Return Purpose," as shown below. Some statistics on these categories are shown in Table 9-6.

- Last Trip of the Day
  - Return to the Establishment
  - Return to the Starting Place (not the Establishment Surveyed)
  - Return to Another Place (not the Establishment Surveyed or the Starting Place)
  - With a Non-Return Purpose (e.g., delivering goods or services)
- Not Last Trip of the Day

Table 9-6 Distribution of recorded last trips

Last Trip Type		# of Trips	Percentage
Last Trip of the Day	Return to the Establishment	578	67.0%
	Return to the Starting Place	59	6.8%
	Return to Another Place	32	3.7%
	With a Non-Return Purpose	64	7.4%
Not Last Trip of the Day		130	15.1%
Total		863	100%

As with vehicles' first trips of the survey day, coordinates and place names were used to determine whether or not vehicles' last trips ended at their associated establishments.

4) Incorporating return trips into principal trip purposes

Return trips were incorporated into the principal trip purposes – Delivering Goods, Delivering Services, Picking Up Goods, Picking Up Supplies for Services, Serving People, Delivering/Retrieving Mail, and Other – as shown in Table 9-4. This follows common practice in trip-based travel demand modeling. The rules utilized for this incorporation were:

- If a vehicle made a non-Other trip right before it made a return trip, that return trip is classified as having the same purpose as the non-Other trip that immediately preceded it.
- If a vehicle first made one or more non-Other trips and then one or more Other trips before returning, the return trip is classified with the same purpose as the last non-Other trip. This was done because most such Other trips are short errand/personal business trips and not the principal purpose of the tour.
- If a vehicle only made Other trips, the return trip is classified as an Other trip.

5) Forming three major trip purposes for the convenience of modeling

As output from Step 2, above, eight trip purposes were created to characterize trips in the survey dataset. However, having data that is divided into a large number of categories with a small number of observations per category could create reliability issues for trip models developed on the basis of that data. As shown in Table 9-4, four of the eight trip purposes include particularly few observations: picking up goods, picking up supplies for services, delivering or retrieving mail, and serving people. Trips with these purposes were therefore reassigned to one of the remaining purposes, based on the following rules:

- Trips for Picking Up Goods become Delivery of Goods trips
- Trips for Picking Up Supplies for Services become Delivery of Services trips
- Trips for Delivering/Retrieving Mail become Other trips
- Trips for Serving People are kept in the survey dataset but not used for model development

Numbers of trips by final trip purposes, following the operations in Steps 4 and 5, are summarized in Table 9-7. The division of these trips between the categories of internal-internal, internal-external, and external-external trips is shown in Table 9-8.

Table 9-7 Trip statistics by final trip purposes

Trip Purpose	# of Trips	Percentage	Used for Model Development?
Delivery of Goods	1,927	32.3%	Yes
Delivery of Services	2,041	44.7%	Yes
Serving People	167	3.7%	No
Other	422	9.3%	Yes
Total	4,557	100%	

Table 9-8 Trip statistics by trip end locations

Trip Purpose	I-I Trips	I-E Trips	E-E Trips	Total
Delivery of Goods	1,258	242	427	1,927
Delivery of Services	1,504	210	327	2,041
Serving People	142	13	12	167
Other	269	42	111	422
Total	3,173	507	877	4,557

6) Investigating and correcting unreasonable trip-making

Some of the surveyed vehicles reported very high numbers of trips on the survey day, with the highest being 108 trips in one day. Because these outliers could have a large impact on the expanded survey results, it was decided that vehicles that reported 26 or more trips on the survey day would be examined for correct reporting. The number 26 was chosen for this purpose mainly due to the amount of time available to address this issue. If a lower number were chosen, more vehicles would have needed to be examined, requiring additional time.

Detailed information about these vehicles' first ten trips recorded in the survey and trip-making data for other, similar vehicles associated with the same establishment, if recorded, were used to check the reasonableness of the data collected for the subject vehicle. In total, 17 vehicles were found to have made 26 or more trips apiece on the survey day. After careful examination of these vehicles, only the one that reported 108 trips was found to be problematic. Another vehicle from the same establishment that did exactly the same work and which had almost the same recorded travel pattern for its first 10 trips of the day, during the first 1.5 hours of the day, only reported 44 trips for the full survey day. Therefore, the number 44 was borrowed from this other vehicle and made to also be the daily trip total for the problematic vehicle that was originally recorded as making 108 trips.

7) Addressing unobserved trips

Unlike a household travel survey, where a complete sample usually means that all household members participated in the survey and all of the trips they made on the survey day were recorded, a commercial vehicle survey is unlikely to include all of the vehicles associated with a sampled establishment or record all of their trips if the establishment has too many vehicles or its vehicles make too many trips per day. Therefore, trip information had to be imputed at two levels in the 2010 Triangle Commercial Vehicle survey:

a. For surveyed vehicles that made more than ten trips on the survey day (i.e., trips reported, but no details recorded for those after the first ten)
b. For un-surveyed vehicles associated with a surveyed establishment (i.e., vehicles reported, but no trips recorded for them)

Addressing trips reported without details

If a vehicle made more than ten trips on the survey day, the eleventh and later trips were not recorded with detailed information, as the survey diary only allowed this for the first ten trips. However, these additional trips were still included in the total number of trips reported in the survey diary. It was assumed that the additional trips have the same distribution as the first ten trips in terms of trip purposes. The following procedure was followed to address these additional trips for the purpose of trip generation modeling:

i. Summarize the number of recorded internal-to-internal (I-I) trips for each surveyed vehicle (up to ten) by trip purpose (i.e. delivery of goods, delivery of services, other, and serve people).

ii. Summarize the number of recorded I-I trips for each surveyed vehicle across all trip purposes to determine total recorded I-I trips (up to ten).

iii. Summarize the number of recorded trips for each surveyed vehicle, including I-I, I-E, E-I, and E-E trips, but not differentiated by trip purpose, to determine total recorded trips (up to ten).

iv. Divide total recorded I-I trips by total recorded trips to get an I-I trip percentage for each vehicle, based on those trips for which there are individual trip records (up to ten).

v. Multiply total reported trips (may be more than ten) for each vehicle by its I-I trip percentage to estimate the vehicle's total I-I trips on the survey day.

vi. For each vehicle, allocate the total estimated I-I trips amongst different trip purposes to estimate I-I trips by the vehicle that were made for each trip purpose. The allocation formula for Delivery of Goods trips is as follows, and the formulas for the other trip purposes are of the same form:

Total I-I Delivery of Goods trips = total I-I trips * (recorded I-I Delivery of Goods trips (up to ten) / total recorded I-I trips for all purposes (up to ten))

Addressing vehicles that are reported but whose trips are not

If an establishment had more vehicles than just those surveyed, the extra vehicles were reported through the survey instrument but no trip information was collected for them. There was no information in the survey dataset indicating whether or not each un-surveyed vehicle was operated on the survey day. According to the consultant who conducted the survey, the sampling of vehicles within an establishment should be random, in theory. However, to improve the usually very low response rate, the coordinator on the establishment side was also instructed to give the survey instrument to those making trips on the survey day. That meant that, in the absence of additional data, it was difficult to know whether the assumption that un-surveyed vehicles associated with an establishment have the same operation characteristics as or similar operation characteristics to those surveyed is reasonable or not. Regardless, some assumption had to be made in order to expand the survey data to the universe of commercial vehicles in the model area, for which purpose a random-sampling assumption was chosen, with the understanding that adjustments would likely be needed in the model calibration and validation stages.

The following procedure was followed to account for un-surveyed vehicles at surveyed establishments during trip generation modeling:

i. Derive average trips per vehicle by trip purpose and vehicle type for each establishment. First, for each surveyed establishment, add up all surveyed vehicles' I-I trips, separated out by trip purpose/vehicle type combination. Then, divide those surveyed-vehicle I-I trips for each combination of trip purpose and vehicle type by the number of surveyed vehicles of the corresponding vehicle type associated with the same establishment. All surveyed vehicles associated with a given establishment are included, regardless of whether or not any given vehicle made any trips on the survey day. This operation produced average trips per vehicle by trip purpose and vehicle type for each establishment.

ii. Calculate total I-I trips by trip purpose and vehicle type for each establishment by multiplying average trips per vehicle by trip purpose and vehicle type by total reported vehicles of the corresponding vehicle type associated with the establishment, including un-surveyed vehicles. In cases where a given establishment had vehicles of a particular type within its fleet, but no vehicles of that type were among the ones surveyed for that establishment, trips made by that specific type of vehicle were assumed to be zero for the establishment in question. The rationale behind this assumption was that the survey consultant suggested to each establishment that they provide data on a representative sample of the different vehicle types in their fleet. If vehicles of a given type were not surveyed for a particular establishment, it is likely that none of their vehicles of that type made any trips on the survey date, even when using the more aggregated vehicle-type categories discussed above.

Deriving trip-representing factors

After total I-I trips by trip purpose and vehicle type were calculated for each surveyed establishment, it was necessary to calculate factors indicating how many overall I-I trips a recorded I-I trip may be taken to represent for each surveyed establishment. The following procedure was followed:

i. Add up surveyed vehicles' I-I trips by trip purpose/vehicle type combination for each establishment.

ii. Compute trip-representing factors that indicate how many overall I-I trips a recorded I-I trip may be taken to represent for each surveyed establishment. These factors are derived by dividing overall I-I trips by recorded I-I trips for each combination of trip purpose and vehicle type for each establishment. If an establishment's fleet includes vehicles of a certain type of vehicles, but no vehicles of that type were among the ones surveyed for that establishment, a factor of zero is assumed.

iii. Assign establishment-specific trip-representing factors to each of the recorded I-I trips, based on vehicle type and trip purpose. The sum of all such factors forms an estimate of the total number of I-I trips made by all vehicles reported to be associated with any of the 486 surveyed establishments. Then, multiplying this result by weighting and expansion factors produces an estimate of I-I trips by vehicles associated with all establishments in the region.

8) Separating out I-I trips made by internal establishments

48 out of the 486 establishments surveyed were outside of the TRMv5 model boundaries (the TRMv5 being the TRM version that was being prepared at the time of the 2010 Triangle Region Commercial Vehicle Travel Survey). Due to the high cost of collecting commercial vehicle data, and also because the 48 establishments that were outside of the model area were still close to its boundaries, the possibility was considered of keeping those 48 establishments in the dataset for model development. However, vehicles associated with these 48 establishments made significantly fewer I-I trips than those associated with the other 438 establishments, as shown in Table 9-9. Including the 48 external establishments would have shifted the average I-I trip rate downward by a non-negligible amount. Therefore, it was decided to remove these 48 establishments and only use the other 438 internal establishments for model development.

Table 9-9 I-I trips from survey

Establishment Type	I-I Trips from Survey*
All 486 establishments	3,173
438 internal establishments	3,141

* Serving People trips are included in this table.

Table 9-10 Trips by internal establishments

Trip Purpose	**I-I Trips**	**Percentage**
Delivery of Goods	1,254	39.9%
Delivery of Services	1,488	47.4%
Serving People	132	4.2%
Other	267	8.5%
Total	3,141	100%

9) Expanding survey data using internal establishments only

With the 48 external establishments removed, the survey data were expanded using the remaining 438 internal establishments. A four-way Fratar procedure was employed for the expansion, and the derived weighting and expansion factors were applied to align the surveyed establishments with the establishment universe within the TRM model region. The factors were also used to expand the surveyed trips to regional totals, which would be used in trip generation model development.

A four-way table was constructed from the survey data with the value in each cell representing the number of businesses fitting a given combination of values for four stratification variables: county, SIC-code group, employment-size group, and fleet-size group. This four-way table was then subjected to an iterative proportional fitting procedure (i.e., a Fratar procedure), so that by iteratively adjusting cell values, the table's marginal totals were matched to the distributions/subtotals of businesses in each of the categories/ranges defined for each of the four stratification variables.

A critical task in the survey weighting and expansion endeavor was deriving distributions of establishments that owned or operated commercial vehicles in the Triangle region. Specifically, control subtotals were needed for each of the strata (categories/ranges) of the four stratification variables.

Data Sources

Two major data sources were identified as being available for these control subtotals: GeoCoder data and DMV commercial-vehicle registration data. In addition, data from the 2010 commercial vehicle survey was able to be used to derive ratios and percentages that helped in the development of control subtotals.

<u>GeoCoder Data</u>

GeoCoder data are GIS-based point data covering all businesses in the Triangle region, with each point representing one business. The GeoCoder also provides attributes associated with each business, including its name, address, coordinates, SIC code, NAICS code, and number of employees. These data are derived from InfoUSA data, with corrections and improvements made by local planners, based on their knowledge of the region. Geocoder data provided detailed information on the stratification variables of county, SIC code, and employment size, but not number of commercial vehicles per establishment. In total, the GeoCoder dataset contains information on 63,956 businesses in a ten-county area in 2010, of which 59,122 were in the Triangle region. Some summary statistics are shown in Table 9-11.

Table 9-11 County businesses according to GeoCoder data

	Chatham	Durham	Franklin	Granville	Harnett	Johnston	Nash	Orange	Person	Wake	Total
Countywide	1,847	10,124	1,543	1,309	2,472	4,664	1,013	4,605	1,222	35,158	63,957
Inside Triangle	1,048	10,124	1,410	577	874	4,125	82	4,605	1,120	35,158	59,122
% Inside Triangle	56.7%	100.0%	91.4%	44.1%	35.4%	88.4%	8.1%	100.0%	91.7%	100.0%	92.4%

DMV Data

DMV commercial-vehicle registration data provide vehicle information associated with a business, if the business has one or more commercial vehicles registered with the DMV. Each record in the dataset is for one registered vehicle and contains information such as Vehicle Identification Number (VIN), business name, address, model year, make, body style, weight, and fuel type. When these records are summarized by business name and location, information about the number of businesses that have commercial vehicles and the number of commercial vehicles associated with each business may be obtained. DMV data cover all commercial vehicles that are registered in the region. Even though they were the best available data for vehicle information, DMV data still have limitations:

- Not all vehicles that are used for commercial purposes are registered as commercial vehicles. This is especially true of light-duty commercial vehicles owned by small businesses, including automobiles, pickup trucks, vans, and SUVs.
- Commercial vehicle registration locations do not necessarily match areas of use. This issue easily arises when a company has multiple locations. Commercial-vehicle renting and leasing may also cause such mismatches. Furthermore, in a large metropolitan area, commercial vehicles that are registered in counties outside the area may be brought into the area for commercial uses, due to the concentration of business opportunities in the metropolitan area.
- Not all users of commercial vehicles are listed in the DMV database. It has been reported that there are many commercial vehicles, especially trucks, that are leased or rented by companies that do not own them. Therefore, a significant number of commercial-vehicle-users are not listed, meaning that the DMV database does not provide a good sampling source or commercial-vehicle-having-establishment population for survey expansion.
- The registration data do not tell if a registered commercial vehicle is garaged at the business’s location or at a residential location.
- The registration database may have a significant number of records for vehicles that are no longer operating in the area.
- Vehicle records are often not keyed in correctly. Use of such records may require substantial data mining to process the raw data and extract information that is truly useful for survey expansion.

With these considerations in mind, it was decided that, when used jointly with GeoCoder data, DMV data would likely be able to provide control subtotals for each stratification variable that are sufficiently accurate. In total, the DMV dataset contained 45,334 records for non-bus commercial vehicle registered in the ten-county area, under the names of 13,309 establishments, an average of 3.406 vehicles per establishment. Geocoding of these establishments was not attempted, because poor-quality data would have greatly increased the amount of time required. Instead, the number of business establishments with commercial vehicles in the Triangle region was estimated by factoring the number in each of the ten counties that are entirely or partially in the region by the percent of each county’s businesses that are in the Triangle region, as calculated from GeoCoder data. This methodology led to an estimated total of 11,315 business establishments in the Triangle region that had commercial vehicles. The same methodology was also used to estimate the number of commercial vehicles associated with those establishments in the Triangle region. These estimation processes are illustrated in Table 9-12 and Table 9-13.

Table 9-12 Businesses with registered CVs by county

	Chatham	Durham	Franklin	Granville	Harnett	Johnston	Nash	Orange	Person	Wake	Total
% Inside Triangle (from GeoCoder)	56.7%	100.0%	91.4%	44.1%	35.4%	88.4%	8.1%	100.0%	91.7%	100.0%	
Countywide	523	1,356	508	367	867	1,574	816	620	318	6,360	13,309
Inside Triangle = Countywide * %In	297	1,356	464	162	307	1,392	66	620	291	6,360	11,315

Table 9-13 Registered CVs by county

	Chatham	Durham	Franklin	Granville	Harnett	Johnston	Nash	Orange	Person	Wake	Total
% Inside (from GeoCoder)	56.7%	100.0%	91.4%	44.1%	35.4%	88.4%	8.1%	100.0%	91.7%	100.0%	
Countywide	1,220	4,754	1,266	900	2,027	3,994	2,857	1,353	1,278	25,685	45,334
Inside Triangle = Countywide * %In	692	4,754	1,157	397	717	3,532	231	1,353	1,171	25,685	39,689

With GeoCoder data on total numbers of businesses and DMV data on businesses with commercial vehicles, the percent of businesses that had commercial vehicles was able to be calculated, both for whole counties and for the portions of them that are in the Triangle region, as shown in Table 9-14 and Table 9-15.

Table 9-14 Percent of businesses that had commercial vehicles: whole counties

	Chatham	Durham	Franklin	Granville	Harnett	Johnston	Nash	Orange	Person	Wake	Total
All Businesses	1,847	10,124	1,543	1,309	2,472	4,664	1,013	4,605	1,222	35,158	63,957
Businesses w/ CVs	523	1,356	508	367	867	1,574	816	620	318	6,360	13,309
%Businesses w/ CVs	28.3%	13.4%	32.9%	28.0%	35.1%	33.7%	80.6%	13.5%	26.0%	18.1%	20.8%

Table 9-15 Percent of businesses that had commercial vehicles: Triangle region

	Chatham	Durham	Franklin	Granville	Harnett	Johnston	Nash	Orange	Person	Wake	Total
All Businesses	1,048	10,123	1,410	577	874	4,125	82	4,605	1,120	35,158	59,122
Businesses w/ CVs	297	1,356	464	162	307	1,392	66	620	291	6,360	11,315
%Businesses w/ CVs	28.3%	13.4%	32.9%	28.0%	35.1%	33.7%	80.6%	13.5%	26.0%	18.1%	19.1%

Adjusting DMV Data Using Commercial Vehicle Survey Data

The commercial-vehicle-survey contractor, NuStats, indicated that they typically do not deliver raw, partial data, such as that from the recruitment stage of a survey, because it is not as accurate as the final data. However, for the purpose of adjusting DMV data, the TRMSB decided that recruitment-stage data from the commercial vehicle survey would likely provide reasonably accurate results at the regional level, if they are not greatly disaggregated, considering that, in a large dataset, the presence both of errors where values are too high and of errors where values are too low may produce averages that are close to the truth.

In the recruitment-stage data from the 2010 commercial vehicle survey, 6,742 establishments clearly answered “yes” or “no” to the question of whether they operated commercial vehicles, as shown in Table 9-16. Of those 6,742 establishments, 1,771 had commercial vehicles garaged at non-residence locations, including buses. Of the latter, 983 completed the recruitment survey, of which 23 establishments had buses only and the remaining 960 had at least one non-bus commercial vehicle. Because these establishments were from two different sampling frames, sampling weights were used to derive unbiased parameter estimates with which to adjust data from the DMV. The weighted counterparts of these counts of establishments in the commercial vehicle survey are shown in Table 9-16. The percent of establishments that had non-bus commercial vehicles garaged at non-residence locations was calculated as:

$$\frac{1{,}560}{1{,}606} \times \frac{2{,}862}{12{,}482} = 22.27\%$$

Multiplying this percentage by the total number of establishments in the region according to the GeoCoder (59,122) resulted in an estimate of 13,168 establishments in the region that had non-bus commercial vehicles garaged at non-residence locations. That is 16.4% greater than the 11,315 businesses with commercial vehicles that were estimated to be in the Triangle region using DMV data. Therefore, a factor of 1.164 was applied to the DMV business data to convert “businesses with registered non-bus commercial vehicles” to “businesses operating non-residence-location-garaged non-bus commercial vehicles” in the control subtotals.

Table 9-16 Statistics from recruitment survey data

No.	Statistic Description	Unweighted	Weighted
(1)	# of establishments that clearly answered “yes” or “no” to the question of whether they operated commercial vehicles	6,742	12,482
(2)	# of establishments that had commercial vehicles (including buses) garaged at non-residence locations	1,771	2,862
(3)	# of establishments that had commercial vehicles garaged at non-residence locations AND completed recruitment survey	983	1,606
(4)	# of establishments that had non-bus commercial vehicles garaged at non-residence locations AND completed recruitment survey	960	1,560

Joint Use of Data to Derive Establishment Distributions and Base Four-Way Table for Survey Data Expansion

The adopted data-expansion approach utilized business distributions by county from DMV data and distributions by SIC code, employment-size group, and fleet size from recruitment-survey data.

As discussed above, the number of businesses in the region operating non-residence-location-garaged commercial vehicles estimated from recruitment-survey data was 16.4% greater than the number of registered commercial vehicles. Therefore, control subtotals of establishments by county derived from DMV data were factored by 1.164. Sampling weights were used in developing a base four-way table for the Fratar process. The steps in this approach were as follows:

i. Estimate the total number of businesses in the region operating commercial vehicles, based on recruitment-survey data.
ii. Obtain from recruitment-survey data the total number of businesses recruited, as well as numbers of businesses by SIC-code group, employment-size group, and fleet size.
iii. For each stratification variable, divide the number of recruitment-survey businesses in each designated group/range of values by the total number of businesses recruited to get percentages for each group/range. Then, multiply each percentage by the total number of businesses operating commercial vehicles in the region to get a control subtotal for each group/range of values for each stratification variable. These control subtotals are used for survey data expansion.
iv. Obtain from DMV data the total number of businesses that have at least one registered commercial vehicle in the region, as well as numbers of businesses by county. Apply the factor 1.164 (as calculated above) to the numbers of businesses by county to get expansion control subtotals by county.
v. Construct a base four-way table from the survey data, with cells for combinations of county, number of employees, SIC code, and vehicle fleet size. Each establishment from the survey is classified into a cell in the four-way table, based on its attributes.
vi. Use a four-way Fratar procedure to iteratively adjust the number of establishments in each cell of the base four-way table to match marginal totals of the table to the control subtotals of the four stratification variables. The result is individual factors for each internal establishment in the commercial vehicle survey by which their trips by vehicle type and trip purpose are multiplied (in addition to being multiplied by trip-representing factors) to expand the survey data to the model universe.

In the adopted grouping scheme for the four stratification variables, counties with small numbers of survey records were grouped, resulting in six subtotals of establishments based on counties. Two-digit SIC codes were aggregated into four groups, numbers of employees were aggregated into four ranges, and vehicle fleet sizes were aggregated into five ranges, as shown in Table 9-17.

Table 9-17 Business distributions by stratification variables in sample and universe

County Group	County Name(s)	# of Businesses in Sample	# of Businesses in Universe
1	Chatham & Harnett	15	515
2	Franklin, Granville, Nash, and Person	39	1,145
3	Durham	62	1,490
4	Johnston	39	1,507
5	Orange	27	690
6	Wake	256	7,822

Total		438	13,168*

*This total is accurate. However, because the numbers above it in this column are rounded to the nearest whole number, they appear to not equal the total.

SIC Group	2-Digit SIC Code	# of Businesses in Sample	of Businesses in Universe(
1	15 – 17	65	1,879
2	20 - 51	99	2,583
3	52 - 67	98	2,954
4	70 - 99	176	5,752
Total		438	13,168

Employment Group	Employment Size Range	# of Businesses in Sample	of Businesses in Universe(
1	1 - 4	129	4,078
2	5 - 9	102	3,151
3	10 - 19	83	2,383
4	20+	124	3,556
Total		438	13,168

Vehicle Group	Fleet Size Range	# of Businesses in Sample	of Businesses in Universe(
1	1	152	4,154
2	2	85	2,833
3	3 - 5	118	3,312
4	6 - 10	45	1,669
5	11+	38	1,200
Total		438	13,168

Summary statistics on the derived weighting and expansion factors are shown in Table 9-18.

Table 9-18 Commercial vehicle survey weighting and expansion factor statistics

Statistic	Factor Value	Remark
Minimum	6.95	
Maximum	69.66	
Mean	30.06	
Median	28.95	
Sum	13,168	Indicates the total number of establishments in the region operating commercial vehicles.

9.1.1.3 Defining New Districts and Deriving District Trip-End Totals

It was decided to use multiple linear regression on district-level data to obtain equations for estimating commercial-vehicle trip ends by vehicle type and trip purpose, as functions of TAZ-level socioeconomic data. A district is an aggregation of several TAZs, and their use is necessary because of the sparseness of observations in the survey data when allocated to TAZs.

A set of districts was defined during development of the TRMv5 person-trip model in 2010. There were 40 districts, into which TAZs were grouped with consideration mainly given to geographical continuity and land use characteristics. These TRMv5 districts were examined for usefulness for developing a commercial vehicle model for the TRMv6. TAZ socioeconomic data, specifically household and employment data, were aggregated to the districts, at which scale they were used as explanatory/independent variables in a regression model. Correlation analysis was conducted for pairs of independent variables, and high correlation was found between most of the variables, as shown in Table 9-19.

Table 9-19 Correlation between independent variables using TRMv5 districts*

	Industrial	Retail	Office	Service	Household
Industrial	1.000	0.872	0.875	0.660	0.808
Retail	-	1.000	0.776	0.786	0.937
Office	-	-	1.000	0.697	0.628
Service	-	-	-	1.000	0.704
Household	-	-	-	-	1.000

* Correlation coefficients in this table were calculated using a version of 2010 socioeconomic data that was made available in March 2013 for the TRMv6.

These high correlation coefficients indicate that the independent variables are not statistically independent from one another and multicollinearity could exist in a model that is estimated using those variables. With multicollinearity, the estimated contribution (i.e., the regression coefficient) of individual explanatory variables to the predictive power of the model may not be valid, and, worse, the sign and/or magnitude of regression coefficients may not make intuitive sense. Also, statistically insignificant coefficients could be estimated for important explanatory variables. Trials were conducted of using the TRMv5 districts to estimate commercial-vehicle trip generation models for the TRMv6, and all of the issues discussed here were encountered. Therefore, a new set of districts was created for the TRMv6 to reduce correlation between independent variables.

9.1.1.3.1 Forming New Districts

A new approach was adopted to form new districts for the TRMv6. To minimize correlation between independent variables, independent variables, themselves, were used as evaluation criteria for grouping TAZs into districts. The goal was to make data as homogeneous as possible within each district and as heterogeneous as possible between districts. Unlike the TRMv5 procedure, where geographical continuity was a major concern, the TRMv6 approach groups TAZs by their socioeconomic characteristics.

Specifically, the TRMv6 approach utilizes a two-hierarchy methodology, where the first hierarchy considers zonal population and employment and the second hierarchy considers different types of employment. The first hierarchy determines which of the following five categories a TAZ falls into:

- Population dominating
- Population leading

▪Balanced
▪Employment leading
▪Employment dominating

The specific methodology utilized was as follows:

i. Normalize the total number of employees in the region to the regional population. According to the 2010 socioeconomic data, the region had a population of 1,640,106 people (including on-campus students) and a total of 842,265 employees (including special-generator employment categories). The population was about 1.95 times the employment. The normalization process multiplies employment by 1.95, in order to make one employee have the same weight as one person.

ii. Employ the following conditions to create five categories:
   - If percent population ≥ 90%, the TAZ is *population dominating*.
   - If percent population > 60% and < 90%, the TAZ is *population leading*.
   - If percent population ≥ 40% and ≤ 60%, the TAZ is *balanced*.
   - If percent population > 20% and < 40%, the TAZ is *employment leading*.
   - If percent population ≤ 20%, the TAZ is *employment dominating*.

For example, according to the 2010 socioeconomic data, TAZ 40 has a population of 421 (including on-campus students, if any) and total employment of 84. Multiplying that employment by 1.95 gives a normalized employment of 164, and the sum of the population and normalized employment is 585. Therefore, the population of the TAZ accounts for about 72% of that sum, meaning that TAZ 40 is a population-leading zone.

Table 9-20 Socioeconomic data of TAZ 40

TAZ#	Industrial	Retail	Office	Service	Population
40	26	26	30	2	421

The second hierarchy compares the percentages of a TAZ's employment that fit different categories, either industrial, retail, office, or service. A TAZ is labeled according to the employment categories that constitute the first and second largest percentages of its overall employment, along with the percentages of overall TAZ employment that each of those two employment categories account for. Instead of TAZs being labeled with the exact percentages of their employment that fit specific categories, those percentages are generalized into brackets representing particular ranges of values, as shown in Table 9-21.

Table 9-21 Employment percentage brackets and ranges

Bracket Name	Percentage Range (%)
100	100 (only one employment type exists)
80	[80, 100)
50	[50, 80)
30	[30, 50)
20	[20, 30)

10	[10, 20)
05	[5, 10)
00	[0, 5)

Using TAZ 40 as an example again, of the total employment, industrial employment accounts for 31%, retail for 31%, office for 35.7%, and service for 2.3%. Office accounts for the highest percentage and industrial and retail tie for the second highest percentage. Arbitrarily picking retail, this TAZ may be labeled "O30-R30" (office in the 30-50% range and retail in the 30-50% range). When combined with its label from the first hierarchy ("population leading"), TAZ 40 has a complete label of "POP Leads-O30-R30."

After all TAZs were labeled, new districts were created from them. The general rule was to combine all TAZs that have the same label. However, additional refinements were also needed. The following considerations were made:

- With 3,141 observed trips in the survey, a reasonable number of districts to create was considered to be between 100 and 150.
- Each district should have at least one observed I-I trip end. A minimum of 3-4 trip ends was preferred.
- It is better for each district to contain multiple TAZs.
- Districts should be further refined when the model is stratified by vehicle type and trip purpose, given that individual vehicle type/trip purpose strata within a district are more likely than the overall district to have zero trips. Zero-trip districts should be merged with the closest district(s), according to their socioeconomic characteristics (i.e., according to the labels discussed above).

The final numbers of districts formed for estimating trip generation models for different combinations of vehicle types and trip purposes are shown in Table 9-22.

Table 9-22 Numbers of districts used for estimating different trip generation models

Vehicle-Purpose Category		# of Districts
All vehicle types	All Purposes	131
Light-Duty CVs	All Purposes	130
	Delivery of Goods	116
	Delivery of Services	130
	Other	98
Single-Unit Trucks	All Purposes	130
	Delivery of Goods	122
	Delivery of Services	122
Multi-Unit Trucks	Delivery of Goods	82

9.1.1.3.2 Checking Correlation between Independent Variables

TAZ socioeconomic data was aggregated to the new TRMv6 districts and correlation analysis was conducted for the independent variables. Significantly lower correlation was achieved than when using the TRMv5 districts, as shown in Table 9-19 and Table 9-23.

Table 9-23 Correlation between independent variables using TRMv6 districts*

	Industrial	Retail	Office	Service	Household
Industrial	1.000	-0.074	-0.146	-0.183	-0.355
Retail	-	1.000	-0.086	0.256	0.515
Office	-	-	1.000	0.130	-0.163
Service	-	-	-	1.000	0.544
Household	-	-	-	-	1.000

* Correlation coefficients in this table were calculated using a version of 2010 socioeconomic data that was made available in March 2013 for the TRMv6.

9.1.1.3.3 Deriving District Trip End Totals

Because the truck-trip models are not commodity-based, they are not defined in terms of productions and attractions (or consumptions). Instead, they use origins and destinations. Truck-trip origins and destinations from the survey were therefore summed to create the dependent variable for linear regression. Summing up both origins and destinations into a single number has the benefit of increasing the sample size, recognizing that, on a daily basis, the numbers of origins and destinations for any given TAZ or district will be equal. The results of the trip generation models represent daily truck trip ends, with half of all trip ends representing origins and the other half representing destinations.

Each trip in the survey dataset has a trip-representing factor and an expansion factor, as described above. Expanded trips are a result of multiplying by the product of these two factors. Origin ends and destination ends are assigned to districts determined on the basis of the socioeconomic characteristics of the TAZs where the trip ends are located. After all of the expanded trips were processed, the number of origins and the number of destinations in each district were not equal for every district, due to varying weighting and expansion factors. Adding these two numbers together gives a more reasonable value to be used for a dependent variable. Trips with the purpose of “Serve People” are not included in the district dataset for model estimation, because they are redundant with person trips, which are usually captured in household travel survey data and are represented in the person-trip model.

To obtain district trips by vehicle type and trip purpose, the above procedure was repeated with further stratifications by vehicle type/trip purpose combination.

Expanded regional trips by vehicle type and trip purpose are shown in Table 9-24 through Table 9-26.

Table 9-24 Expanded regional trips by vehicle type

Veh. Type	Light-duty CVs	Single-Unit Trucks	Multi-Unit Trucks	Total
Trips	240,123	148,844	43,686	432,653
Percentage	55.5%	34.4%	10.1%	100%

Table 9-25 Expanded regional trips by trip purpose

Purpose	Goods	Services	Other	Total
Trips	170,836	162,410	99,407	432,653
Trip Percentage	39.5%	37.5%	23%	100%

Table 9-26 Expanded regional trips by vehicle type and trip purpose

Veh. Type	Light-duty CVs			Single-Unit Trucks			Multi-Unit Trucks		
Purpose	Goods	Services	Other	Goods	Services	Other	Goods	Services	Other
Trips	80,674	63,516	95,933	47,438	98,071	3,336	42,725	823	139

The percentages of trips that are for the Services and Other purposes are not the same in Table 9-25 as in Table 9-10. This is because the results in Table 9-10 are from a step prior to the final use of weighting and expansion factors, instead only incorporating trip-representing factors, which only expand data from the sampled vehicles associated with a particular establishment to the sampled establishment as a whole, as opposed to expanding from the sampled establishments to all establishments in the model region.

9.1.1.4 Model Estimation and Results

This section discusses the estimation of commercial vehicle trip generation models for trips that begin and end within the Triangle region. As discussed earlier, trips were modeled in the form of origins and destinations. Multiple linear regression was performed on district-level data to obtain equations for estimating commercial-vehicle trip ends by vehicle type and trip purpose as functions of socioeconomic data. Linear regression was selected, due both to its tractability and to its successful usage in truck-trip generation modeling efforts in other regions.

Although the models were developed using district-level data, they must be applied at the TAZ level in the model application process. Therefore, the district-level regressions of trip totals were estimated with the constant term always set to zero. Setting all constants to zero guarantees that trip generation is zero when there are no employees in the zone, which is reasonable.

Again, due to use of the sum of origins and destinations in model estimation, the results of the trip generation models represent both origin ends and destination ends, with half of the trip ends representing origins and half representing destinations.

Model estimation started with all four employment types being entered into the model as separate independent variables. Because these four employment types are not highly correlated, their contribution to the model can be validly identified via their regression coefficients. The guidelines followed to select independent variables were:

- Keep all of the four employment types in the model, if at all possible;
- Keep the four employment types as separate independent variables, if at all possible;
- Keep each employment type in the model, as long as its t-statistic is greater than or equal to 1.0 (for some cases, variables with a t-statistic close to 1 are also retained).

Model estimation results are summarized in Table 9-27 through Table 9-34. They represent the best results that were able to be achieved, given the size of the sample and the limited availability of independent variables. For reasonableness checking, trip rates from the Quick Response Freight Manual are also shown in Table 9-27, Table 9-31, and Table 9-34. To compare the estimated coefficients with the QRFM rates, the coefficients must be halved before comparison, due to the use of sums of origins and destinations in model estimation. With the coefficients halved, it may be seen that the coefficients are about 1/6 to 2 times the QRFM rates. This range was deemed to be reasonable, based on experience.

Overall, the coefficient of determination (R-squared), which measures the goodness of fit of the models, ranged from 0.15 to 0.48. Compared to passenger trip regression models, these R-squared values are low. However, considering the complexity and heterogeneity of commercial-vehicle travel patterns and the sample size and quality of the survey, these R-squared values were deemed to be acceptable. For comparison, the Southeast Michigan Council of Governments (SEMCOG, the MPO of the Detroit area) reported that the truck travel model they developed in 2002 achieved R-squared values of 0.39, 0.25, and 0.28 for light, medium, and heavy truck models, respectively. The R-squared values achieved by the TRMv6 commercial vehicle trip generation models are in a comparable range.

As shown in Table 9-27, Table 9-31, and Table 9-34, households generate more light-duty-CV trips than single-unit-truck trips, and many more light- and medium-duty-CV trips than multi-unit-truck trips. This is an expected result. In general, industrial employment generates more commercial vehicle trips than other types of employment, with the exception for single-unit trucks delivering goods.

For light-duty commercial vehicle (LCV) trips delivering services, two models were considered, as shown in Table 9-29. Model # 3-1 includes retail employment as a separate predictor, while Model # 3-2, the one that was ultimately adopted, merges retail with office and service employment. As can be seen from Model # 3-1, a retail employee generates more than twice as many trips as an office or service employee; combining retail employment with office and service employment as one variable obscures this difference and therefore appears to be a not-so-good choice. However, the combined variable (Model # 3-2) results in a higher t-statistic than those which would be associated with separate variables (Model #3-1).

As shown in Table 9-33, only industrial and office employment were found to be significant in explaining trip-making by single-unit trucks (SUTs) delivering services. The other two types of employment – retail and service – are not significant, with service employment even having a negative coefficient. Combining different types of employment into one variable did not generate satisfactory results. Therefore, the final model only includes industrial and office employment as predictors.

Table 9-27 Light-duty commercial vehicle all-purpose trip model

Model #	Explanatory Variable	Coefficient*	t Statistic	p-Value	Adjusted R^2	QRFM
#1	Industrial	0.8116	3.505	0.001	0.391	0.938
	Retail	0.1361	2.756	0.007		0.888
	Office					0.437
	Service					
	Households	0.3341	5.890	0.000		0.251

* To compare with the QRFM rates, the coefficients need to be halved first.

Table 9-28 Light-duty commercial vehicle Delivery of Goods trip model

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#2	Industrial	0.2146	1.593	0.114	0.193
	Retail	0.0308	1.107	0.271	
	Office				
	Service				
	Households	0.1350	4.185	0.000	

Table 9-29 Light-duty commercial vehicle Delivery of Services trip model

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#3-1	Industrial	0.1977	3.097	0.002	0.416
	Retail	0.0340	0.902	0.369	
	Office	0.0149	0.949	0.344	
	Service				
	Households	0.1193	7.632	0.000	

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#3-2 (adopted)	Industrial	0.1991	3.133	0.002	0.420
	Retail	0.0183	1.353	0.178	
	Office				
	Service				
	Households	0.1195	7.676	0.000	

Table 9-30 Light-duty commercial vehicle Other trip model

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#4	Industrial	0.3827	2.299	0.024	0.153
	Retail	0.0538	1.571	0.120	
	Office				
	Service				
	Households	0.0769	1.864	0.065	

Table 9-31 Single-unit truck all-purpose trip model

Model #	Explanatory Variable	Coefficient*	t Statistic	p-Value	Adjusted R^2	QRFM
#5	Industrial	0.9156	5.699	0.000	0.40	0.242
	Retail	0.1615	1.703	0.091		0.253
	Office	0.0686	1.739	0.085		0.068
	Service					0.068
	Households	0.1580	4.022	0.000		0.099

* To compare with the QRFM rates, the coefficients need to be halved first.

Table 9-32 Single-unit truck Delivery of Goods trip model

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#6	Industrial	0.0764	1.433	0.154	0.341
	Retail	0.0964	2.980	0.004	
	Office	0.0401	2.994	0.003	
	Service				
	Households	0.0552	4.143	0.000	

Table 9-33 Single-unit truck Delivery of Services trip model

Model #	Explanatory Variable	Coefficient	t Statistic	p-Value	Adjusted R^2
#7	Industrial	1.0885	7.942	0.000	0.419
	Office	0.0569	1.102	0.273	
	Households	0.0974	2.662	0.009	

Table 9-34 Multi-unit truck Delivery of Goods* trip model

Model #	Explanatory Variable	Coefficient**	t Statistic	p-Value	Adjusted R^2	QRFM
#8	Industrial	0.2648	5.590	0.000	0.479	0.104
	Retail	0.0401	1.292	0.200		0.065
	Office	0.0307	2.701	0.008		0.009
	Service					0.009
	Households	0.0122	1.475	0.144		0.038

* Delivery of Goods trips accounts for 96.5% of multi-unit truck trips.
** To compare with the QRFM rates, the coefficients need to be halved first.

9.1.1.5 Model Calibration

The initial calibration of the commercial vehicle trip generation model consisted of trying to align numbers of regional trips estimated by the model with expanded numbers of trips from the commercial vehicle survey by adjusting model coefficients and/or applying factors. This is different from a full model calibration process, which usually checks model estimates against traffic counts and against vehicle miles traveled (VMT) figures reported by reliable external sources. A full model calibration would be conducted after trip distribution and assignment, on which occasion no more model adjustments were made, beyond those in the initial calibration.

By applying the estimated commercial vehicle trip generation model to the TRMv6 regional socioeconomic dataset, the numbers of trips by vehicle type and trip purpose shown in Table 9-35 were arrived at. Along with the model estimates, this table also shows the numbers of trips expanded from the 2010 commercial vehicle survey.

Table 9-35 Survey expanded and model estimated commercial vehicle trips for the region

Vehicle Type	LCV			SUT		MUT
Trip Purpose	Goods	Services	Other	Goods	Services	Goods

Trips Expanded from Survey	80,674	63,516	95,933	47,438	98,071	42,725
Trips Estimated by Model	68,547	58,325	70,014	41,344	115,045	33,924
Percent Difference	-15.0%	-8.2%	-27.0%	-12.8%	17.3%	-20.6%
Multiplication Factor	1.177	1.089	1.370	1.147	0.852	1.259

Table 9-35 shows that the numbers of model-estimated trips deviated from those of the survey-expanded trips by between negative 27% and positive 17%, approximately. To align the model-estimated numbers with the survey numbers, factors were used, ranging from 0.852 to 1.37, as shown in Table 9-35.

9.1.2 Survey Trip Imputation and Time-Of-Day Analysis

This section documents the trip imputation process and time-of-day analysis conducted on the results of the 2010 Triangle Region Commercial Vehicle Travel Survey. Similar to the role of time-of-day factors in passenger trip models, commercial-vehicle time-of-day factors are mainly used to split generated trips, which are usually modeled on a daily basis, into several mutually exclusive time periods of the day, for better capturing and modeling of trip-making characteristics. Those time periods conventionally include the morning peak period, midday, the evening peak period, and nighttime, but could vary among different models. The TRMSB decided that the TRMv6 would represent four time periods, expanded from the three time periods used in the TRMv5 by splitting the Off-Peak time period into midday and nighttime. The definitions of the four time periods of the day in the TRMv6 are as follows: AM peak period is 6:00-10:00; Midday is 10:00-15:30; PM peak period is 15:30-19:30; and Night is 19:30-6:00 on the next day.

The calculation of commercial-vehicle-trip time-of-day factors is simpler than that of person-trip time-of-day factors. Person trips are usually modeled in a production-attraction form in earlier steps and then converted to an origin-destination form for route assignment. To get correct person trips in an origin-destination form, directions of travel have to be taken into account when computing time-of-day factors. In contrast, commercial vehicle trips are usually modeled directly in an origin-destination form, in which the directions of trips are already accounted for. In addition, because commercial vehicle trips are modeled directly in the form of vehicle trips, only vehicle-based time-of-day factors are needed; there is no need for person-based time-of-day factors, as there would be in a person trip model.

9.1.2.1 Impact of Survey Data Weighting and Expansion

The time-of-day analysis documented here is based on weighted and expanded survey data. Theoretically, weighted/expanded survey data, by design, should statistically represent the population from which the survey sample is drawn. However, due to practical limitations, survey data could be biased. While it is very often not realistic to eliminate such bias, it has to be kept in mind when working with the data. Specifically, with respect to the 2010 Triangle Region Commercial Vehicle Travel Survey, the survey data expansion process involved making assumptions due to lack of data, the impact of which is discussed in detail below.

Unlike a household travel survey, where a complete sample is usually defined as one where all household members participated in the survey and all of their trips on the survey day were recorded, a commercial vehicle survey is unlikely to have records for all of the commercial vehicles associated with a surveyed establishment or have all trips recorded, if the establishment has a large number of vehicles or a vehicle makes a large number of trips in one day, as was often the case with the 2010 commercial vehicle survey. In that survey, 81 out of 438 establishments (18.5%) did not have all of their commercial vehicles surveyed and 124 out of 1,331 vehicles (9.3%) did not have all of their trips recorded, as shown in Table 9-36. Even though these percentages are not particularly large, they make a significant difference:

1) The 81 establishments not all of whose vehicles were surveyed had 1,193 unsurveyed vehicles between them, which gives those establishments a much higher commercial-vehicle ownership rate than the region-wide average of 5.76 per establishment (2,524 vehicles divided by 438 establishments).
2) The 124 vehicles not all of whose trips were recorded made 980 unrecorded trips between them, which gives those vehicles a much higher trip rate than the region-wide average of 2.01 trips per commercial vehicle per day (5,071 trips per survey day divided by 2,524 vehicles).

Table 9-36 Statistics of commercial vehicle travel survey*

Item #	Item	Statistics	Notes
1	Total establishments surveyed	438	
2	Surveyed establishments with unsurveyed CVs	81	
3	Total commercial vehicles garaged at non-residence locations and operated by the surveyed establishments	2,524	
4	Surveyed CVs	1,331	
5	Unsurveyed CVs	1,193	Item #3 – Item #4
6	Surveyed CVs with all of their trips recorded	1,207	Item #4 – Item #7
7	Surveyed CVs with one or more trips unrecorded	124	
8	Total trips made	5,071**	
9	Trips recorded	4,091**	
10	Trips reported but not recorded in detail	980**	Item #8 – Item #9

* Only internal establishments (of which there are 438) and vehicles associated with them are included in the statistics in this table.
** All I-I, I-E/E-I, and E-E trips made by vehicles associated with internal establishments are included.

Assumptions had to be made to impute trip information for the 980 counted-but-unrecorded trips and 1,193 counted-but-unsurveyed vehicles. The first assumption was that unrecorded trips by a given vehicle have the same distribution as recorded trips made by the same vehicle in terms of trip purposes, travel times, stop times at destinations, and whether they are I-I, I-E, or E-E trips. The second assumption was that unsurveyed vehicles have the same trip-making characteristics as those of the same vehicle type that were surveyed for the same establishment. Discussions about the reasonableness of these assumptions may be found in the section on commercial vehicle trip generation. The TRMSB believes that the first assumption is more reasonable than the second one. Moreover, data generated on the basis of these assumptions can more safely be used for trip generation model development than for trip distribution model development, as the latter requires two other very critical pieces of information – trip origin and trip destination. Even though trip origins and destinations are aggregated to the TAZ level for trip distribution modeling, imputing information at this level of spatial resolution and getting reasonable results would be challenging (if not impossible), and was therefore not attempted.

9.1.2.2 Treating Unrecorded Trips and Ad Hoc Imputation

Two approaches, factoring and ad hoc imputation, were tested for treating trips that were reported but not recorded in detail in the survey diaries. While these two approaches are different, their purposes are the same, to represent all trips that were made on the survey days using only data on those trips for which information was recorded. Ad hoc imputation was the approach ultimately adopted.

The factoring approach is used in the trip generation step to develop a daily trip generation model (for details on this approach, see the section on commercial vehicle trip generation model development). However, when analyzing trip-making by time of day, the factoring approach shows some limitations. Figure 9-2 shows the distribution of recorded trips and the distribution of the combination of recorded trips and trips generated using the factoring approach. As can be seen in that figure, the line representing only recorded trips is flatter and peaks and plateaus between 9:00 AM and 4:00 PM; during that period, between approximately 4% and 7% of recorded trips took place in each half-hour interval. The slopes of the recorded-trips-only line while it is climbing to its morning peak and while it is going down after the evening peak are both relatively gentle. When the factoring approach is used and its results are added to the recorded trips, the distribution has a very high peak of greater than 12% of trips occurring in the 7:30 AM-8:00 PM time interval, after which it drops quickly during the next 1.5 hours or so to about 6%, before the decreasing slope becomes gentler for the remainder of the day. The reason that these two distributions are so different is that the survey data is biased towards earlier time periods of the day, due to the fact that only the first 10 trips that any given vehicle made on the survey day were able to be recorded in the survey diary. Therefore, when using the factoring approach to simply factor up recorded trips without giving consideration to the temporal dimension of the trips, time-of-day distributions are distorted and biased towards the earlier time periods of the day.

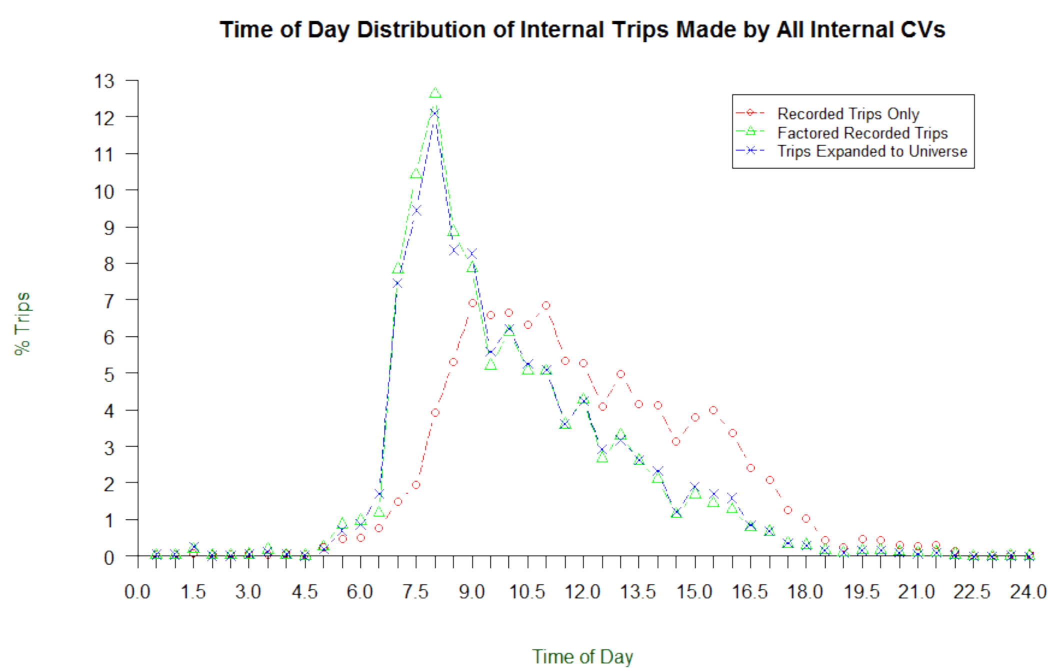


Figure 9-2 Time-of-day distribution of I-I trips made by all internal vehicles (no trip imputation)

The second approach tried was called ad hoc imputation, wherein one draws from the recorded trips made by a given vehicle and uses the characteristics of the drawn trip record to represent the vehicle's 11th or a later trip(s) (if any), which would not have been recorded in the survey diary. As stated earlier, it was assumed that a vehicle's 11th and later trips follow the same distributions as the first 10 recorded trips in terms of trip purpose, travel time, stop time at destinations, and whether they are I-I, I-E, or E-E trips. Simple random sampling was used for the drawing. For imputation of the 11th trip, the first drawn trip record was added to the trip list following the 10th trip, with some of its original information retained, including trip purpose, travel time, stop time at the destination, and whether it was an I-I, I-E, or E-E trip. Then, the starting time and ending time of the trip were adjusted as follows:

- Starting time of 11th trip = Ending time of 10th trip + Stop time at destination of 10th trip
- Ending time of 11th trip = Starting time of 11th trip + Travel time of 11th trip

A second trip record was drawn from the pool of recorded trips (excluding any imputed trips) to impute the 12th trip (if any), with starting and ending times adjusted using the same approach as for the 11th trip. This process was repeated until all necessary trips have been imputed.

Although additional trips beyond the 10th one were reported for some vehicles in the dataset, many of the recorded stop times at the destinations of the 10th trips were very long, usually lasting until 24:00, the survey ending time, when added to the ending times of the 10th trips. That left no time in the day for the 11th and later trips, even though those trips were reported. It is not clear how these errors were generated; however, to make the 10th trips make sense and create time in the day for the 11th and later trips, the stop times at the destinations of the 10th trips were examined and adjusted where needed. No formulas were used for these adjustments. Instead, an arbitrary stop time was picked that was either within the range of the same vehicle's stop times at earlier destinations or close to that range.

This trip imputation process was conducted for all commercial vehicles with more than 10 trips reported, regardless of whether the establishment that operated/owned the vehicle was within the study area or not. All of a given vehicle's trips for which details were recorded were used in the sampling pool for its imputed trips, regardless of whether those trips were internal to the model area or not.

After all necessary trips were imputed, the ending time of each vehicle's last trip was examined. In some cases, that ending time was after midnight, due to some trip records with long (but legitimate) stop times having been sampled. Those trip record were replaced with re-sampled ones, after which all vehicles with imputed trips had their last trip end time of the survey day no later than midnight.

Imputation Results Analysis

As shown in Table 9-37 and Figure 9-3, a total of 1,047 trips were imputed via this process. Of those imputed trips, 81.1% end by 16:00, 88.6% end by 18:00, and 94.7% end by 20:00. Overall, these numbers were judged to be reasonable. Grouped into the time-of-day periods used in the TRMv6, 9.3% of the imputed trips are in the AM peak period (6:00 – 10:00), 67% in the midday period (10:00 – 15:30), 17% in the PM peak period (15:30 – 19:30), and 6-7% in the nighttime period (19:30-6:00 on the next day).

Table 9-37 Ending-time distribution of all imputed trips

Time	Count	Percent	Cumulative Percent
8:00 - 9:00	21	2.0%	2.0%
9:00 - 10:00	76	7.3%	9.3%
10:00 - 11:00	102	9.7%	19.0%
11:00 - 12:00	132	12.6%	31.6%
12:00 - 13:00	144	13.8%	45.4%
13:00 - 14:00	152	14.5%	59.9%
14:00 - 15:00	118	11.3%	71.2%
15:00 - 16:00	104	9.9%	81.1%
16:00 - 17:00	42	4.0%	85.1%
17:00 - 18:00	37	3.5%	88.6%
18:00 - 19:00	40	3.8%	92.5%
19:00 - 20:00	24	2.3%	94.7%
20:00 - 21:00	15	1.4%	96.2%
21:00 - 22:00	14	1.3%	97.5%
22:00 - 23:00	19	1.8%	99.3%
23:00 - 24:00	7	0.7%	100.0%
Total	1,047	100.0%	

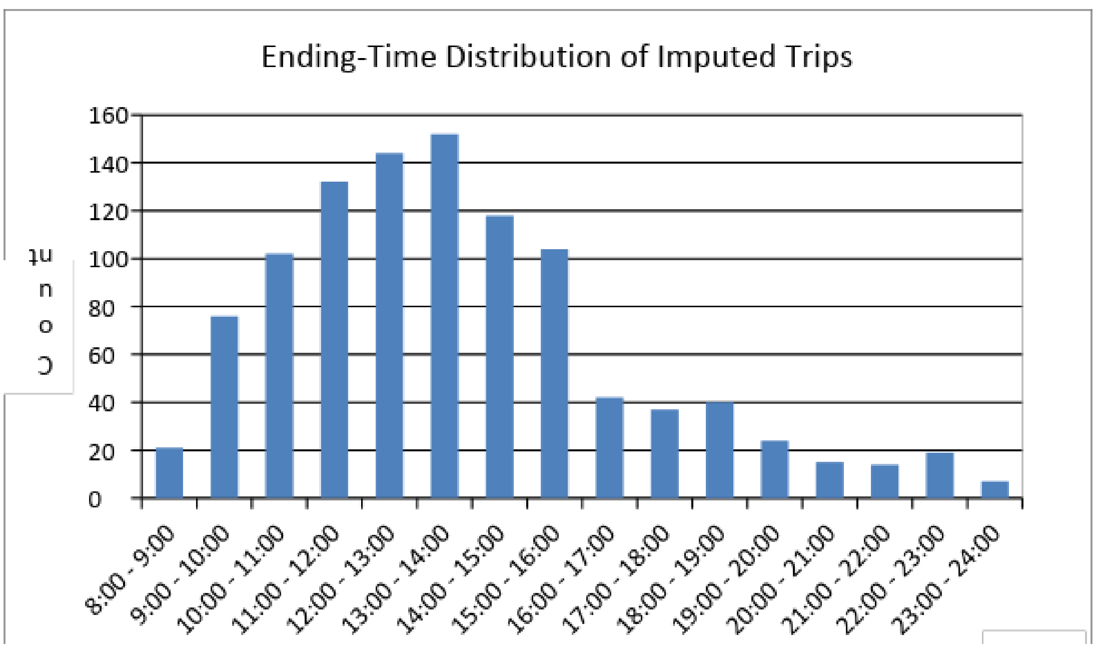


Figure 9-3 Ending-time distribution of all imputed trips

With imputed trips included, analysis was conducted again on the time-of-day distribution of internal trips made by internal establishments (I-I-I trips), the results of which are shown in Figure 9-4. This figure shows the time-of-day distribution of recorded and imputed trips, combined, without any factoring or expansion, as well as their distribution after being factored to also represent trips made by unsurveyed vehicles associated with the sampled establishments. A third line in the figure expands the results to the universe of commercial vehicle trips in the region.

All of the lines in Figure 9-4 show more evenly distributed patterns than their imputation-less counterparts in Figure 9-2. Also, with trip imputation, the factored and the expanded trip distributions much better agree with the distribution of observed trips. This is a direct effect of tagging imputed trips with later, more realistic timestamps. A detailed comparison of the recorded-trips-only scenario (Figure 9-2) and the recorded-and-imputed-trips scenario (Figure 9-4) is shown in Table 9-38. In general, trip percentages in the recorded-and-imputed-trips scenario are lower than in the imputation-less scenario before 11:00 AM and higher after 11:00 AM.

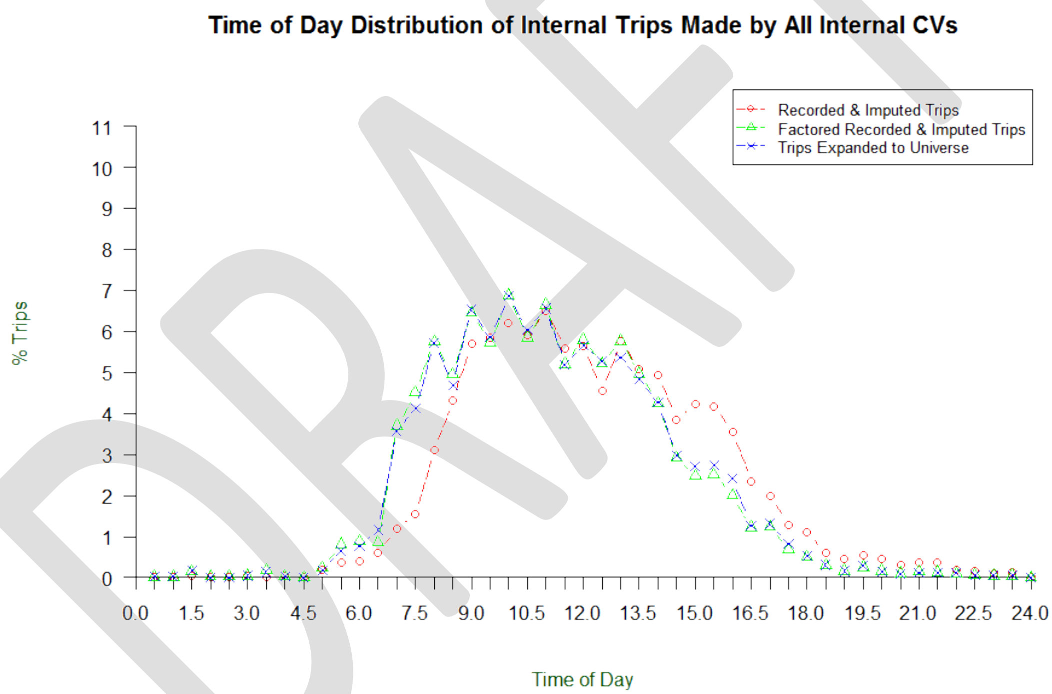


Figure 9-4 Time-of-day distribution of I-I trips made by all internal commercial vehicles (with trip imputation)

Table 9-38 Comparison of time-of-day distributions of I-I trips made by internal vehicles

Time	Recorded Trips Only (i)	Percent (Recorded Trips Only) (ii)	Recorded and Imputed Trips (iii)	Percent (Recorded and Imputed Trips) (iv)	% Difference between Percentages = (iv) / (ii) - 1
0:00 – 0:30	1	0.03%	1	0.03%	-20.5%

0:30 – 1:00	1	0.03%	1	0.03%	-20.5%
1:00 – 1:30	2	0.06%	2	0.05%	-20.5%
1:30 – 2:00	1	0.03%	1	0.03%	-20.5%
2:00 – 2:30	1	0.03%	1	0.03%	-20.5%
2:30 – 3:00	2	0.06%	2	0.05%	-20.5%
3:00 – 3:30	1	0.03%	1	0.03%	-20.5%
3:30 – 4:00	2	0.06%	2	0.05%	-20.5%
4:00 – 4:30	1	0.03%	1	0.03%	-20.5%
4:30 – 5:00	7	0.22%	7	0.18%	-20.5%
5:00 – 5:30	15	0.48%	15	0.38%	-20.5%
5:30 – 6:00	16	0.51%	16	0.41%	-20.5%
6:00 – 6:30	24	0.76%	24	0.61%	-20.5%
6:30 – 7:00	47	1.50%	47	1.19%	-20.5%
7:00 – 7:30	61	1.94%	61	1.54%	-20.5%
7:30 – 8:00	123	3.92%	123	3.11%	-20.5%
8:00 – 8:30	167	5.32%	170	4.30%	-19.0%
8:30 – 9:00	217	6.91%	225	5.70%	-17.5%
9:00 – 9:30	207	6.59%	231	5.85%	-11.2%
9:30 – 10:00	209	6.65%	245	6.20%	-6.8%
10:00 – 10:30	199	6.34%	233	5.90%	-6.9%
10:30 – 11:00	215	6.84%	257	6.51%	-4.9%
11:00 – 11:30	168	5.35%	220	5.57%	4.2%
11:30 – 12:00	165	5.25%	223	5.65%	7.5%
12:00 – 12:30	128	4.08%	180	4.56%	11.9%
12:30 – 13:00	156	4.97%	227	5.75%	15.7%
13:00 – 13:30	130	4.14%	201	5.09%	23.0%
13:30 – 14:00	129	4.11%	195	4.94%	20.2%
14:00 – 14:30	98	3.12%	152	3.85%	23.4%
14:30 – 15:00	119	3.79%	167	4.23%	11.6%
15:00 – 15:30	125	3.98%	165	4.18%	5.0%
15:30 – 16:00	106	3.37%	140	3.55%	5.1%
16:00 – 16:30	76	2.42%	92	2.33%	-3.7%
16:30 – 17:00	65	2.07%	79	2.00%	-3.3%
17:00 – 17:30	40	1.27%	51	1.29%	1.4%
17:30 – 18:00	32	1.02%	44	1.11%	9.4%
18:00 – 18:30	14	0.45%	24	0.61%	36.4%
18:30 – 19:00	7	0.22%	18	0.46%	104.5%
19:00 – 19:30	15	0.48%	22	0.56%	16.7%
19:30 – 20:00	14	0.45%	18	0.46%	2.3%
20:00 – 20:30	10	0.32%	12	0.30%	-4.6%
20:30 – 21:00	9	0.29%	15	0.38%	32.6%

21:00 – 21:30	10	0.32%	14	0.35%	11.4%
21:30 – 22:00	4	0.13%	8	0.20%	59.1%
22:00 – 22:30	0	0.00%	6	0.15%	0.0%
22:30 – 23:00	0	0.00%	4	0.10%	0.0%
23:00 – 23:30	1	0.03%	5	0.13%	297.7%
23:30 – 24:00	1	0.03%	1	0.03%	-20.5%
Total	3,141	100%	3,949	100%	

9.1.2.3 Derivation of Time-of-Day Factors

Time-of-day factors were calculated by vehicle type and trip purpose for the AM peak period, midday, the PM peak period, and nighttime. As indicated in the sections on commercial vehicle trip generation and trip distribution, the combinations of vehicle types and trip purposes for which models have been developed include light-duty commercial vehicles delivering goods (LCV_Goods), light-duty commercial vehicles delivering services (LCV_Service), light-duty commercial vehicles with other trip purposes (LCV_Other), single-unit trucks delivering goods (SUT_Goods), single-unit trucks delivering services (SUT_Service), and multi-unit trucks delivering goods (MUT_Goods). Time-of-day factors were calculated for these same vehicle type and trip purpose combinations.

Only internal-to-internal trips made by vehicles associated with establishments that are internal to the TRM study area (I-I-I trips) are considered in the time-of-day analysis. There were 3,141 recorded I-I-I trips in the survey dataset, plus 808 imputed I-I-I trips, for a total of 3,949. Of these trip records, 230 "unqualified" records were removed due to belonging to the categories listed in Table 9-39. The remaining 3,719 trip records, from the categories shown in Table 9-40, were used for the time-of-day analysis, after being appropriately factored and expanded. The factoring process referred to here is different from the one described in the previous subsection. The purpose of that factoring process was to account for trips that were reported in the commercial vehicle survey but not recorded in detail in the survey diaries; it was ultimately not implemented, in favor of the ad hoc trip imputation process, as described above. The purpose of the factoring process being discussed here is to address trips that were made by unsurveyed commercial vehicles that were associated with surveyed establishments. After being multiplied by a series of factors (called "trip-representing factors," hereafter), the recorded and imputed trips represent all trips made by all commercial vehicles that were operated by the surveyed establishments on their respective survey days. Then, trips made by vehicles associated with surveyed establishments were expanded to the universe of establishments in the model area that operate commercial vehicles.

Details about the derivation of trip-representing factors and establishment expansion factors may be found in Section 9.1.1.2. Some statistics about the trip-representing factors and survey expansion factors may be found in Table 9-41 and Table 9-42.

Table 9-39 "Unqualified" trip records*

Type	Number of Trip Records
Serving People	154
SUT Other	58
MUT Delivery of Services	13
MUT Other	5
Total	230

* Including imputed trips

Table 9-40 Trip records* used for time-of-day analysis

Vehicle Type + Trip Purpose	Number of Trip Records
LCV All Purposes	1,956
LCV Delivery of Goods	648
LCV Delivery of Services	1,051
LCV Other	257
SUT All Purposes	1,494
SUT Delivery of Goods	676
SUT Delivery of Services	818
MUT Delivery of Goods	269
Total	3,719

* Including imputed trips

Table 9-41 Statistics of trip-representing factors

	Value*
Minimum	1
Maximum	40
Mean	3.62

* Based on the 3,719 trip records described in Table 9-40

Table 9-42 Statistics of expansion factors

	Value*
Minimum	6.95
Maximum	69.66
Mean	30.06

* Based on the 438 internal establishments from the 2010 commercial vehicle survey

To derive time-of-day factors, each of the 3,719 trip records being used first needed to be classified into one of the four periods of the day being considered in the model, depending on the starting and ending times of the trips. If a trip started and ended during the same period, it was classified into that period. If a trip started during one period but ended during a different period, it was classified into the period when the midpoint of the trip's duration occurred. The starting and ending times used for this classification are the ones reported in the survey.

Time-of-day factors were calculated as the weighted/expanded number of trips in each time period divided by the weighted/expanded number of trips in the overall day. These factors are shown in Table 9-43, along with unexpanded versions of the values used to create them. The numbers in the "Expanded %" columns are the time-of-day factors used in the model.

Table 9-43 Commercial vehicle trip time-of-day factors based on 2010 CV survey

Vehicle Type & Purpose	AM Peak				Midday			
	Counted	Counted %	Expanded	Expanded %	Counted	Counted %	Expanded	Expanded %
LCV_Goods	136	21.0%	37350.6	46.3%	448	69.1%	41477.5	51.4%
LCV_Service	263	25.0%	16442.8	25.8%	540	51.4%	33756.2	52.9%
LCV_Other	85	33.1%	45951.5	47.8%	153	59.5%	46297.0	48.2%
SUT_Goods	212	31.4%	13366.2	28.1%	400	59.2%	32332.0	67.9%
SUT_Service	262	32.0%	37672.0	38.1%	453	55.4%	50781.6	51.3%
MUT_Goods	96	35.7%	16854.8	39.4%	123	45.7%	16624.6	38.9%
Subtotal	1054	28.3%	167637.9	39.0%	2117	56.9%	221268.8	51.5%

Vehicle Type & Purpose	PM Peak				Night			
	Counted	Counted %	Expanded	Expanded %	Counted	Counted %	Expanded	Expanded %
LCV_Goods	60	9.3%	1782.8	2.2%	4	0.6%	114.9	0.1%
LCV_Service	189	18.0%	11015.7	17.3%	59	5.6%	2590.6	4.1%
LCV_Other	18	7.0%	3790.3	3.9%	1	0.4%	39.4	0.0%
SUT_Goods	59	8.7%	1724.8	3.6%	5	0.7%	176.7	0.4%
SUT_Service	86	10.5%	9518.1	9.6%	17	2.1%	948.4	1.0%
MUT_Goods	13	4.8%	1619.5	3.8%	37	13.8%	7661.5	17.9%
Subtotal	425	11.4%	29451.2	6.9%	123	3.3%	11531.4	2.7%

9.1.2.4 Hourly Distribution of Commercial Vehicle Trips

Hourly distributions of commercial vehicle trips by vehicle type alone, by trip purpose alone, and by vehicle type/trip purpose combinations, after the application of trip-representing factors and survey expansion factors, are depicted in Figure 9-5 through Figure 9-9. Overall, these distributions appear reasonable correspond with establishments' usual hours of operation. As shown in Figure 9-7, multi-unit trucks delivering goods tend to start their days earlier and end their days earlier than other commercial vehicles, while light-duty commercial vehicles delivering services tend to both start and end their days later than other commercial vehicles, as shown in Figure 9-6.

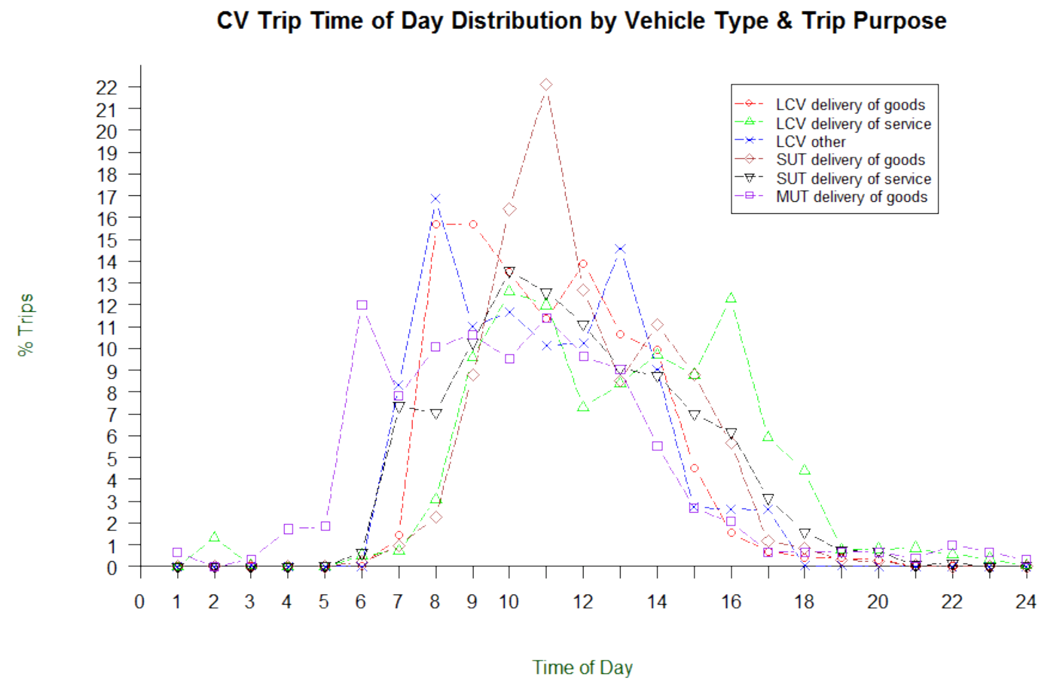


Figure 9-5 I-I-I trip time-of-day (hourly) distributions by vehicle type and trip purpose

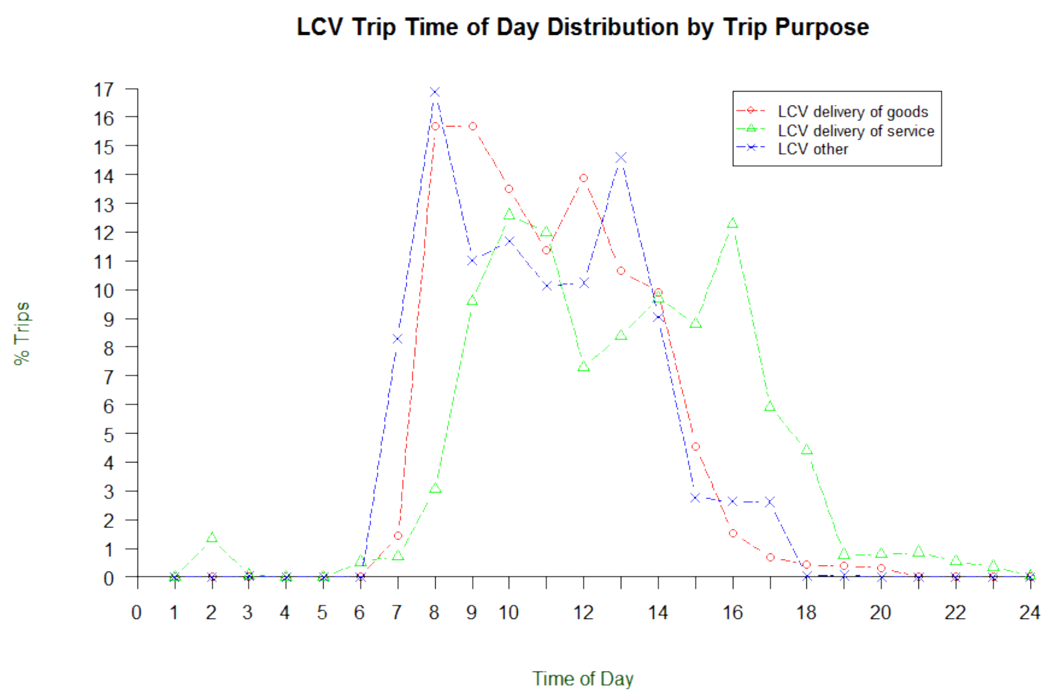


Figure 9-6 LCV I-I-I trip time-of-day (hourly) distributions by trip purpose

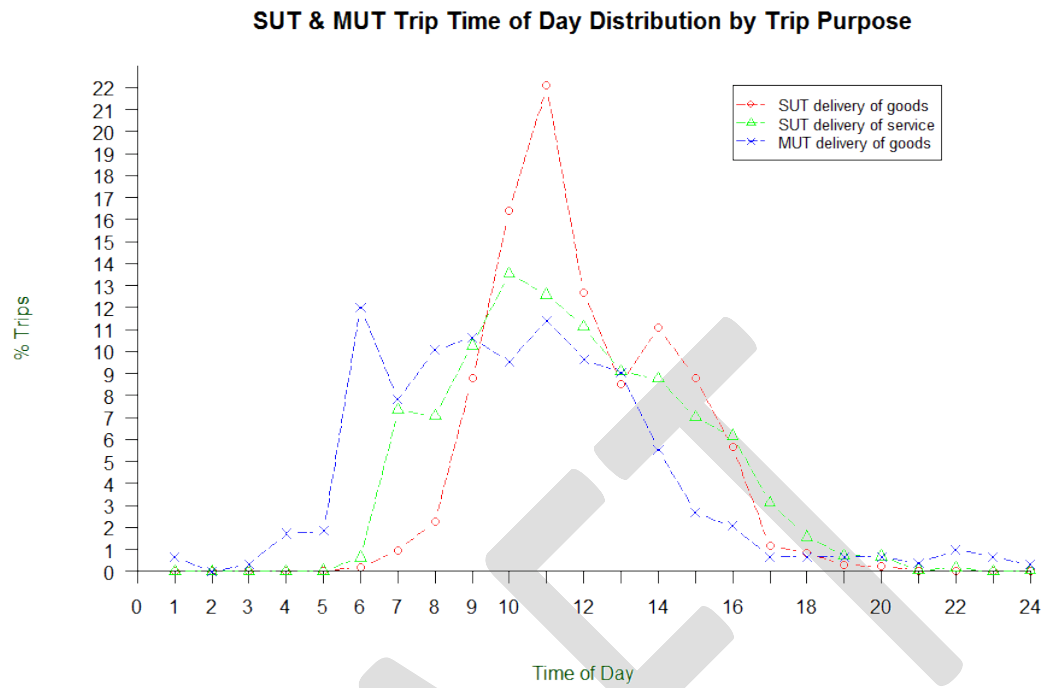


Figure 9-7 SUT and MUT I-I-I trip time-of-day (hourly) distributions by trip purpose

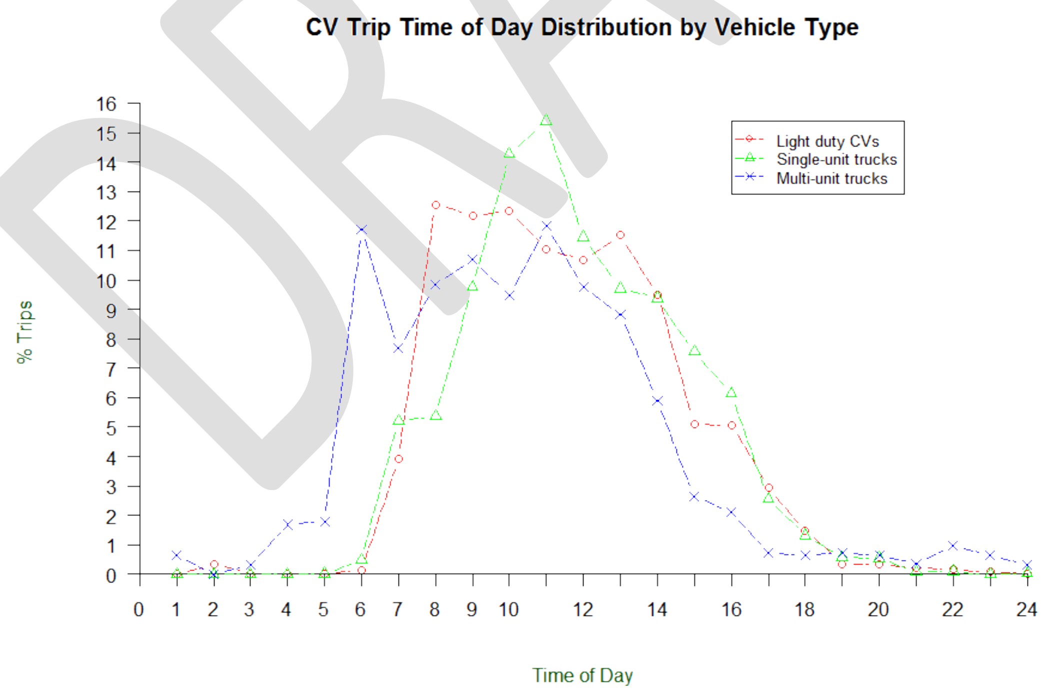


Figure 9-8 I-I-I trip time-of-day (hourly) distributions by vehicle type

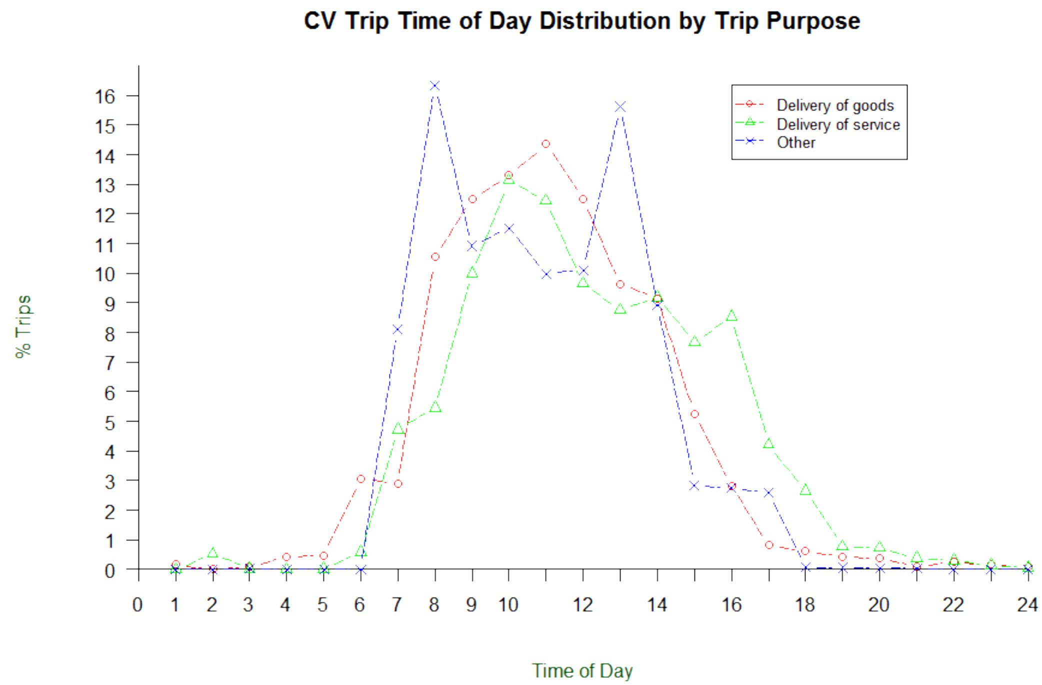


Figure 9-9 I-I-I trip time-of-day (hourly) distributions by trip purpose

9.1.3 Trip Distribution

Destination choice models were used to distribute commercial vehicle trips between TAZs. To estimate those models, data from several sources needed to be organized in a specific format that was required by the model estimation software package. Sources of model estimation data included: (1) the 2010 commercial vehicle travel survey; (2) the TRMv6 TAZ-level 2010 socioeconomic dataset; and (3) inter-zonal travel impedances from the TRMv6. The free, open-source software Biogeme version 2.2 was utilized for this model estimation.

A destination choice model evaluates every eligible destination zone and assigns it a probability of being chosen. For model estimation, however, it is not necessary to use every destination zone as a choice alternative. Taking advantage of the independence of irrelevant alternatives (IIA) property of the logit model, a subset of the full alternative set can be used to improve model estimation efficiency, while consistent estimation results are still preserved. Therefore, only a sample of the TAZs in the region was selected for model estimation, and the Importance Sampling with Replacement (ISwR) method, as described by Ben-Akiva and Lerman (1985),[12] was utilized for the sampling. The ISwR method is similar to the method that was used to estimate TRMv5 passenger-trip destination choice models. How this method was used is described below.

[12] Ben-Akiva M. and Lerman S. (1985) Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge.

Also presented here are the calculation of travel impedances and socioeconomic variables, the format of the model estimation data file, and the initial results of model estimation and calibration.

9.1.3.1 TAZ Sampling Procedure

The Importance Sampling with Replacement (ISwR) method is fully described by Ben-Akiva and Lerman (1985). The rationale behind using Importance Sampling is that it is more efficient than simple random sampling for drawing a sample of alternatives, wherein the alternatives that are the most likely to be chosen by the decision-maker have higher probabilities of being selected. This method was used for the TRMv6 commercial vehicle model.

9.1.3.1.1 Selection Weight and Selection Probability

Unlike simple random sampling, wherein each TAZ is treated as having an equal probability of being chosen, the Importance Sampling method assigns unequal selection probabilities to different TAZs, and the probability of a given TAZ being selected depends on its characteristics and the travel impedance between the origin TAZ and the potential destination TAZ in question. The process that was used to calculate selection probabilities was as follows.

First, calculate the selection weight of destination TAZ j relative to origin TAZ i, using the following equation. Selection weights are computed by vehicle type and trip purpose.

$$W_{ij} = A_j \times e^{\left(-2\times\frac{D_{ij}}{D_{avg}}\right)} \tag{9-1}$$

where

W_{ij} = selection weight of destination TAZ j relative to origin TAZ i;
A_j = size variable for TAZ j, trip attraction (destination) ends by vehicle type and trip purpose;
D_{ij} = highway distance in miles from TAZ i to TAZ j; and
D_{avg} = regional average distance of I-I-I trips (I-I trips by vehicles associated with internal establishments) by vehicle type and trip purpose, derived from 2010 Commercial Vehicle Travel Survey data, as shown in Table 9-44.

Table 9-44 Regional average trip distances by vehicle type and trip purpose*

Vehicle Type + Trip Purpose	D_{avg} (miles) weighted	D_{avg} (miles) unweighted
LCV Delivery of Goods	4.97	8.33
LCV Delivery of Services	8.85	9.17
LCV Other	3.63	6.55
SUT Delivery of Goods	6.65	10.07
SUT Delivery of Services	7.86	9.31
MUT Delivery of Goods	13.04	13.87
All	6.90	9.45

* Values in this table are derived from the 2010 Triangle Region Commercial Vehicle Survey, and only the weighted distances are used in selection weight calculation.

Next, use selection weights to calculate selection probabilities by vehicle type and trip purpose, using the equation

$$P_{ij} = \frac{W_{ij}}{\sum_{k=1}^{N} \quad W_{ik}} \tag{9-2}$$

where

P_{ij} = selection probability of destination TAZ j for trip starting from TAZ i, and
N = total number of internal TAZs in the TRMv6 (2,857 TAZs).

9.1.3.1.2 Selection Process

From selection probabilities P_{ij}, the TRMSB computed cumulative selection probability cP_{ij} of destination TAZ *j*, with values of *j* counting from 1 to 2857. The cP_{ij} of TAZ *j* consists of a range, with a lower limit equal to the sum of the selection probabilities of TAZs 1 through *j*-1 (i.e., $\sum_{k=1}^{j-1} \quad P_{ik}$) and an upper limit equal to the sum of the lower limit and the selection probability of TAZ *j*, itself (i.e., $\sum_{k=1}^{j} \quad P_{ik}$). The lower limit of $cP_{i,1}$ is zero, and the upper limit of $cP_{i,2857}$ is exactly one.

Twenty random numbers between zero and one were generated for each trip record in the survey, using Microsoft Excel's *rand()* function. If one of those random number was in the range denoted by cP_{ij}, TAZ *j* was selected into the sample set. In this manner, twenty TAZs were drawn into the sample set for each trip record, some of which could be duplicates of the same TAZ. Then, the TRMSB deleted any duplicate TAZs from the sample set and added in the TAZ that was actually traveled to by the survey respondent, if it was not already selected. Due to the deletion of duplicate TAZs, this process results in different numbers of sampled TAZs for different trip records, with a maximum of 21 TAZs and a minimum of 1 TAZ (which would necessarily be the TAZ that was actually chosen by the survey respondent).

9.1.3.1.3 Correction Factor

When sampling alternatives for model estimation, biases are introduced and correction factors are needed to obtain consistent estimates of the model parameters (Ben-Akiva and Lerman 1985). Correction factors were only applied to the sampled alternatives, and took the following form:

$$CF_{ij} = -\, ln\, ln\, q_{ij} \;\; = (P_{ij} \times n) \tag{9-3}$$

where

CF_{ij} = correction factor of sampled TAZ j for trip starting from TAZ i,
q_{ij} = probability of TAZ j being selected into sample set for model estimation,
P_{ij} = selection probability of TAZ j for trip starting from TAZ i, and
n = number of selected TAZs in sample set (20, in this case).

Correction factors were used only during model estimation and not during model application. Using correction factors makes model parameters that are estimated from a subset of alternatives consistent with those that would result from accounting for all alternatives. Using a subset of alternatives with correction factors makes model estimation more efficient, especially when there is a large number of alternatives (as is typical with destination choice models). If model parameters are rendered consistent in this manner, that consistency carries through to model application results.

Correction factors were added to utility functions as a linear additive term. The coefficients of correction factors were always constrained to one (Ben-Akiva and Lerman 1985).

When a TAZ has no employees of any type and no households, it cannot generate any trips, which means it has zero probability of being selected as a destination (P_{ij} = 0). However, in the survey dataset, a few trips were observed to have destinations in those zero-probability TAZs. Mathematically, P_{ij} being 0 leads to CF_{ij} being infinity. Therefore, a CF_{ij} value of 99.99 was assigned in such cases, in order to avoid a computational crash. TAZs of this description were excluded from model estimation.

9.1.3.2 Data File for Model Estimation

One single model estimation data file was created, with all vehicle types and trip purposes included. The [Exclude] block of the Biogeme model file was used to separate out target combinations of vehicle type and trip purpose for model estimation. Only internal-to-internal (I-I) trips made by establishments within the TRM study area (i.e., internal establishments) are included in the file, also called I-I-I trips. In total, there were 3,141 I-I-I trip records in the survey dataset. Of those trip records, 132 were made to serve people (such as picking up and dropping off passengers), even though the vehicles were claimed to be commercial autos, pickups, or single unit trucks. Treated the same as in the trip generation model, those serving-people trip records were removed from the dataset for model estimation. Moreover, since the numbers of observations of single-unit truck trips with the “other” purpose and of multi-unit truck trips with purposes of “delivering services” or “other” were very low in the survey dataset, it was impossible to develop corresponding models of trips of those types, for which reason those trip records were removed from the dataset, as well. A summary of such “unqualified” records is shown in Table 9-45.

Table 9-45 "Unqualified" trip records

Type	Number of Trip Records
Serving People	132
SUT Other	58
MUT Delivery of Services	13
MUT Other	5
Total	208

Numbers of trip records by vehicle type and trip purpose that were used for model estimation are shown in Table 9-46.

Table 9-46 Trip records for model estimation

Vehicle Type + Trip Purpose	Number of Trip Records

LCV All Purposes	1,638
LCV Delivery of Goods	487
LCV Delivery of Services	947
LCV Other	204
SUT All Purposes	1,053
SUT Delivery of Goods	525
SUT Delivery of Services	528
MUT All Purposes	242
MUT Delivery of Goods	242
Total	2,933

There were 538 data fields in the estimation data file. The structure of that file is shown in Table 9-47. The data file contains all data items that were considered to be potential explanatory variables for the models, although only a portion of these data items was found to be statistically significant in explaining the trip distribution patterns of commercial vehicles.

Table 9-47 Destination choice model estimation data file structure

Column	Variable	Description
1	Trip_ID	Trip ID. Each trip has a unique trip ID.
2	Weight	Weight in 2010 CV Survey dataset (does not include expansion factors)
3	NAICS	2-digit NAICS code of the establishment that made the trip
4	TOD	Time of Day, 1 = AM peak, 2 = PM peak, and 3 = Off-peak
5	CTYPE_PURP	Combination of vehicle type and trip purpose: 1 = LCV Delivery of Goods, 2 = LCV Delivery of Services, 3 = LCV Other 4 = SUT Delivery of Goods, 5 = SUT Delivery of Services, 6 = MUT Delivery of Goods
6	TAZ_From	Origin TAZ of the trip
7	TAZ_To	Destination TAZ of the trip
8	Choice	The ID of the alternative that was actually chosen. This value is always set to 1, since the TAZ the trip actually ended at is always placed as the first alternative in the estimation data file.
9	TAZ1	The first alternative TAZ (The first alternative TAZ is always the actually chosen TAZ. Therefore it is always the same as TAZ_To.)
10	Avail1	Availability of the first alternative TAZ to the trip record (The value of Avail1 is always 1, since the first alternative TAZ is always the one actually chosen.)
11	Area1	Area of TAZ1 in square miles
12	HH1	TNumber of households in TAZ1
13	Industrial1	Industrial employees in TAZ1, including those from special generators
14	Retail1	Retail + HwyRetail employees in TAZ1, including those from special generators
15	Office1	Office employees in TAZ1, including those from special generators

16	Service1	Service employees in TAZ1, including those from special generators
17	Attractions1	Trip attraction ends of the CTYPE_PURP category, as estimated using the corresponding trip generation model for TAZ1
18	CrossCounty1	Dummy variable: if two trip ends are in two different counties, 1; otherwise, 0
19	Cross_WD1	Dummy variable: if one trip end in Wake and the other in Durham, 1; otherwise, 0
20	Cross_WO1	Dummy variable: if one trip end in Wake and the other in Orange, 1; otherwise, 0
21	Cross_DO1	Dummy variable: if one trip end in Durham and the other in Orange, 1; otherwise, 0
22	Cross_WJ1	Dummy variable: if one trip end in Wake and the other in Johnston, 1; otherwise, 0
23	CrossOthers1	Dummy variable: if two trip ends in two different counties other than Wake, Durham, Orange, and Johnston, 1; otherwise, 0
24	TravelTime1	Travel time in minutes from TAZ_From to TAZ1. It depends on times of day: If the trip took place in AM peak, AM congested travel time is used; otherwise, free-flow travel time.
25	TravelDist1	Travel distance in miles from TAZ_From to TAZ1. It depends on times of day: If the trip took place in AM peak, travel distance corresponding to AM shortest-duration path is used; otherwise, distance of free-flow-travel path is used.
26	Urban_Urban1	Dummy variable: if both trip ends are in urban area, 1; otherwise, 0
27	Urban_Suburb1	Dummy variable: if one end in urban area and the other end in suburban area, 1; otherwise, 0
28	Urban_Rural1	Dummy variable: if one end in urban area and the other end in rural area, 1; otherwise, 0
29	Suburb_Suburb1	Dummy variable: if both trip ends are in suburban area, 1; otherwise, 0
30	Suburb_Rural1	Dummy variable: if one end in suburban area and the other end in rural area, 1; otherwise, 0
31	CF1	Correction factor for TAZ1
32 - 538		Similar to columns 9 – 31, for TAZ2 to TAZ21, if applicable

9.1.3.3 Model Specification and Estimation Results

9.1.3.3.1 Model Specification

Destination choice models were estimated for three vehicle types and three trip purposes. The vehicle types were light-duty commercial vehicles (FHWA Classes 2 and 3), single-unit trucks (Classes 5, 6, and 7), and multi-unit trucks (Classes 8, 9, 10, 11, 12, and 13). The three trip purposes modeled were delivery of goods, delivery of services, and other. As indicated above, because the numbers of observations of single-unit truck trips with "other" purposes and multi-unit truck trips with "delivery of services" or "other" purposes are very low in the survey dataset, models were not developed for those vehicle type/trip purpose combinations. As a result, the following six models were estimated.

(1) Light-Duty Commercial Vehicle Delivery of Goods
(2) Light-Duty Commercial Vehicle Delivery of Services
(3) Light-Duty Commercial Vehicle Other Trip Purposes
(4) Single-Unit Truck Delivery of Goods

(5) Single-Unit Truck Delivery of Services
(6) Multi-Unit Truck Delivery of Goods

To increase model estimation sample size and the statistical reliability of the estimated models, models were not estimated by time of day. Instead, all trip records that fell into a vehicle type/trip purpose category were used together to estimate the corresponding model for that combination. However, time-of-day characteristics of trips were still used in model estimation, via the use of travel times corresponding to when the trips took place on the survey day. Therefore, the estimated models are not daily models, as they have the capability to differentiate times of day.

As shown above, the data used to estimate these models included trip information from the commercial vehicle travel survey, TAZ attributes, travel cost and impedance variables, and a trip-making characteristics derived from survey data and TAZ data.

A typical destination choice model has the following general form:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^{N} \quad V_{ik}} \tag{9-4}$$

where

P_{ij} = probability of TAZ *j* being chosen as destination for trip from origin TAZ *I*, and
V_{ij} = measurable perceived utility of TAZ *j* as destination for trip from origin TAZ *i*.

Utility, V_{ij}, can be expressed as a function of several factors:

$$V_{ij} = \alpha \times f(t_{ij}) + \beta \times ln\, ln\, s_j + \gamma \times z_{ij}$$
(9-5)

where

t_{ij} = travel impedance between TAZs *i* and *j*, most often in terms of travel time and/or distance;
$f(t_{ij})$ = function of travel impedance between TAZs *i* and *j*;
s_j = size of TAZ *j*, commonly in terms of households, population, employment by type, or trip attraction ends, and usually in logarithmic form;
z_{ij} = other explanatory variables, such as dummy variables indicating river crossings, border crossings, presence in CBD, etc.

<u>Size variable</u>

Zonal trip attractions were used directly as the size variable in the utility function. The trip generation models, estimated and calibrated using 2010 commercial vehicle survey data, were employed to estimate daily trip ends for each TAZ, and then time-of-day factors were used to split those trip ends into four periods of the day: AM peak, midday, PM peak, and night. The time-of-day factors were derived from the commercial vehicle survey data after expansion, as shown in Table 9-48.

Table 9-48 Time-of-day factors by vehicle type and trip purpose

VEH_PURP	AM	Midday	PM	Night Time	Total

LCV_Goods	0.6284	0.3506	0.0198	0.0012	1.0
LCV_Service	0.2771	0.5227	0.1566	0.0436	1.0
LCV_Other	0.6236	0.3398	0.0362	0.0004	1.0
SUT_Goods	0.2984	0.6641	0.0340	0.0036	1.0
SUT_Service	0.4150	0.4820	0.0907	0.0123	1.0
MUT_Goods	0.4017	0.3855	0.0400	0.1728	1.0

Travel impedance

Because travel time is more sensitive to congestion levels than travel distance, it was chosen as the travel impedance variable for all six models. Four function forms were tested for incorporating travel time into the utility function:

- Travel time alone;
- Travel time and squared travel time;
- Square root of travel time; and
- Travel time and square root of travel time.

It was found that the second and fourth functions, with estimated coefficients, were not monotonic, even within the range of observed trip lengths and were therefore not used. The first and third were both monotonic, and the main difference between them was in the marginal effect (e.g., will a one-minute increase in travel time from 50 minutes to 51 minutes have the same effect as if it were from 10 minutes to 11 minutes?). Model estimation results showed higher t-statistics when using the square root of travel time than when using travel time directly. Also, the models achieved a slightly better goodness of fit (i.e., rho-squared) when using the square root of travel time. Therefore, the square root of travel time was chosen to be used in the final utility functions within the destination choice models.

Other explanatory variables

Destination choice models have the advantage over gravity models that they can accommodate more explanatory variables. Besides the size and impedance variables just discussed, other potential explanatory variables that were considered mainly included cross-county and cross-area-type dummy variables. The rationale behind the cross-county dummy variables was that county boundaries may be perceived as a barrier, imposing heavier impedance to commercial vehicle trips than travel time, alone. It is also possible that economic interactions between different counties may vary and therefore result in different trip distribution patterns. As they are unable to separate out individual effects, the dummy variables were expected to reflect compounded overall effects. In this model-estimation effort, five crossing-county dummy variables were created, treating four major trip-generating counties separately: Wake, Durham, Orange, and Johnston. The five dummy variables were as follows:

(1) Durham-Orange crossing,
(2) Wake-Durham crossing,
(3) Wake-Orange crossing,
(4) Wake-Johnston crossing, and
(5) Other-County crossing.

The reasons for testing the use of cross-area-type dummy variables were that urban areas tend to have more employees and travel times are relatively shorter between an urban zone and another urban zone or a suburban zone than between other combinations of types of zones (based on the TRM's definitions of area types). Having more employees and shorter travel times could lead to an over-distribution of trips between those zones. It was also noticed from the mapping of the survey data that multi-unit trucks have more spatially–dispersed trip ends than do single-unit trucks, and, in turn, single-unit trucks have more dispersed trip ends than light-duty commercial vehicles. Figure 9-10, Figure 9-11, and Figure 9-12 show spatial distributions of trip ends for these three types of vehicles.

The TRMv6 defines four area types: CBD, Urban, Suburban, and Rural. Because there were few TAZs in the CBD areas, they were merged into the Urban area type for the present purpose. As a result, there were considered to be six possible combinations for the two ends of any trip in terms of area type:

(1) urban-urban,
(2) urban-suburban,
(3) urban-rural,
(4) suburban-suburban,
(5) suburban-rural, and
(6) rural-rural.

Because these six combinations cover all possibilities, only five dummy variables were needed to represent all of them. When all five dummy variables have a value of zero, it indicates a designated reference combination. The rural-rural combination was chosen to be the reference, and all other combinations are interpreted relative to it.

<u>Final utility function</u>

As a summary, the final specification of the utility function is shown in the equation below, which includes all of the terms discussed above.

$$V_{ij} = \alpha\sqrt{t_{ij}} + \beta\ ln\ ln\ (s_j)$$

(9-6)

$$+ \gamma_1 dummy_{Durham-Orange}$$
$$+ \gamma_2 dummy_{Wake-Durham}$$
$$+ \gamma_3 dummy_{Wake-Johnston}$$
$$+ \gamma_4 dummy_{Wake-Orange}$$
$$+ \gamma_5 dummy_{inter-Other-Counties}$$
$$+ \gamma_6 dummy_{suburban-rural}$$
$$+ \gamma_7 dummy_{suburban-suburban}$$
$$+ \gamma_8 dummy_{urban-rural}$$
$$+ \gamma_9 dummy_{urban-suburban}$$
$$+ \gamma_{10} dummy_{urban-urban}$$

where

α = coefficient for travel impedance between TAZs *i* and *j*,

t_{ij} = travel time (impedance) between TAZs *i* and *j*,
β = coefficient for size term,
s_j = trip attractions to TAZ *j* (size term),
$dummy_{County1-County2}$ = dummy variable whose value is 1 if trip has one end in County 1 and the other in County 2,
$dummy_{area\ type1-area\ type2}$ = dummy variable whose value is 1 if trip has one end in area type 1 and the other in area type 2, and
$\gamma_1, \ldots, \gamma_{10}$ = coefficients for corresponding dummy variables.

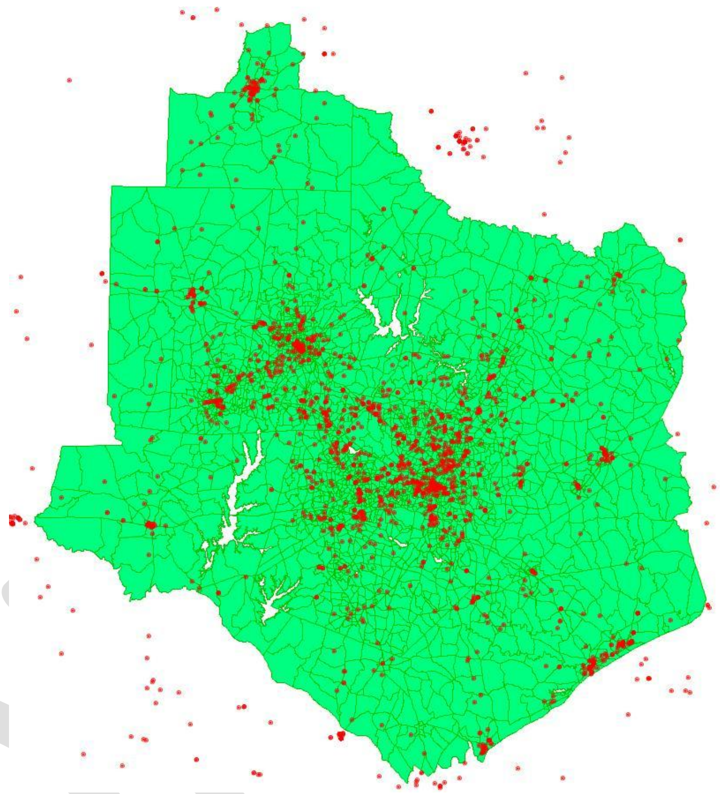


Figure 9-10 Spatial distribution of light-duty-commercial-vehicle trip ends

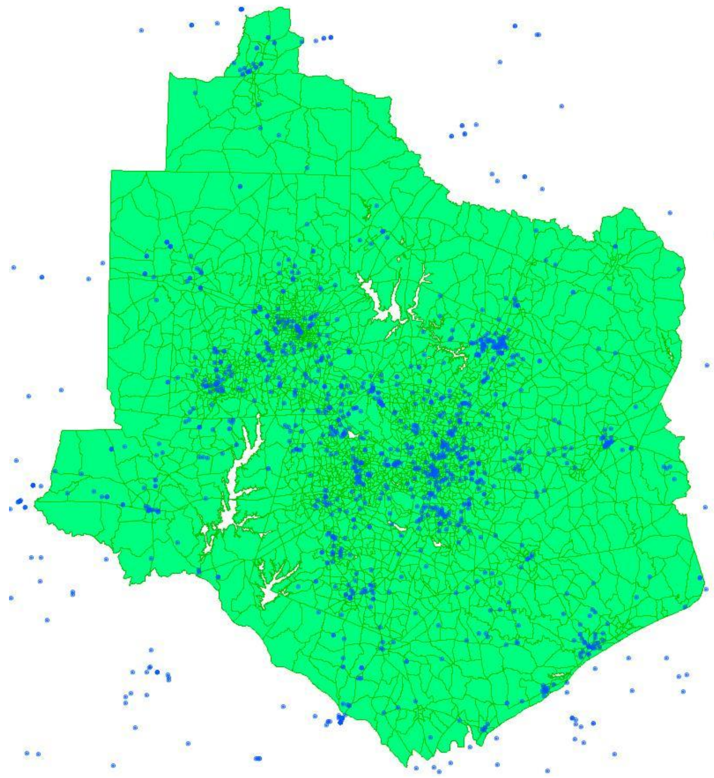


Figure 9-11 Spatial distribution of single-unit-truck trip ends

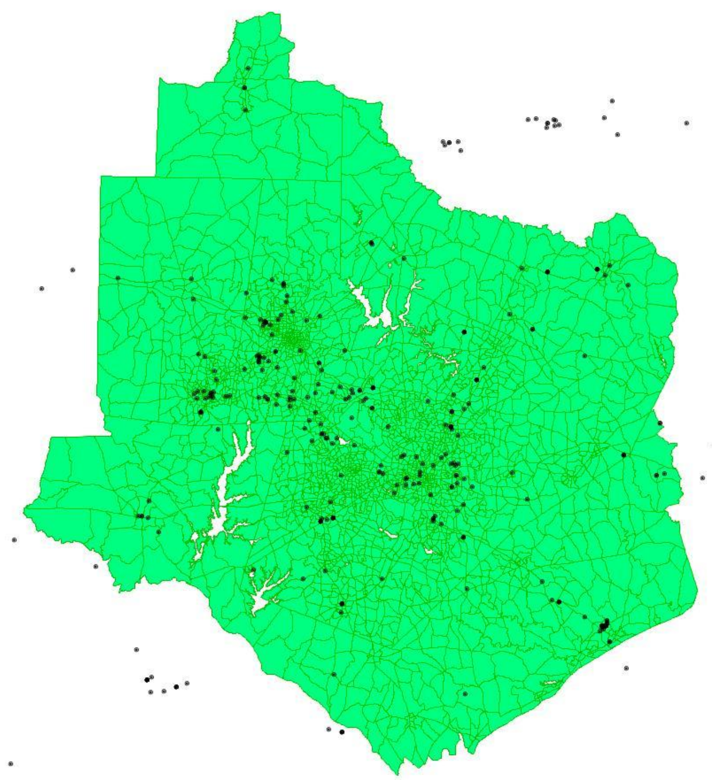


Figure 9-12 Spatial distribution of multi-unit-truck trip ends

9.1.3.3.2 Model Estimation Results

Model estimation results are shown below by vehicle type and trip purpose. A minimum *t*-statistic of 1.0 was regarded as necessary to retain a given explanatory variable in a given model.

(1) Light-Duty Commercial Vehicle Delivery of Goods

As shown in Table 9-49, the coefficient for travel time has a correct sign and is statistically significant at the 99% confidence level. LCV goods delivery trips between Wake and Johnston are less probable than comparable trips within one county, and intercounty trips other than those amongst Wake, Durham, and Orange Counties are even less likely, holding other variables constant. It was also found that trip-making is more likely between more developed areas than between rural areas. The R^2 value is 0.229.

Table 9-49 Light-duty commercial vehicle Delivery of Goods destination choice model

Variable	Coefficient	t-stat
Attraction Ends	1	fixed
Wake-Johnston Crossing	-0.496	-1.42
Other Inter-County Crossing	-0.832	-1.92
Square Root of Travel Time	-1.36	-26.04
Suburb-Rural Crossing	1.45	2.79
Suburb-Suburb Crossing	1.44	2.53
Urban-Rural Crossing	1.31	2.24
Urban-Suburb Crossing	0.842	1.47
Urban-Urban Crossing	0.849	1.45
Model Performance		
Initial log-likelihood	-1528.615	
Final log-likelihood	-1179.182	
R^2	0.229	

(2) Light-Duty Commercial Vehicle Delivery of Services

More county-crossing dummy variables showed enough effect to be included in the LCV service-delivery trip distribution model than the LCV goods-delivery model. With the exception of the Wake-Durham Crossing variable, all of the county-crossing dummy variables have coefficients with negative signs, indicating that trips are less likely to be between those pairs of counties than to by entirely intra-county. The travel-time coefficient has a correct sign and is significant at the 99% confidence level. Trips are more likely to be between suburban areas and other suburban areas, between suburban areas and rural areas, and between urban areas and rural areas than between other area-type combinations, if all else is held constant. The R^2 value is 0.304.

Table 9-50 Light-duty commercial vehicle Delivery of Services destination choice model

Variable	Coefficient	t-stat
Attraction Ends	1	fixed
Durham-Orange Crossing	-0.24	-1.01
Wake-Durham Crossing	0.24	1.68
Wake-Johnston Crossing	-1.18	-3.32
Other-County Crossing	-1.2	-5.31
Square Root of Travel Time	-1.22	-37.98
Suburb-Rural Crossing	0.456	3.28
Suburb-Suburb Crossing	0.498	3.84
Urban-Rural Crossing	0.287	1.7
Model Performance		
Initial log-likelihood	-3750.616	
Final log-likelihood	-2609.216	
R^2	0.304	

(3) Light-Duty Commercial Vehicle Other Trip Purposes

The coefficient for travel time has a correct sign, and its magnitude is comparable to, but slightly larger than, those of its counterparts in the other two LCV trip-distribution models. This greater magnitude may indicate that trips with the purpose of "Other" are more sensitive to travel time. In fact, trips for fueling, eating, banking, and so on are usually to the nearest destinations that can satisfy the driver's needs, and, therefore, are generally not long. This reasoning is confirmed by the numbers in Table 9-44, which shows average trip distances derived from the survey, with LCV Other trips having the shortest lengths.

None of the five cross-area-type dummy variables had a t-statistic greater than 1.0, and therefore none of them were included in the final model. Light-duty commercial vehicles traveling for "other" purposes are less likely to travel between Durham and Orange Counties or between Durham and Wake Counties than to make intra-county trips or travel between other pairs of counties. The R^2 value is 0.270.

Table 9-51 Light-duty commercial vehicle Other Trip Purposes destination choice model

Variable	Coefficient	t-stat
Attraction Ends	1	fixed
Durham-Orange Crossing	-1.9	-3.16
Wake-Durham Crossing	-1.33	-2.47
Square Root of Travel Time	-1.58	-19.04
Model Performance		
Initial log-likelihood	-638.244	
Final log-likelihood	-465.896	
R^2	0.270	

(4) Single-Unit Truck Delivery of Goods

The coefficient for travel time in this model has a correct, negative sign and its magnitude is comparable to those in the other models. It is strongly significant at the 99% confidence level.

All five cross-area-type dummy variables are significant at the 95% confidence level. All of their coefficients have negative signs and magnitudes that generally get larger when moving from less developed pairs of area types to more developed pairs of area types. The latter observation means that the more developed two areas are, the lesser the chances are that SUT goods-delivery trips will be made between them. Overall, this means that more single-unit trucks delivering goods travel outside of the most developed areas, hence increasing trip distances. This reflects what has been observed in the real world.

The model estimation results also indicate a higher probability of single-unit trucks delivering goods between Wake County and Durham County and a lower probability of them doing so between Wake County and Johnston County.

The R^2 value achieved by this model is 0.268.

Table 9-52 Single-unit truck Delivery of Goods destination choice model

Variable	Coefficient	t-stat
Attraction Ends	1	fixed
Wake-Durham Crossing	0.494	2.37
Wake-Johnston Crossing	-0.74	-2.38
Square Root of Travel Time	-1.23	-26.44
Suburb-Rural Crossing	-0.804	-3.15
Suburb-Suburb Crossing	-1.11	-3.62
Urban-Rural Crossing	-1.46	-5.28
Urban-Suburb Crossing	-1.94	-6.33
Urban-Urban Crossing	-2.64	-8.05
Model Performance		
Initial log-likelihood	-1768.025	
Final log-likelihood	-1294.127	
R^2	0.268	

(5) Single-Unit Truck Delivery of Services

As shown in Table 9-53, the destination-choice model estimation results for single-unit-truck Delivery of Service trips follow similar patterns to those for single-unit-truck Delivery of Goods trips, especially in terms of travel time and the cross-area-type dummy variables. However, cross-county dummy variables show more effect in this model than in its Delivery-of-Goods counterpart. Delivery of Service trips are slightly less likely to cross county borders than they are to stay within a single county. This model has the greatest goodness-of-fit of all the estimated commercial-vehicle destination-choice models, with an R^2 value of 0.354.

Table 9-53 Single-unit truck Delivery of Services destination choice model

Variable	Coefficient	t-stat
Attraction Ends	1	fixed
Durham-Orange Crossing	-2.15	-2.84
Wake-Durham Crossing	-0.392	-1.88
Wake-Johnston Crossing	-0.498	-1.14
Other-County Crossing	-0.856	-3.63
Square Root of Travel Time	-1.26	-28.75
Suburb-Rural Crossing	-0.572	-2.14
Suburb-Suburb Crossing	-0.769	-2.44
Urban-Rural Crossing	-1.63	-4.88
Urban-Suburb Crossing	-1.18	-3.61
Urban-Urban Crossing	-1.92	-5.42
Model Performance		
Initial log-likelihood	-2048.646	
Final log-likelihood	-1324.101	
R^2	0.354	

(6) Multi-Unit Truck Delivery of Goods

Most heavy trucks are used to transport goods between warehouses, manufacturing facilities, farms, etc. They tend to travel long distances and in less developed areas, as shown in Table 9-44 and Figure 9-12. The estimated coefficient for travel time in this model has a correct, negative sign and is statistically significant at the 99% confidence level. Its magnitude is comparable to, but smaller than, its counterparts in the single-unit-truck destination-choice models. This indicates that users of multi-unit trucks tolerate longer trips than do users of single-unit trucks.

All five cross-area-type dummy variables are significant at the 95% confidence level. They also show a clear pattern similar to those of single-unit-truck models – all of their coefficients have negative signs and their magnitudes get larger when moving from less developed pairs of area types to more developed pairs of area types. Given that the reference area-type combination for this set of dummy variables is that of traveling from a rural area to a rural area, this indicates that multi-unit trucks tend to less frequently travel in more developed areas. This is consistent with what has been observed in the real world. Traveling more frequently in less developed areas usually leads to long travel distances on average, as well.

The model estimation results also indicate that multi-unit trucks are less likely to transport goods between Wake and Durham Counties or between Wake and Orange Counties, but more likely to do so between Wake and Johnston Counties.

The R^2 value is 0.283.

Table 9-54 Multi-unit truck Delivery of Goods destination choice model

Variable	Coefficient	t-stat

Attraction Ends	1	fixed
Wake-Durham Crossing	-0.411	-1.46
Wake-Johnston Crossing	0.812	2.31
Wake-Orange Crossing	-0.533	-0.88
Square Root of Travel Time	-0.955	-15.37
Suburb-Rural Crossing	-1.9	-5.14
Suburb-Suburb Crossing	-2.14	-4.42
Urban-Rural Crossing	-2.24	-5.27
Urban-Suburb Crossing	-2.65	-6.14
Urban-Urban Crossing	-2.95	-6.5
Model Performance		
Initial log-likelihood	-858.269	
Final log-likelihood	-615.528	
R^2Rho-squared	0.283	

9.1.3.4 Model Calibration

The initial calibration of the commercial vehicle trip distribution model consisted of trying to make the estimated average trip durations (in minutes) on par with those derived from the 2010 commercial vehicle travel survey data. This is different from a full model calibration process, which usually checks model estimates against traffic counts and against vehicle miles traveled (VMT) figures reported by reliable external sources and then makes adjustments to the model where needed. A full model calibration would be conducted after the addition of an I-E/E-I/E-E module and the completion of traffic assignment, on which occasion no more model adjustments were made, beyond those in the initial calibration.

By applying the estimated commercial vehicle destination choice models to the 2010 socioeconomic data and highway-network data that are used in the TRMv6, trip interchanges between each origin TAZ and each destination TAZ by vehicle type and trip purpose were estimated. Average trip durations derived from the model output are shown in Table 9-55. Table 9-55 also shows average trip durations derived from the 2010 commercial vehicle survey after expansion, called observed trip durations here. Reported travel times for each trip record in the survey dataset were replaced with ones derived from the model highway network, which were used in the calculation of observed average trip durations. Because the numbers of observations in the survey data are small for the PM peak period and the nighttime period, trips during those two time periods were merged with midday trips for the evaluation of average trip durations.

Table 9-55 shows that in the AM peak period, observed average trip lengths ranged from about 6 minutes to 18 minutes, whereas the modeled average trip lengths ranged from about 8 minutes to 15 minutes. The percent deviations ranged from about -15% to +30%, except for a deviation of +61.2% for light-duty commercial vehicles delivering goods. In the midday, PM peak, and nighttime periods, combined, observed average trip lengths ranged from about 7 minutes to 16 minutes, and modeled average trip lengths ranged from about 8 minutes to 14 minutes. The percent deviations ranged from about -12% to +15%.

Table 9-55 Average trip lengths in minutes by vehicle type and trip purpose without calibration

Vehicle + Purpose	AM Peak			Midday, PM Peak, and Night		
	Observed	Modeled (Original)	% Deviation	Observed	Modeled (Original)	% Deviation
LCV_Goods	6.89	11.11	+61.2%	9.90	11.10	+12.1%
LCV_Services	13.50	12.23	-9.4%	11.53	12.05	+4.5%
LCV_Other	6.14	8.03	+30.8%	7.09	8.17	+15.2%
SUT_Goods	9.80	12.39	+26.4%	9.85	12.24	+24.3%
SUT_Services	9.54	10.49	+10.0%	11.75	10.37	-11.7%
MUT_Goods	17.57	15.02	-14.5%	15.55	14.34	-7.8%

Calibration of the commercial-vehicle destination-choice models involved adding zone-to-zone travel distances as an additional term in the utility functions and adjusting the coefficients for those travel distances to ensure that the models produce average trip durations that are close to observed values. This calibration effort resulted in the average trip durations shown in Table 9-56. The calibrated coefficients for travel distances used to produce those results are shown in Table 9-57. As may be seen in Table 9-56, the calibrated trip durations are very close to the observed durations, with percent deviations ranging from almost 0% to slightly more than 4% in absolute magnitude (if distinction is not made between positive and negative deviation).

Table 9-56 Average trip lengths in minutes by vehicle type and trip purpose after calibration

Vehicle + Purpose	AM Peak			Midday, PM Peak, and Night		
	Observed	Modeled (Calibrated)	% Deviation	Observed	Modeled (Calibrated)	% Deviation
LCV_Goods	6.89	7.09	+3.0%	9.90	9.85	-0.5%
LCV_Services	13.50	13.63	+1.0%	11.53	11.45	-0.7%
LCV_Other	6.14	6.28	+2.3%	7.09	6.96	-1.8%
SUT_Goods	9.80	9.75	-0.5%	9.85	9.58	-2.7%
SUT_Services	9.54	9.56	+0.2%	11.75	11.23	-4.4%
MUT_Goods	17.57	17.52	-0.3%	15.55	15.23	-2.1%

Table 9-57 Calibrated coefficients for trip distance in utility functions

VARIABLE	LCV_GOODS	LCV_SRVCS	LCV_OTHER	SUT_GOODS	SUT_SRVCS	MUT_GOODS
Distance_AM	-0.120	0.020	-0.070	-0.050	-0.020	0.025
Distance_MD	-0.025	-0.010	-0.040	-0.050	0.015	0.010
Distance_PM	-0.025	-0.010	-0.040	-0.050	0.015	0.010
Distance_NT	-0.025	-0.010	-0.040	-0.050	0.015	0.010

9.1.4 Interfacing with NCSTM to Model External Trips

Modeling and forecasting commercial vehicle trips that have one end or both ends outside the Triangle region is more challenging than modeling intraregional travel, because commercial vehicle travel is substantially influenced by the economies both of the region studied and of the state, or even country, that it is within. The TRMv5 used a two-step process to model such trips: (1) forecast traffic volumes at external stations; and (2) distribute traffic between external stations and internal TAZs using a gravity model. This approach has a couple of weaknesses. First, it is difficult to forecast future traffic volumes at external stations without additional data; for this, the TRMv5 used simple growth factors. Second, distributing trips between external stations and internal TAZs can be problematic, because external trips do not actually start from or end at the external stations; they may travel far beyond those stations.

To improve the modeling and forecasting of external commercial vehicle trips in the TRMv6, the TRMSB utilized forecasts from the North Carolina Statewide Travel Model (NCSTM). The statewide model uses nationwide and more economy-sensitive Freight Analysis Framework (FAF) data to forecast freight-related truck trips throughout the state of North Carolina. Because their data is linked to economic activities and covers a much larger area than just the TRM region, it is believed that incorporating statewide model forecasts into the regional model is a better approach than the one used for the TRMv5. Many places in the U.S. have utilized statewide model results in regional models, although the specific approaches employed have varied.

This section documents work conducted to interface the commercial vehicle component of the Triangle Regional Model with the truck component of the North Carolina Statewide Travel Model. Since two different models were involved in this work, which use different terminologies in some situations, please note that the following definitions are adhered to in this section: ”Commercial vehicles” (CV) refers to light-duty commercial vehicles (LCV, including vehicles of FHWA Vehicle Classes 2 and 3 used for commercial purposes), single-unit trucks (SUT, including vehicles of FHWA Vehicle Classes 5, 6, and 7), and multi-unit trucks (MUT, including vehicles of FHWA Vehicle Classes 8 and above). “External trips” include internal-to-external (I-E), external-to-internal (E-I), and external-to-external (E-E) trips, unless any of those three subtypes are mentioned explicitly. All trips discussed in this report are commercial vehicle trips, unless otherwise noted.

9.1.4.1 Data

The Triangle Regional Model (TRM) and the NC Statewide Travel Model (NCSTM) are the two main inputs for this work. A copy of version 1 of the NCSTM was obtained by the TRM Service Bureau in September 2013, which is the version used in this study.

Specific data items used from these two models are as follows:

1) Triangle Regional Model: TAZ system, socioeconomic data, and highway network.
2) NC Statewide Travel Model: TAZ system, highway network, and truck trip matrices. There were two truck trip matrix files, one for trucks carrying long-haul FAF commodities and the other for local short-haul truck trips that are not covered by FAF data.

9.1.4.2 Methods and Procedures

Only those trips that either have one end outside of the TRM region or have both ends outside of the region yet pass through it were brought from the NCSTM into the TRM. The general methodology to bring in NCSTM forecasts was to disaggregate NCSTM trip interchange estimates from the NCSTM TAZ structure to the TRM's TAZs. The steps involved in this process are discussed below.

9.1.4.2.1 Creating a Subarea and Obtaining Subarea Trip Matrix from NCSTM

The NCSTM covers a much larger area than the Triangle region. A subarea of the NCSTM was created that matched the geographical boundaries defined for the TRM. Then, a subarea analysis using the NCSTM was conducted in TransCAD, as shown in Figure 9-13, to generate a trip matrix for the TRM region. Figure 9-13 shows the NCSTM highway network, with the part of it that is within the Triangle region highlighted in red.

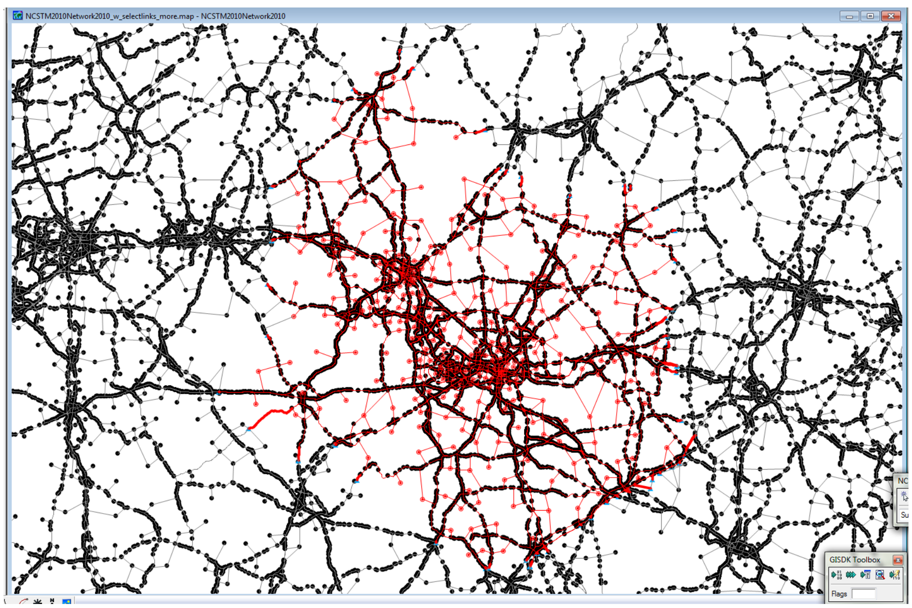


Figure 9-13 Subarea analysis for Triangle region using NCSTM

The generated subarea trip matrix contained trip interchanges among NCSTM TAZs that were inside the Triangle region, between those TAZs inside and outside of the Triangle region, and among TAZs that were all outside of the region. Because trips between TAZs that are within the Triangle region are defined as internal-to-internal (I-I) trips and are modeled separately in the TRMv6 commercial vehicle model, this portion of the subarea trip matrix was discarded. While the original NCSTM TAZ IDs of TAZs internal to the Triangle region were retained in the subarea trip matrix, TAZs outside of that region were compressed and represented by the IDs of the endpoints of the trip links that cross the boundaries of the Triangle region. There were 299 internal TAZs in the subarea trip matrix and 69 endpoints where trips crossed in and out of the region, for a total of 368 TAZs. Next, a correspondence table was created between the 299 NCSTM TAZs within the Triangle region and the TRM's internal TAZs, as well as another correspondence table between the 69 regional-boundary endpoints created from the NCSTM and the TRM's 99 designated external stations.

9.1.4.2.2 Developing an Initial Correspondence Table between TRM Internal TAZs and NCSTM TAZs

For trip matrix disaggregation, a correspondence table between source TAZs (NCSTM TAZs) and target TAZs (TRM TAZs) was developed. The purpose of this process was to compute what percent of the trip ends associated with a given NCSTM TAZ should be allocated to each of the TRM TAZs that geographically overlap it. When the NCSTM was created, its TAZs for the Triangle region were created by aggregating TAZs that were originally created for the TRMv5. The TRMv6's TAZs were also based on those from the TRMv5, but with some changes. As a result, most TRMv6 TAZ boundaries align well with the NCSTM's TAZs, each overlapping only one NCSTM TAZ; in these cases, the entire TRMv6 TAZ was assigned to its one overlapping NCSTM TAZ. However, there were still some TRMv6 TAZs that overlapped two or more NCSTM TAZs. In these cases, each TRMv6 TAZ was split into subzones, based on the boundaries of the overlapping NCSTM TAZs, and then each subzone was assigned to the NCSTM TAZ that it overlapped. The subzones were re-aggregated back to the original TRM TAZs, weighted by area.

Figure 9-14 shows an example of a TRM TAZ that overlaps multiple NCSTM TAZs. Table 9-58 shows a portion of the initial correspondence table between TRM internal TAZs and NCSTM TAZs.

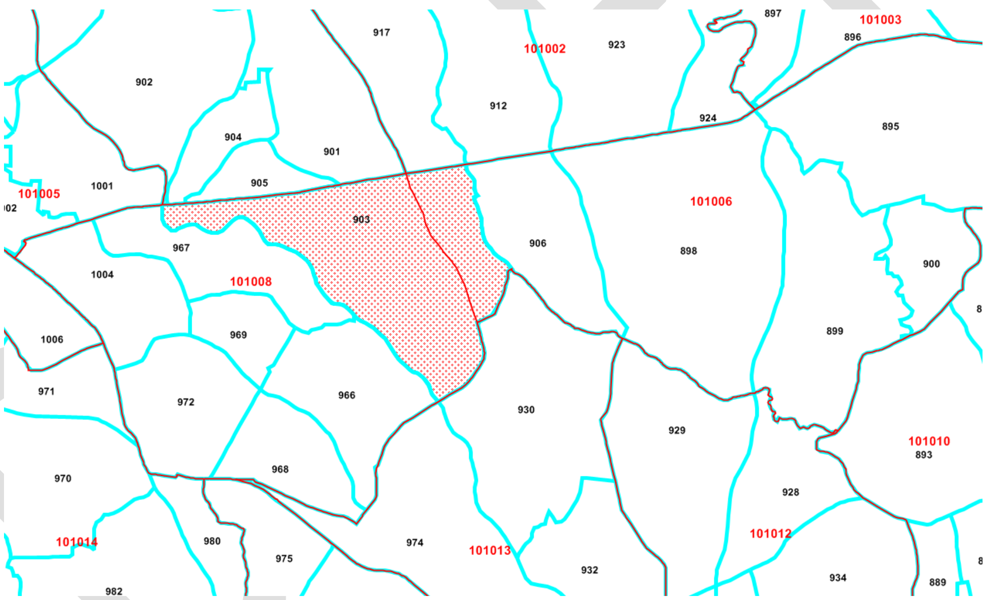


Figure 9-14 TRM TAZ 903 crossing multiple NCSTM TAZs (101006 and 101008)

Table 9-58 Part of initial correspondence table between TRM internal TAZs and NCSTM TAZs

NCSTM_TAZ	TRM_TAZ	TRM_TAZ Split_Share
101010	886	1
101010	892	1
101010	891	1
101010	888	1
101010	887	1
101010	893	1
101010	889	1

101010	890	1
101008	903	0.793
101006	903	0.207
101008	966	1
101008	967	1
101008	968	1
101008	972	1
101008	969	1
101008	1004	1
101006	895	1
101006	898	1
101006	906	1
101006	899	1
101006	900	1
…	…	…

9.1.4.2.3 Developing Linear Regression Models for Estimating Internal Truck Trip Ends (Ultimately Serving NCSTM Trip Matrix Disaggregation)

Using the above-described correspondence table directly to disaggregate NCSTM trip matrices was deemed to be insufficient. Area-based disaggregation erroneously assumes a spatially uniform distribution of the factors that impact commercial vehicle trip generation. For instance, some TAZs have more industrial employees while others have more office employees, and different types of employees have different trip generation rates. Therefore, to take these effects into account, regression models were developed, relating base-year commercial-vehicle trip ends in NCSTM TAZs to the numbers of households and of employees by type in those TAZs. Because these regression models would be applied to TRM TAZs, input data on numbers of households, numbers of employees, and employment types were all taken from TRM socioeconomic data files.

To populate NCSTM TAZs with TRM household and employment data, the TRMSB first allocated TRM socioeconomic data to each TRM TAZ or subzone created by overlapping more than one NCSTM TAZ, split proportionally by area (as described above). Using the same sample TAZs as are shown in Table 9-58, Table 9-59 demonstrates this allocation, wherein numbers of households and numbers of employees by type (industrial, office, service, and retail) are multiplied by "TRM_TAZ Split_Share" to get the values in the five rightmost columns.

Table 9-59 TRM socioeconomic data split based on initial correspondence table

NCSTM_TAZ	TRM_TAZ	TRM_TAZ Split_Share	TRM_HH	TRM_IND	TRM_OFF	TRM_SER	TRM_RET	TRM_HH Split	TRM_IND Split	TRM_OFF Split	TRM_SER Split	TRM_RET Split
101010	886	1	166	2	86	27	0	166	2	86	27	0
101010	892	1	72	0	3	0	0	72	0	3	0	0
101010	891	1	287	5	17	8	4	287	5	17	8	4
101010	888	1	159	33	86	25	14	159	33	86	25	14
101010	887	1	6	120	134	120	24	6	120	134	120	24
101010	893	1	173	0	10	4	0	173	0	10	4	0
101010	889	1	52	20	3	9	38	52	20	3	9	38
101010	890	1	188	0	63	5	0	188	0	63	5	0
101008	903	0.793	598	15	26	27	2	474.16	11.89	20.62	21.41	1.59
101006	903	0.207	598	15	26	27	2	123.84	3.11	5.38	5.59	0.41
101008	966	1	310	0	12	13	0	310	0	12	13	0
101008	967	1	849	42	20	46	6	849	42	20	46	6
101008	968	1	157	105	102	29	5	157	105	102	29	5
101008	972	1	87	184	161	50	0	87	184	161	50	0
101008	969	1	245	5	76	5	3	245	5	76	5	3
101008	1004	1	245	583	2155	73	88	245	583	2155	73	88
101006	895	1	467	1	7	13	6	467	1	7	13	6
101006	898	1	319	33	10	13	2	319	33	10	13	2
101006	906	1	115	0	0	0	0	115	0	0	0	0
101006	899	1	234	26	15	2	0	234	26	15	2	0
101006	900	1	57	20	6	0	0	57	20	6	0	0

These computed socioeconomic data were then aggregated to NCSTM TAZs, as shown in Table 9-60. With this aggregation step, predictive variables were ready for developing the intended regression models.

Table 9-60 Aggregation of TRM SE data to NCSTM TAZs

NCSTM_TAZ	Sum of TRM_HH_Split	Sum of TRM_IND_Split	Sum of TRM_OFF_Split	Sum of TRM_SER_Split	Sum of TRM_RET_Split
101010	1103	180	402	198	80
101008	2367.16	930.89	2546.62	237.41	103.59
101006	1315.84	83.11	43.38	33.59	8.41
…	…	…	…	…	…

Data to which to match the dependent variable in the regression models, trip ends by NCSTM TAZ, were obtained from the NCSTM for SUT and MUT trips. These data were exported directly from two NCSTM output trip matrix files. Both matrix files contained trips by both single-unit trucks and multi-unit trucks. One file was for long-haul, FAF-based truck trips, while the other was for local short-haul truck trips.

Light-duty commercial vehicle trips were not included in version 1 of the NCSTM. Therefore, the TRMSB had to estimate base-year light-duty commercial vehicle trips for the NCSTM. The North Carolina Statewide Travel Model (NCSTM) uses truck trip rates from the FHWA Freight Quick Response

Manual (FQRM) to estimate local short-haul single-unit-truck and multi-unit-truck trips. These rates are shown in Table 9-61. To be consistent with NCSTM truck trip generation, trip rates for four-tire vehicles were borrowed from the FQRM to estimate light-duty commercial-vehicle trips for the external-trip portion of the TRM commercial vehicle model. These rates are shown in Table 9-62. Numbers of trip origin ends and destination ends were calculated for each TAZ based on NCSTM household and employment data. The FQRM trip rates are generally high, potentially resulting in overly-high estimated numbers of trips, which it was acknowledged could require adjustments during calibration of the TRMv6.

Table 9-61 QRFM truck trip rates by NCSTM employment industry

Employment Industry	Multi-Unit Trucks	Single-Unit trucks
Education	0.009	0.068
Government	0.009	0.068
Military	0.104	0.242
High Industrial	0.104	0.242
High Retail	0.065	0.253
Industrial	0.104	0.242
Office	0.009	0.068
Retail	0.065	0.253
Service	0.009	0.068
Hospital	0.009	0.068
Households	0.038	0.099

Table 9-62 QRFM LCV trip rates by NCSTM employment industry

Employment Industry	Light-Duty Commercial Vehicles
Education	0.437
Government	0.437
Military	0.938
High Industrial	0.938
High Retail	0.888
Industrial	0.938
Office	0.437
Retail	0.888
Service	0.437
Hospital	0.437
Households	0.251

To distribute trips between TAZs, a doubly-constrained gravity model with an exponential function used for the friction factors. The friction factor equation is shown below. The parameter of -0.08 was directly borrowed from the FQRM.

$$F_{ij} = e^{-0.08 * t_{ij}} \qquad (7)$$

where

F_{ij} = friction factor between origin TAZ *i* and destination TAZ *j*, and
t_{ij} = travel time between origin TAZ *i* and destination TAZ *j*.

To achieve more accurate trip distributions for the Triangle region, TAZs and network segments from outside of North Carolina were removed. In other words, only North Carolina TAZs were retained for trip distribution and trips were distributed only among North Carolina TAZs. Finally, a statewide LCV trip matrix was generated, which was used in the NCSTM subarea analysis process to generate a subarea trip matrix for the Triangle region.

The statewide LCV trip matrix featured a mean travel time of 22.45 minutes. Its trip duration frequency distribution is shown in Figure 9-15. Overall, this distribution was deemed to not be unreasonable, even though it carried a significant chance of requiring adjustments during the model calibration process.

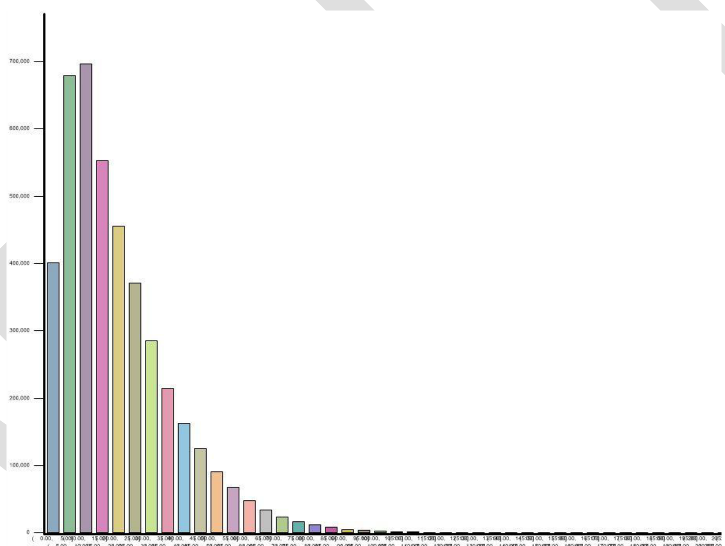


Figure 9-15 Trip duration frequency distribution of statewide LCV trips (five-minute intervals)

Table 9-63 shows a sample of dependent-variable data by vehicle type (SUT, MUT, and LCV) and long haul/short haul distinction. In total, there were 299 data records, one for each NCSTM TAZ in the Triangle region. The column headings in Table 9-63 have the following meanings, each corresponding to a different type of commercial vehicle trip:

i. TripEnds_NatSUT – trip ends of nationwide, long-haul, FAF-based, single-unit trucks
ii. TripEnds_NatMUT – trip ends of nationwide, long-haul, FAF-based, multi-unit trucks
iii. TripEnds_LocSUT – trip ends of local, short-haul, single-unit trucks
iv. TripEnds_LocMUT – trip ends of local, short-haul, multi-unit trucks
v. TripEnds_LocLCV – trip ends of local, light-duty commercial vehicles

Table 9-63 Trips by vehicle type and long haul/short haul from NCSTM model

NCSTM_TAZ	TripEnds_NatSUT	TripEnds_NatMUT	TripEnds_LocSUT	TripEnds_LocMUT	TripEnds_LocLCV*
101010	3.16	2.66	47.93	22.66	800.54
101008	46.99	36.69	278.21	188.51	3451.31
101006	1.49	1.33	10.66	6.52	429.03
…	…	…	…	…	…

* Local LCV trips were computed by TRM Service Bureau using NCSTM TAZ data

Regression models were developed for each of these five types of trips. The regression models took the following mathematical form shown below. The estimated coefficients of the explanatory variables in the models are shown in Table 9-64 through Table 9-68.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots \tag{8}$$

where

Y = trips,
β_0 = intercept,
X_1, X_2, X_3, … = independent variables, and
$\beta_1, \beta_2, \beta_3$, … = coefficients of independent variables.

Table 9-64 Regression model for long-haul, FAF-based single-unit truck trips (NatSUT)

Predictive Variable	Coefficient	t Statistic	Adjusted R^2
Industrial employees	0.0305	11.84	0.67
Office employees	0.0062	6.30	
Service employees	0.0017	1.93	
Retail employees	0.0077	2.50	

Table 9-65 Regression model for long-haul, FAF-based multi-unit truck trips (NatMUT)

Predictive Variable	Coefficient	t Statistic	Adjusted R^2
Industrial employees	0.0220	11.37	0.69
Office employees	0.0052	7.01	
Service employees	0.0014	2.09	
Retail employees	0.0073	3.17	

Table 9-66 Regression model for local, short-haul single-unit truck trips (LocSUT)

Predictive Variable	Coefficient	t Statistic	Adjusted R^2
Industrial employees	0.0895	16.90	0.95
Office employees	0.0409	20.04	
Service employees	0.0363	20.52	
Retail employees	0.0967	15.34	

Table 9-67 Regression model for local, short-haul multi-unit truck trips (LocMUT)

Predictive Variable	Coefficient	t Statistic	Adjusted R^2
Industrial employees	0.0599	13.48	0.84
Office employees	0.0174	10.17	
Service employees	0.0094	6.36	
Retail employees	0.0411	7.77	

Table 9-68 Regression model for local, short-haul light-duty commercial vehicle trips (LocLCV)

Predictive Variable	Coefficient	t Statistic	Adjusted R^2
Households	0.2464	17.44	0.98
Industrial employees	0.9275	21.33	
Office employees	0.5644	34.12	
Service employees	0.5394	37.46	
Retail employees	0.8464	14.65	

9.1.4.2.4 *Developing Final Correspondence Table between TRM Internal TAZs and NCSTM TAZs*

Each of the above regression models was applied to TRMv6 socioeconomic data at the level of TAZs and subzones (i.e., five rightmost columns in Table 9-59) to compute numbers of trips generated from those TAZs and partial TAZs. The calculated trips were then summarized by NCSTM TAZs, based on the correspondences shown in the first two columns of Table 9-59. Finally, shares were derived for each TRM TAZ or partial TAZ by dividing its number of trips by the summarized number of trips in the overlapping NCSTM TAZ. This share was eventually used to disaggregate NCSTM trip ends to TRM internal TAZs. Table 9-69 shows a portion of the final correspondence table with shares of NCSTM trip ends in the five rightmost columns for each type of commercial vehicle trip.

Table 9-69 Part of final correspondence table between TRM internal TAZs and NCSTM TAZs

TRM_TAZ	NCSTM_TAZ	SUT_Nat_Share	MUT_Nat_Share	SUT_Loc_Share	MUT_Loc_Share	LCV_Loc_Share
1	37001	0.2557	0.2434	0.1560	0.2077	0.1206
2	37001	0.2099	0.2194	0.2265	0.2157	0.1612
3	37001	0.0675	0.0754	0.1024	0.0925	0.1314
4	37001	0.0784	0.0789	0.1149	0.0952	0.1849
5	37001	0.0362	0.0353	0.0311	0.0331	0.0512
6	37001	0.0523	0.0563	0.0791	0.0652	0.1112
7	37001	0.0414	0.0425	0.0923	0.0615	0.0753
8	37001	0.0100	0.0120	0.0211	0.0185	0.0340
9	37001	0.2351	0.2225	0.1384	0.1868	0.0922
10	37001	0.0131	0.0140	0.0372	0.0229	0.0370
11	37008	0.1089	0.1104	0.1262	0.1108	0.1556
12	37008	0.5685	0.5630	0.4703	0.5464	0.4741
13	37002	0.0292	0.0278	0.0324	0.0279	0.0615
14	37002	0.1363	0.1428	0.1388	0.1313	0.2179
15	37002	0.0037	0.0043	0.0065	0.0060	0.0066
16	37002	0.0061	0.0062	0.0125	0.0089	0.0151
17	37002	0.0401	0.0463	0.0687	0.0646	0.0425
18	37002	0.1049	0.1006	0.1122	0.1010	0.1832
19	37002	0.5248	0.5174	0.4178	0.4829	0.2444

9.1.4.2.5 *Developing Correspondence Tables between TRM External Stations and NCSTM Nodes*

There are 99 external stations in the TRM network, but only 69 links in the NCSTM that cross the TRM's external border. Of those 69 links, 26 are paired directional links (such as separately-counted halves of a divided interstate highway), which consequently only correspond to 13 TRM external stations. A correspondence table was required to relate the outside-the-TRM-area endpoints of the 69 crossing links in the NCSTM and the TRM's 99 external stations. Each of the 69 NCSTM link endpoints fell into one of the following five categories:

i. NCSTM endpoint corresponding exactly to one TRM external station.
ii. NCSTM endpoint needing to be linked with multiple TRM external stations. This was the largest category, because there were more TRM external stations than crossing-link endpoints from the NCSTM, caused by some low-functional-class roads being present in the TRM but not the NCSTM.
iii. Set of two NCSTM endpoints corresponding to paired directional links that need to be merged for matching to one TRM external station. These are cases where a set of dualized directional highway links (i.e., a divided highway) in the NCSTM match up to a TRM external station. In the TRM, a single external station is used for both the inbound and outbound portions of such a pair of direction-specific highway links.
iv. Combination of the conditions in categories i and ii, above. Set of two NCSTM endpoints corresponding to paired directional links that need to be merged for matching to multiple TRM external stations.
v. Multiple NCSTM endpoints of non-paired links needing to be merged for matching to one TRM external station. There were only two instances of this, caused by links existing in the NCSTM that do not have counterparts in the TRM.

Actions taken in response to each of these five situations were (i) replace, (ii) disaggregate, (iii) aggregate, (iv) aggregate and then disaggregate, and (v) aggregate, respectively. "Replace" may be conceived of as a special case of one-to-one disaggregation or aggregation. Therefore, two steps were taken to convert NCSTM crossing-link endpoints to TRM external stations. In each step, a correspondence sub-table was created, with the first one being for aggregation and the second one being for disaggregation, as partially shown in Table 9-70 and Table 9-71. Because the process involved two steps, intermediate zones were created as a bridge between the two steps. These intermediate zones were a mix of TRM external stations and NCSTM crossing-link endpoints. Any intermediate zones present in the aggregation table (Table 9-70) had to also be present in the disaggregation table (Table 9-71).

Table 9-70 Part of correspondence sub-table for NCSTM trip matrix aggregation

NCSTM Node ID	Intermediate Zone*	Action
671502	2860	replace
662762	2876	aggregate
662765	2876	aggregate
671942	2881	aggregate & disaggregate
671949	2881	aggregate & disaggregate
672046	2897	aggregate
672049	2897	aggregate
674323	2898	replace
674326	2899	replace
674317	2901	aggregate & disaggregate
674318	2901	aggregate & disaggregate
674290	2904	replace
644536	2905	aggregate

644541	2905	aggregate
657966	657966	disaggregate
658822	658822	disaggregate
…	…	…

* Intermediate zones are either TRM external stations or NCSTM crossing-link endpoints

Table 9-71 Part of correspondence sub-table for NCSTM trip matrix disaggregation

Intermediate Zone*	TRM External Station	Share	Action
2860	2860	1	replace
2876	2876	1	aggregate
2881	2881	0.9754	aggregate & disaggregate
2881	2880	0.0111	aggregate & disaggregate
2881	2882	0.0135	aggregate & disaggregate
2897	2897	1	aggregate
2898	2898	1	replace
2899	2899	1	replace
2901	2901	0.9839	aggregate & disaggregate
2901	2900	0.0161	aggregate & disaggregate
2904	2904	1	replace
2905	2905	1	aggregate
657966	2920	0.5949	disaggregate
657966	2921	0.2894	disaggregate
657966	2922	0.1157	disaggregate
658822	2912	0.6074	disaggregate
658822	2913	0.3926	disaggregate
…	…	…	…

* Intermediate zones are either TRM external stations or NCSTM crossing-link endpoints

In Table 9-70 and Table 9-71, the “Action” column is not required for the aggregation/disaggregation process. Instead, it indicates the action that had to be taken to adapt data from each NCSTM endpoint to one or more TRM external stations.

In the disaggregation table (Table 9-71), the “Share” column reports the share of total trips from each intermediate zone that was allocated to a given TRM external station. A one-to-one match is indicated by a value of 1. In the event of a one-to-many match (e.g., intermediate zone 2881 matched to TRM external stations 2881, 2880, and 2882), the shares in the output rows add up to 1. The method used to derive these shares was as follows:

i. Obtain total average daily traffic (ADT) counts and truck percentages (PCTCV) for each external station from the TRM 2010 socioeconomic data file.
ii. Multiply ADT by PCTCV to get truck traffic counts (TRKCOUNTS) at each external station.
iii. Because each NCSTM endpoint is associated with one or more TRM external stations, aggregate TRKCOUNTS to NCSTM endpoints to get total truck traffic counts (TOT_ TRKCOUNTS) for each NCSTM endpoint.
iv. Divide TRKCOUNTS value for each TRM external station by the TOT_ TRKCOUNTS value for its associated NCSTM endpoint to calculate shares, as shown in Table 9-71.

9.1.4.2.6 NCSTM Trip Matrix Disaggregation

A GISDK script was developed to automate the process of disaggregating NCSTM trip matrices. It converted a 368-NCSTM-TAZ subarea trip matrix to a 2,956-TRM-TAZ trip matrix for each of five types of commercial vehicle trips.

9.1.4.2.7 Adjustment of Disaggregated Trip Matrix Using Fratar Procedure

After the NCSTM subarea trip matrix was disaggregated, trips at each TRM external station were summarized by vehicle type and compared with truck traffic counts at the same locations. In keeping with expectations, this revealed differences between modeled and observed values. To align modeled trips with counts, a Fratar procedure was employed. Because there was not a separate set of traffic-count data for light-duty commercial vehicles (LCV), only single-unit-truck (SUT) and multi-unit-truck (MUT) trips were adjusted to match corresponding traffic counts. LCV trips were merged with passenger automobile trips, and those trips were adjusted together, a process not discussed in this section.

Table 9-72 lists disaggregated trips and observed counts for SUTs and MUTs at each TRM external station. Because there were no observed data about SUT/MUT split at each external station, a ratio of 60/40 was assumed, barring the availability of better information and subject to the possibility of adjustment during model calibration.

As shown in Table 9-72, the estimated total number of truck trips at all external stations was 49,825.5 (20,721.6 SUT trips + 29,103.9 MUT trips), while the observed total was 69,827 (41,898 SUT trips + 27,929 MUT trips). Overall, the estimated trips were about 29% less than observed, which was deemed to not be an overly-large deviation.

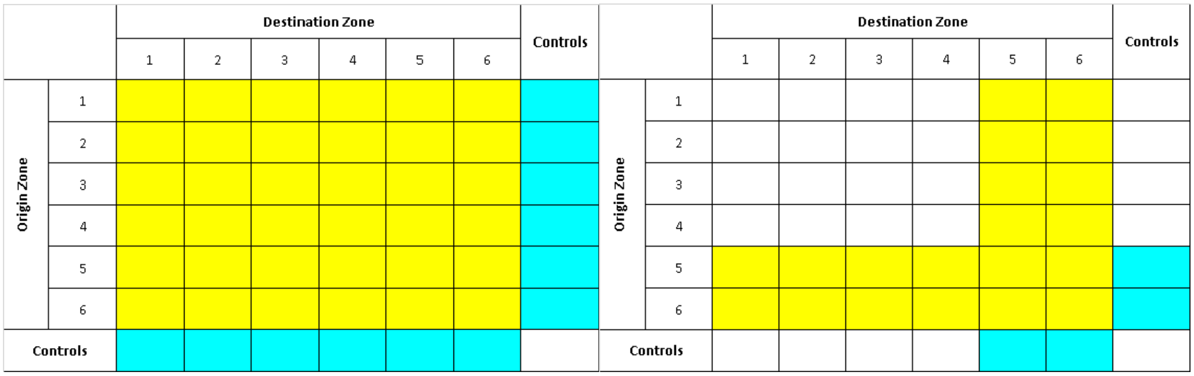
Table 9-72 Disaggregated trips and observed counts for SUTs and MUTs at TRM external stations

TRM TAZ	SUT disaggr.	MUT disaggr.	SUT observed	MUT observed		TRM TAZ	SUT disaggr.	MUT disaggr.	SUT observed	MUT observed
2858	12.9	17.6	53	35		2908	210.6	141.3	132	88
2859	96.4	130.7	394	263		2909	274.1	211.8	70	46
2860	32.7	27.9	115	77		2910	19.8	15.9	29	19
2861	94.9	81.7	557	371		2911	28.0	22.5	41	27
2862	6.5	5.6	38	26		2912	22.4	13.2	24	16
2863	5.3	4.6	31	21		2913	14.4	8.5	15	10
2864	2.4	2.0	14	9		2914	59.1	38.0	168	112
2865	3.7	3.1	23	15		2915	128.4	84.0	595	397
2866	67.2	56.9	412	275		2916	1188.8	1404.3	1446	964
2867	18.5	17.6	134	90		2917	177.4	185.4	229	153
2868	5.0	4.7	36	24		2918	77.6	52.5	65	43
2869	4.6	4.4	34	22		2919	193.8	148.5	370	246
2870	0.7	0.6	5	3		2920	60.9	49.8	89	59
2871	4.2	3.8	29	19		2921	29.6	24.2	43	29
2872	44.2	40.6	304	202		2922	11.8	9.7	17	12
2873	3.8	3.5	26	18		2923	874.0	1377.8	1489	993
2874	38.4	39.0	115	77		2924	242.5	182.6	230	154
2875	24.0	24.4	72	48		2925	1893.8	3733.4	5275	3521
2876	1734.8	2308.1	2515	1677		2926	173.9	123.4	191	127
2877	79.1	80.3	237	158		2927	57.0	40.4	62	42
2878	47.0	54.8	173	115		2928	18.8	13.8	96	64
2879	11.5	13.4	42	28		2929	38.7	28.5	198	132
2880	3.9	4.8	11	7		2930	250.9	218.1	724	483
2881	347.2	420.4	950	634		2931	10.0	8.7	29	19
2882	4.8	5.8	13	9		2932	565.6	504.8	1536	1024
2883	14.9	11.4	17	11		2933	35.5	29.4	105	70
2884	210.2	160.9	241	161		2934	19.8	14.3	110	73
2885	35.4	25.4	67	45		2935	533.3	654.5	1579	1052

2886	15.2	10.9	29	19	2936	96.8	80.9	369	246
2887	83.8	65.2	173	115	2937	15.1	11.6	35	24
2888	12.8	10.0	26	18	2938	29.0	22.3	68	45
2889	45.5	49.4	139	93	2939	4.5	4.4	12	8
2890	3.9	4.3	12	8	2940	402.8	393.1	1022	681
2891	57.1	47.0	22	14	2941	47.3	46.2	120	80
2892	12.0	9.9	5	3	2942	2.6	2.4	17	11
2893	15.8	13.1	6	4	2943	0.8	0.7	5	3
2894	8.9	7.3	3	2	2944	20.4	18.3	128	86
2895	6.8	5.1	14	9	2945	22.9	20.5	144	96
2896	36.0	27.0	74	50	2946	28.1	24.1	60	40
2897	920.9	1615.5	2194	1463	2947	117.4	100.4	252	168
2898	6.0	4.2	59	39	2948	6.6	5.7	14	9
2899	4.5	2.5	36	24	2949	89.2	132.9	110	73
2900	16.9	25.3	29	19	2950	28.0	41.7	34	23
2901	1036.0	1549.9	1765	1177	2951	5915.5	8808.5	7282	4854
2902	4.1	1.6	58	38	2952	47.1	32.3	350	233
2903	0.6	0.2	8	5	2953	17.4	11.9	129	86
2904	57.0	46.1	94	62	2954	9.4	10.6	46	31
2905	1165.9	2735.1	4009	2669	2955	22.3	25.2	110	73
2906	5.3	4.3	74	50	2956	3.8	4.3	19	12
2907	114.9	178.7	1128	751	**TOTAL**	**20721.6**	**29103.9**	**41898**	**27929**

The Fratar approach used in this modeling effort was slightly different from the one conventionally used. The conventional approach would be applied to all of the rows and columns in a two-way table, with control values for every row and every column. In this case, there were only control totals available for the TRM's external stations, meaning that only external-station estimates could be aligned with counts, even though internal TAZs contribute substantially to trips at external stations. Figure 9-16 illustrates the difference between the conventional approach (Figure 9-16a) and the one used here (Figure 9-16b). In both figures, the yellow cells are those to which the Fratar approach is applied, and the cyan cells are control totals for each row or column. Zones 1 through 4 are internal TAZs, and zones 5 and 6 are external TAZs. In Figure 9-16a, all origin-destination pairs are subject to both row-based adjustment and column-based adjustment. In Figure 9-16b, some cells are subject to row-based adjustment but not column-based adjustment (trips with origins in TAZs 5 or 6 and destinations in TAZs 1, 2, 3, or 4), while others are subject to column-based adjustment but not row-based adjustment (trips with origins in TAZs 1, 2, 3, or 4 and destinations in TAZs 5 or 6). Only external-to-external cells (i.e., trips with both their origins and their destinations in either TAZ 5 or TAZ 6) experience two-way adjustment, like in the conventional approach.

In some other regional travel models in the U.S. (e.g., SEMCOG), the conventional Fratar approach is used only to adjust E-E trips. They remove trips between internal TAZs (TAZ 1 through 4 in Figure 9-16b) and external zones (TAZs 5 and 6 in Figure 9-16b) from the trip matrix, leaving only those between pairs of external zones for the Fratar process. By doing this, they assume that I-E and E-I trips obtained by disaggregating their respective statewide models are accurate, and that only E-E trips need to be adjusted. The TRMSB chose to not make this assumption.



(a) Conventional Fratar Approach (b) Fratar Approach Used for External-Station CV Trips

Figure 9-16 Fratar process illustration

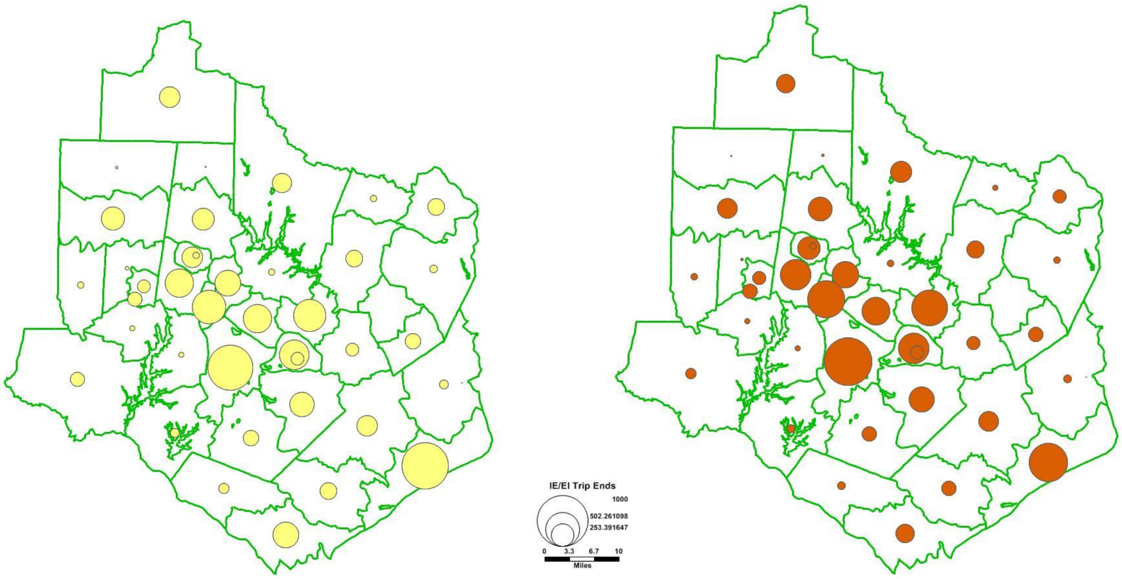
9.1.4.3 Resulting Data Files

9.1.4.3.1 <u>Base Year Trip Matrices</u>

The final results of the steps described above are three disaggregated trip matrices for the base year, originating from the NCSTM, consisting of one for light-duty commercial vehicles, one for single-unit trucks, and one for multi-unit trucks. The SUT and MUT trip matrices were subjected to a Fratar process to align them with base-year truck counts. The LCV matrix was subjected to a Fratar process after being merged with external passenger automobile trips, a process not covered in this section.

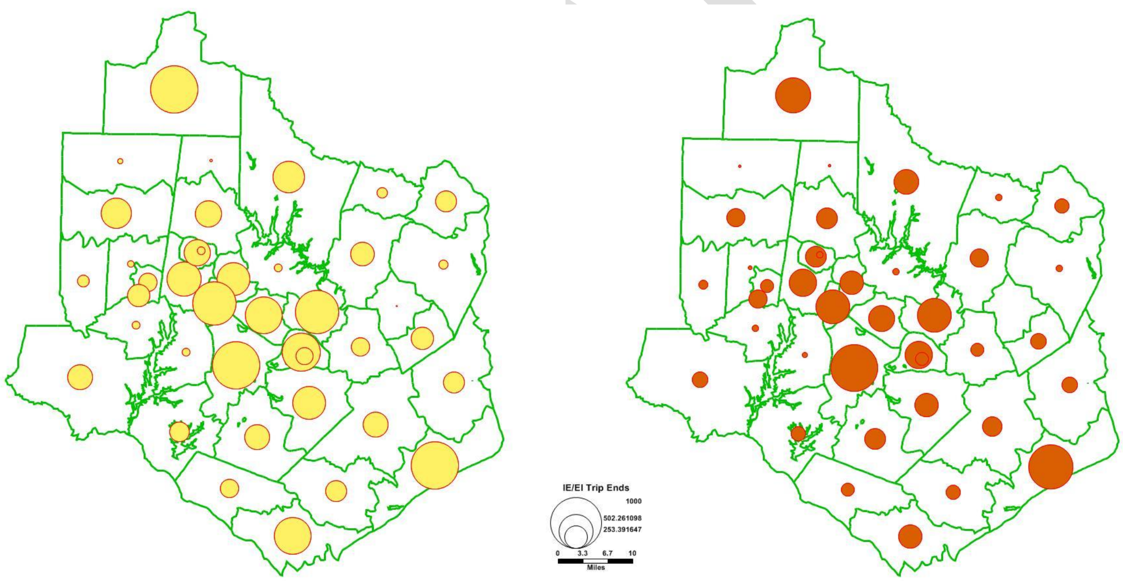
Spatial distribution of trip ends by district

I-E and E-I truck trips that start from or end in TRM internal TAZs are summarized by districts in Figure 9-17 and Figure 9-18, which show magnitudes of trip ends before and after the Fratar process, respectively. Overall, these spatial distributions were deemed to be reasonable and to correspond well with land use intensity patterns.



(a) SUT Trip Ends (b) MUT Trip Ends

Figure 9-17 I-E/E-I truck trip ends by TRM district before Fratar process



(a) SUT Trip Ends (b) MUT Trip Ends

Figure 9-18 I-E/E-I truck trip ends by TRM district after Fratar process

Average trip lengths and trip-length frequency distributions

TRM free-flow travel-time and travel-distance matrices were used to produce average trip lengths and trip-length frequency distributions of truck trips for analysis. Average trip durations (in minutes) and distances (in miles) are shown in Table 9-73 and Table 9-74. Trip duration and distance frequency distributions are shown in Figure 9-19 and Figure 9-20, respectively.

Table 9-73 Average lengths of I-E/E-I trips in model

Trip Type	Average Travel Time (minutes)	Average Travel Distance (miles)
SUT (before Fratar)	29.2	36.7
SUT (after Fratar)	27.6	34.7
MUT (before Fratar)	32.4	43.5
MUT (after Fratar)	29.6	36.8

Table 9-74 Average lengths of cordon survey I-E/E-I trips

Trip Type	Average Travel Time (minutes)	Average Travel Distance (miles)
Medium Truck	30.2	36.7
Heavy Truck	33.6	43.5

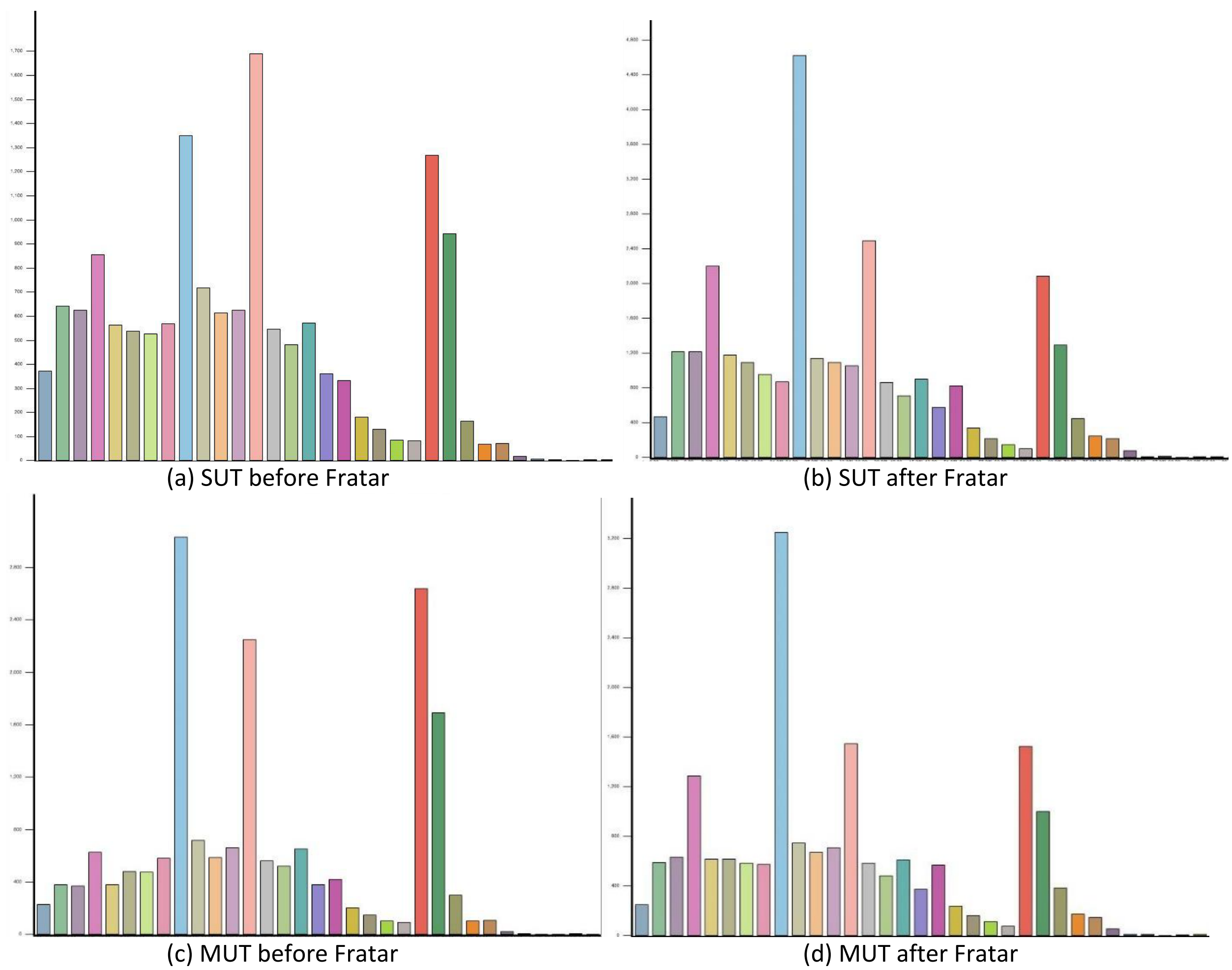
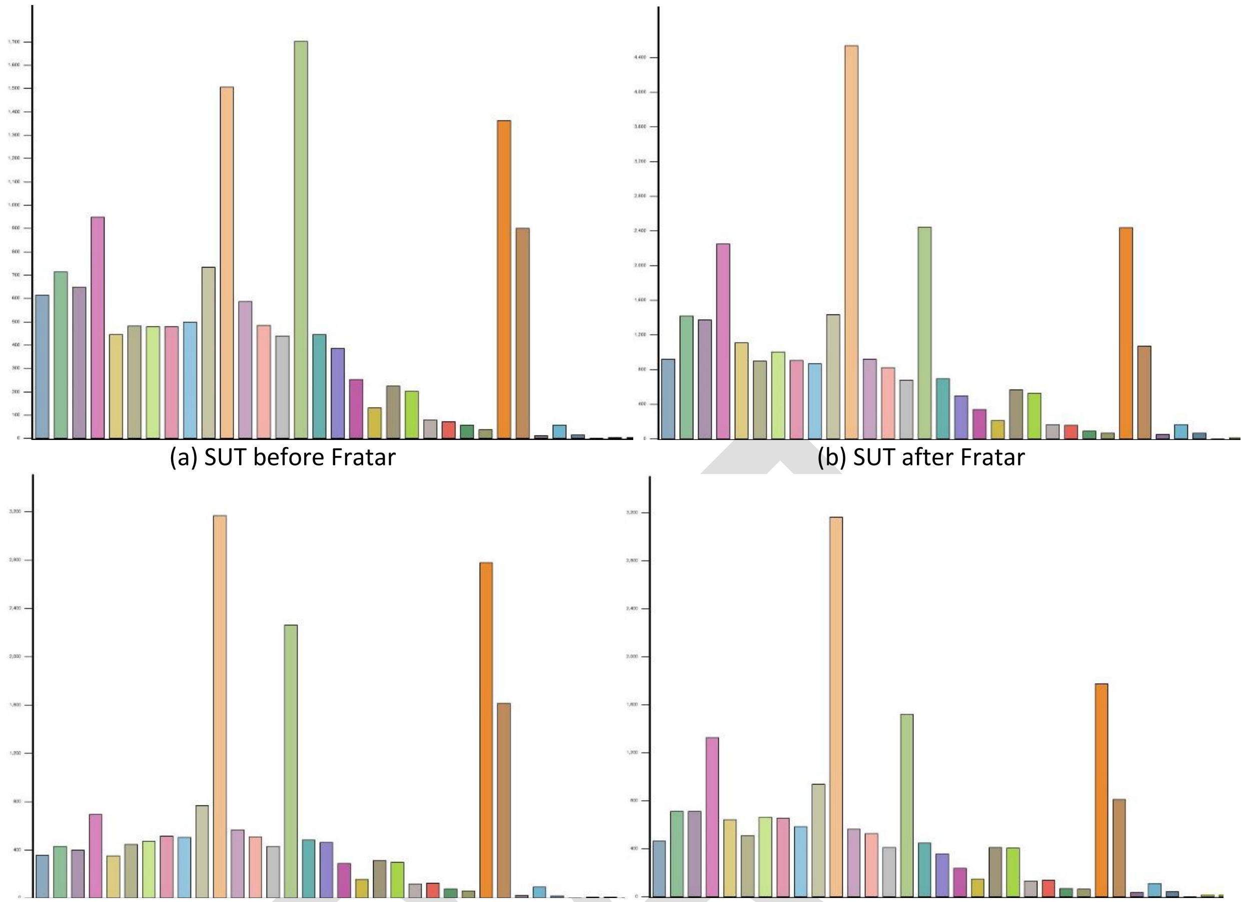


Figure 9-19 Trip duration frequency distributions (three-minute intervals)



(a) SUT before Fratar (b) SUT after Fratar

(c) MUT before Fratar (d) MUT after Fratar

Figure 9-20 Trip distance frequency distributions (three-mile intervals)

These averages and distributions were deemed to make sense for trips that have one end outside of the region and have to be truncated at the external stations when computing such statistics. On average, external trips are much longer than internal trips. Their duration and distance frequency distributions are also more uniform than those of internal trips, due to trip truncation. The spikes in the trip duration and distance frequency distributions are not abnormal. They correspond to some very common yet also long-duration/long-distance trips, such as external-external trips along I-40 or I-85, or trips from external stations to urbanized areas, the largest of which are close to the center of the region.

While the Fratar process caused some changes to the numbers of trips to and from each TAZ and changes in average trip lengths, it did not substantially change the overall patterns.

9.1.4.3.2 <u>Future Year Trip Matrices</u>

The information that the TRMSB was able to obtain from version 1 of the NCSTM only included base-year data. Therefore, for all future-year runs of the TRMv6, an assumed annual growth rate was applied to the derived base-year external-trip matrix.

9.2 University Student Model

It was decided that, in contrast to previous model versions, the TRMv6 would incorporate a separate model for university students' travel, including the steps of trip generation, trip distribution, non-motorized trip split, and motorized mode choice. This decision was made because the travel behavior of university students is markedly different from that of other people. University students account for a far larger percentage of the region's public transit trips than they do of the region's population, and trips that start or end on a university campus are much more likely than other trips to be made by non-motorized modes.

The university student model in the TRMv6 only represents travel by students at the four major universities in the Triangle region: North Carolina State University (NCSU), North Carolina Central University (NCCU), Duke University, and the University of North Carolina at Chapel Hill (UNC). Although there are other, smaller postsecondary institutions in the model area, those schools' students are not accounted for in the university student model, because those students are a small percentage of all university students in the region and including them in the university student model would have required significant additional time and data.

As described below, the university student model only divides people into two strata, students living on campus and students living off of campus, as opposed to the strata based on household income and numbers of vehicles that are used to model travel by the general population. Furthermore, only four trip purposes are considered: Home Based University (HBU), Home Based Other (HBO), University Based Non Home (UBNH), and Non Home None University (NHNU).

The principal data source used to develop the university student model was the 2001 NCSU Student Survey. More recent university-student travel surveys from the Triangle region were not available, nor were travel survey of students at UNC, NCCU, or Duke.

9.2.1 Data Preparation

This section documents how university-student data were prepared to support the model development work. It covers the processing of the 2001 NCSU Student Survey, the collection of new input variables, and the development of explanatory variables.

9.2.1.1 Processing of the 2001 NCSU Student Survey

In the 2001 North Carolina State University (NCSU) Student Survey, NCSU officials randomly selected 4,000 on-campus students and 4,000 off-campus students from the student registry for the spring 2001 semester. Students were asked to complete a travel diary for a preassigned "travel day." The survey materials were mailed to students, and each student was called back to collect their travel information. The responses were coded and entered into an Access database. Error-checking procedures were run to verify the records and fix obvious inconsistencies. Locations were geocoded using a latitude/longitude coordinate system. The survey collected 843 valid student records, representing 3.2% of the total NCSU student population at the time.

It was decided that the dataset from the 2001 NCSU Student Survey needed further processing for the following reasons:

- The trip purposes needed to be redefined to match the trip purposes defined in the TRMv6 for student trips
- Not all locations were geocoded
- Some locations were incorrectly geocoded
- The data set needed to be weighted and expanded

9.2.1.1.1 Defining New Trip Purposes

When the 2001 NCSU Student Survey was used to support model development work in the TRMv5, student trip purposes followed the trip purposes defined for the general population: Home Based Work (HBW), Home Based University (HBU), Home Based Shopping (HBS), Home Based Other (HBO), Work Based Non Home (WBNH), and Non Home Non Work (NHNW).

Distinct trip purposes from those for the general population were used for student trips in the TRMv6: Home Based University (HBU), Home Based Other (HBO), University Based Non Home (UBNH) and Non Home Non University (NHNU). The survey dataset was processed to add these new trip purposes based on place types of trip origins and destinations, as shown in Table 9-75. Table 9-75 also shows how to determine whether or not the origin of a trip is the production end, which is used to convert ODs in the survey to PAs in the model.

Table 9-75 Definitions of student trip purposes

		Place type of origin	Place type of destination	Whether origin is production
On-Campus Student	HBU	Home	Home or NCSU	1
		NCSU	Home	0
	HBO	Home	Work or Other	1
		Work or Other	Home	0
	UBNH	NCSU	Work, NCSU, or Other	1
		Work or Other	NCSU	0
	NHNW	Work or Other	Work or Other	1
Off-Campus Student	HBU	Home	NCSU	0
		NCSU	Home	1
	HBO	Home	Home, Work, or Other	1
		Work or Other	Home	0
	UBNH	NCSU	Work, NCSU, or Other	1
		Work or Other	NCSU	0
	NHNW	Work or Other	Work or Other	1

9.2.1.1.2 Geocoding Addresses

There are 5,434 trip records in the original survey data set, of which 242 (4.5%) were not geocoded. The TRMSB made efforts to geocode these missing trip ends based on Google, Google Maps, Google

Earth, the NCSU Campus Map, and local knowledge. The TRMSB successfully geocoded 200 of these trip ends.

9.2.1.1.3 Correcting Geocoding Errors

It was found that some geocoding was incorrect in the original dataset. Figure 9-21 shows some examples of the geocoding errors. The red dots are the production ends of UBNH trips made by off-campus students, and the yellow areas are NCSU TAZs. Since these are university-based trips, the production ends should be located on the NCSU campus. However, Figure 9-21 shows some trip ends as being outside of the NCSU campus, which indicates either that the trip ends were incorrectly geocoded or that the trip purposes were incorrectly defined. The TRMSB checked the production ends and the attraction ends for both on-campus and off-campus students for all four trip purposes and examined and corrected each illogical trip end. Figure 9-22 is similar to Figure 9-21, but it shows post-data-cleaning production ends in logical locations.

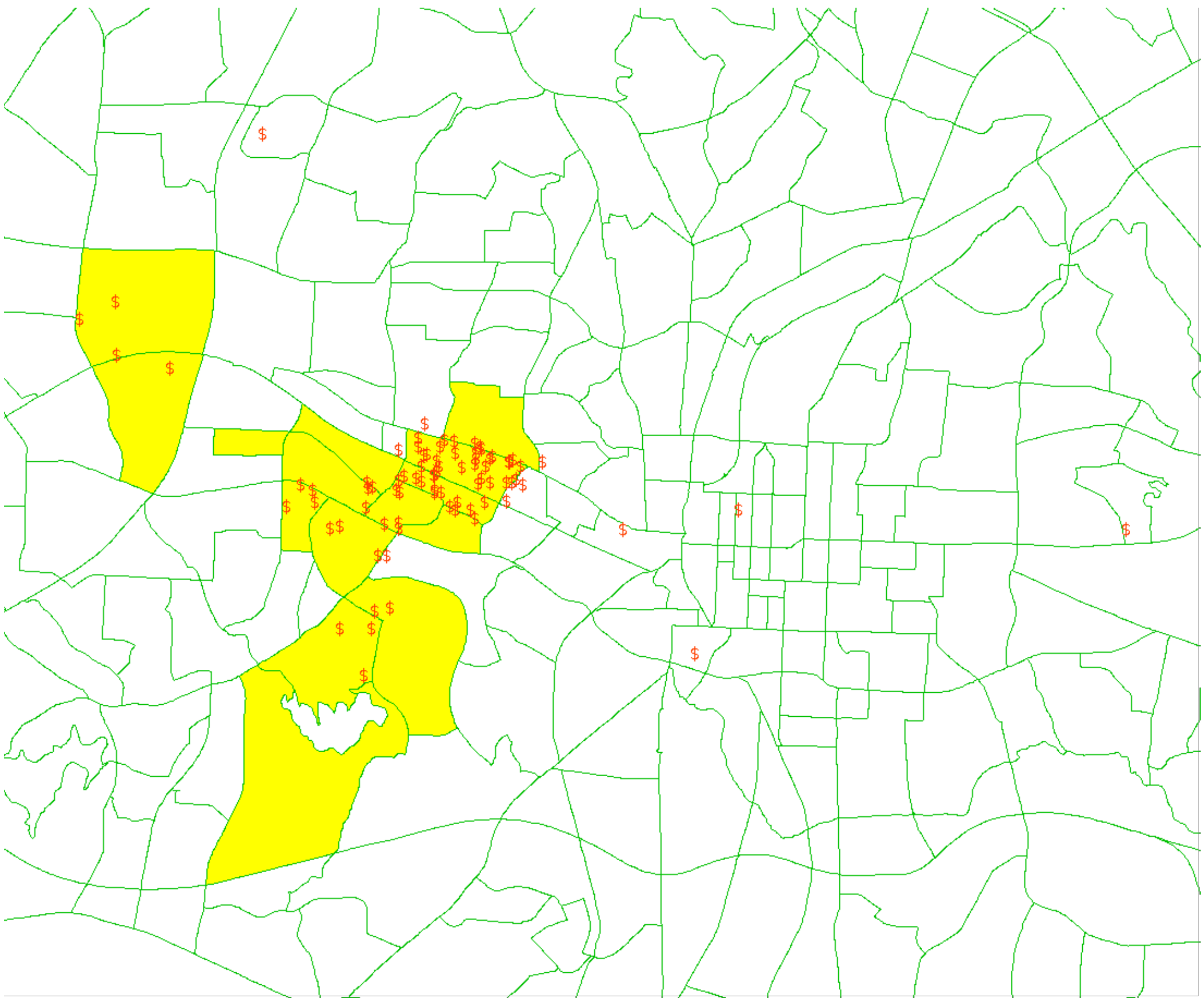


Figure 9-21 Production ends of UBNH trips made by off-campus students, before data cleaning

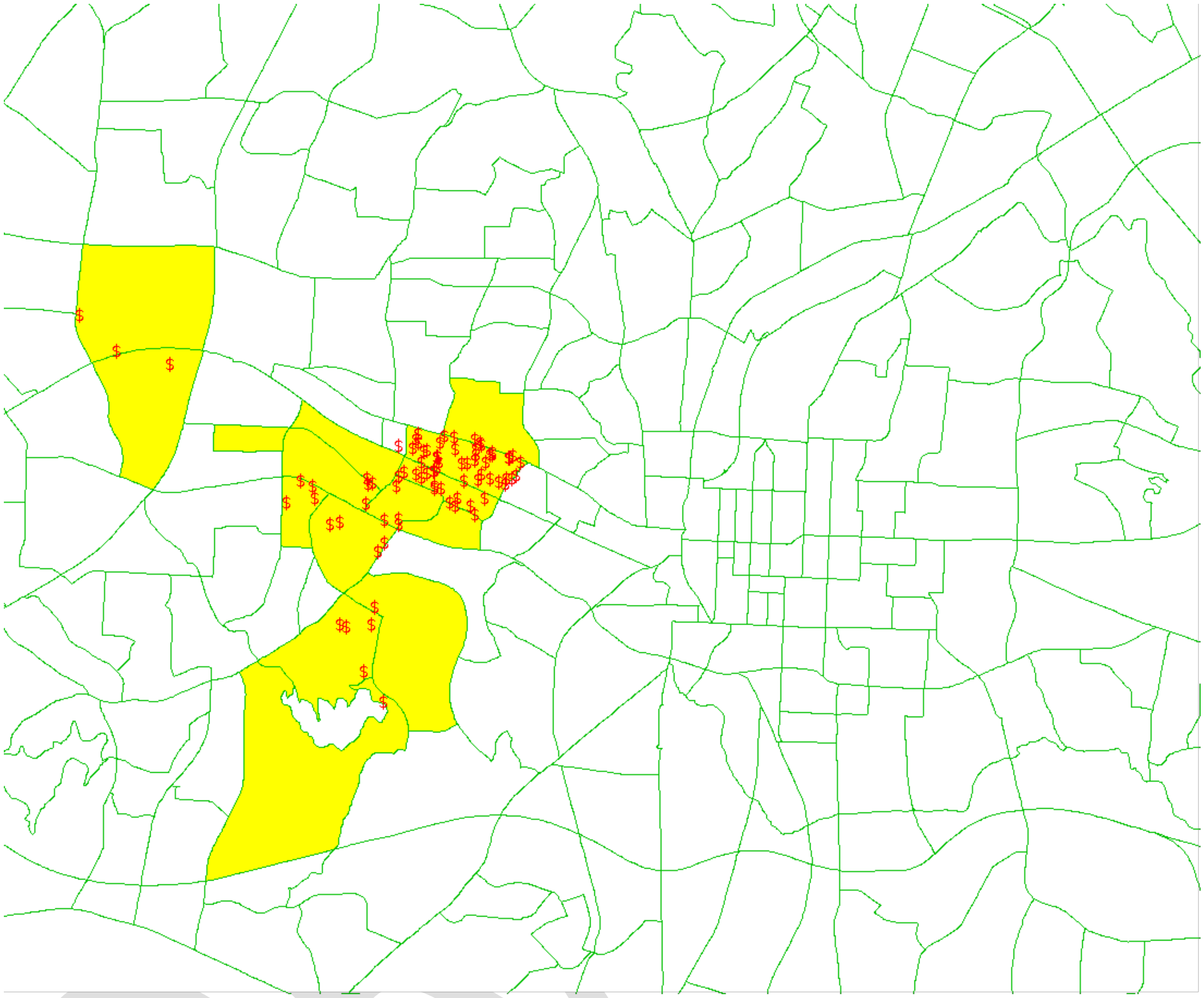


Figure 9-22 Production ends of UBNH trips made by off-campus students, after data cleaning

9.2.1.1.4 *Weighting and Expansion to 2001 Enrollment Data*

Table 9-76 shows students surveyed in the 2001 NCSU Student Survey by student type, after the data cleaning.

Table 9-76 Numbers of students in the 2001 NCSU Student Survey

		Full-Time	Part-Time	Total
On Campus	Undergraduate	394	8	402
	Graduate	14	5	19
	Subtotal	408	13	421
Off Campus	Undergraduate	189	36	225
	Graduate	98	72	170
	Subtotal	287	108	395
Total		695	121	816

The NCSU Student Survey recorded very few part-time students living on campus, which might not be representative of the overall population of part-time students living on campus. Therefore, only one weighting and expansion factor was developed for all on-campus students, both undergraduate and graduate. Similarly, one weighing and expansion factor was developed for off-campus undergraduate students and one for off-campus graduate students. These weighting and expansion factors are summarized in Table 9-77.

Table 9-77 Person weighting and expansion factors for 2001

	Samples	2001 population	Weighting and expansion factor
On-campus	421	7,364	17.49
Off-campus undergraduate	225	12,797	56.87
Off-campus graduate	170	5,516	32.45

The "2001 Population" numbers in Table 9-77 are based on the information from NCSU website, including the webpages for "University Planning and Analysis" and "University Housing." Universities keep detailed enrollment numbers, but they do not classify students as on-campus or off-campus. To derive the populations of on-campus, off-campus undergraduate, and off-campus graduate students, some key information was that NCSU's current total on-campus housing capacity is 8,568 students, including Wolf Village, which was opened in 2005 (after the time of the survey) and has 1,204 beds. About 35% of undergraduate students lived on campus[13]. The population numbers in Table 9-77 exclude distance education students.

As mentioned in Section 9.2.1.1.2, some trip ends were not successfully geocoded, and the corresponding trips were removed in the trip attraction analysis and all subsequent model steps. To account for the missing geocoding information, a geocoding weight was developed for each student type and each trip purpose, as shown in Table 9-78. The final trip weighting and expansion factor is the product of the geocoding weight and the corresponding person weighting and expansion factor.

Table 9-78 Trip weighting and expansion factors for 2001

		Number of trip records	Number of trip records with completed geocoding information	Geocoding weight	Final factor
On-campus	HBU	1805	1802	1.0017	17.52
	HBO	308	304	1.0132	17.72
	UBNH	964	961	1.0031	17.55
	NHNU	82	74	1.1081	19.38
Off-campus undergraduate	HBU	465	465	1.0000	56.87
	HBO	363	356	1.0197	57.99
	UBNH	435	435	1.0000	56.87
	NHNU	113	108	1.0463	59.51

[13] http://www.ncsu.edu/housing/fastfacts.php

Off-campus graduate	HBU	260	257	1.0117	32.83
	HBO	246	242	1.0165	32.99
	UBNH	253	249	1.0161	32.97
	NHNU	108	103	1.0485	34.02

9.2.1.1.5 Weighting and Expansion to 2010 Enrollment Data

Weighting and expansion factors were also developed for 2010, following the same method described in Section 9.2.1.1.4. The results are shown in Table 9-79 and Table 9-80.

Table 9-79 Person weighting and expansion factors for 2010

	Samples	2010 population	Weighting and expansion factor
On-campus	421	8,568	20.35
Off-campus undergraduate	225	14,346	63.76
Off-campus graduate	170	5,840	34.35

Table 9-80 Trip weighting and expansion factors for 2010

		Number of trip records	Number of trip records with completed geocoding information	Geocoding weight	Final factor
On-campus	HBU	1805	1802	1.0017	20.39
	HBO	308	304	1.0132	20.62
	UBNH	964	961	1.0031	20.42
	NHNU	82	74	1.1081	22.55
Off-campus undergraduate	HBU	465	465	1.0000	63.76
	HBO	363	356	1.0197	65.01
	UBNH	435	435	1.0000	63.76
	NHNU	113	108	1.0463	66.71
Off-campus graduate	HBU	260	257	1.0117	34.75
	HBO	246	242	1.0165	34.92
	UBNH	253	249	1.0161	34.90
	NHNU	108	103	1.0485	36.02

9.2.1.2 Collection of New Input Variables

The major on-campus trip attractors include classrooms, libraries, gyms, dining halls, etc., but there are usually not many employees working at these locations, so employment may not be a good explanatory variable. It was suggested to test a new variable, the area of on-campus buildings, to see if it works better. However, it is expected that new on-campus buildings could impact students' travel patterns significantly. For example, a new, large library, the Hunt Library, was just opened on the NCSU campus in spring of 2013, and a new on-campus housing facility, the Wolf Ridge, opened in fall of 2013. Both buildings are located on the NCSU Centennial Campus, which is about 1-2 miles away from the main campus. These two buildings attract a lot of students and change on-campus travel patterns. Building area is a straightforward variable by which to catch such changes.

University facility offices and city or state governments usually have inventories of on-campus buildings, including area and sometimes usage information. They also have development plans, which can be used to obtain the building areas for future years.

The TRMSB reached out to collect building areas from the four major universities in the TRM model area: North Carolina State University (NCSU), the University of North Carolina at Chapel Hill (UNC), North Carolina Central University (NCCU), and Duke University. Building area and usage information for all on-campus buildings was collected and aggregated to each TAZ based on building locations. Buildings were classified according to their major function: service buildings include buildings used for classrooms, gyms, student services, and libraries; office buildings include buildings used for research, administration, offices, and maintenance; residence buildings include buildings used for on-campus housing; and “other” buildings include buildings that do not fit any of the first three categories. 2010 building areas were collected for all four major universities and 2001 building areas were also collected for NCSU, since the NCSU Student Survey was conducted in 2001. Table 9-81 shows 2001 NCSU building areas by category in each on-campus TAZ.

Table 9-81 2001 NCSU building areas by building category in each on-campus TAZ (Unit: 1000 square feet)

TRMv6 TAZ ID	Service	Office	Residential	Other
1483	0	0	0	9
1485	226	138	0	0
1486	587	74	0	0
1487	2	75	115	0
1488	85	27	472	0
1489	0	0	211	0
1490	579	61	496	764
1491	2534	133	104	0
1498	0	42	74	0
1501	3	1	0	0
1503	0	0	0	450
1609	0	327	0	0
1610	0	0	0	0
1611	432	377	0	0
1613	0	0	0	899
1624	333	5	0	0
1630	0	104	0	7
1647	0	71	432	0
1648	106	18	0	0
1650	0	1	0	0
1653	0	127	0	0

9.2.1.3 Development of Explanatory Variables

A set of possible explanatory variables were prepared for the development of equations in the university student model. Some were from the SE table, such as population, employment, household income, and area type. Some were from the skim matrix, such as highway distance, auto travel time, and transit composite travel time. Some were interaction variables that were composed of two or more other variables, such as population divided by the square of the distance to the NCSU campus. For a full list of explanatory variables developed, please refer to the following section on trip generation, 9.2.2.

9.2.2 Trip Generation

This section documents the university student trip generation models used in the TRMv6. It covers trip production models and trip attraction models.

9.2.2.1 Trip Production Models

A literature review showed that many regions have used production rates in university-student trip production models. The production rates were usually calculated by student type, such as on-campus vs. off-campus. It was suggested to follow this practice in the TRMv6.

9.2.2.1.1 Trip Production Rates

The above section on data preparation, 0, showed that due to the limitation of the sample size of the 2001 NCSU Student Survey, students can only be classified into three categories. The trip production rates for each category and each trip purpose are summarized in Table 9-82.

Table 9-82 Trip rates for each student category and each trip purpose

	HBU	HBO	UBNH	NHNU	Total
On-campus	4.30	0.79	2.35	0.21	7.65
Off-campus undergraduate	1.96	1.56	1.89	0.50	5.90
Off-campus graduate	1.56	1.50	1.53	0.66	5.23

Table 9-82 shows that on-campus students make more total trips than off-campus undergraduate students, which make more total trips than off-campus graduate students. In detail, on-campus students make more Home Based University (HBU) and University Based Non Home (UBNH) trips than off-campus students (whether undergraduate or graduate), but fewer Home Based Other (HBO) and Non Home Non University (NHNU) trips. Among off-campus students, undergraduate students make more HBU, HBO and UBNH trips than do graduate students, but fewer NHNU trips. These trip rates are consistent with expectations.

Because it is easy to obtain the number of on-campus students in each TAZ, it was decided that the number of on-campus-student HBU trips produced in each TAZ would simply be the product of the number of on-campus students in each TAZ and the associated trip rate (4.30 trips per student per day), and that the same would be done for HBO trips made by on-campus students (with a trip rate of 0.79). However, it is much more difficult to obtain the number of off-campus students in each TAZ. Such numbers were provided as input data in the SE table for the TRMv5 (called “Stud_OFF”), prepared based on student home locations provided by universities. However, universities usually did not require students to accurately provide their most current local-residence locations, so those locations could be students' parents' home locations, or billing addresses, or their prior residence locations, any of which would be incorrect information to use in the model. Furthermore, the stakeholders suggested removing "Stud_OFF" from the SE table entirely, so that planners do not have to predict it for future years. For these reasons, the TRMSB developed a different method to estimate numbers of HBU trips made by off-campus students, as well as numbers of off-campus students in each TAZ (refer to Sections 9.2.2.1.2 and 9.2.2.1.3 for more details). Meanwhile, off-campus-student HBO trip productions are estimated as the product of the number of off-campus students in each TAZ and the off-campus HBO trip rate.

For UBNH trips made by both on-campus and off-campus students, the control total is the product of the number of student in a university and the applicable trip rate (2.35 for on-campus students, 1.89 for off-campus undergraduate students, and 1.53 for off-campus graduate students). To obtain the number of UBNH trips produced in each TAZ, it was suggested to distribute the control total to each TAZ based on the zonal building square footage of floor space designated for classrooms, gyms, libraries, dining halls, and other student services. The control total for NHNU trips is determined using the same method as for UBNH trips. The number of NHNU trips produced in each TAZ is set to equal the number of NHNU trips attracted to each TAZ (refer to Sections 9.2.2.2.5 and 9.2.2.2.9 for information on NHNU trip attractions).

9.2.2.1.2 Trip Production Models for HBU Trips Made by Off-Campus Students

As mentioned in Section 9.2.2.1.1, it was suggested by stakeholders that the number of off-campus students in each TAZ no longer be included in the SE table. As a result, trip rates cannot be used to model productions of HBU trips made by off-campus students (called "off-campus HBU trips" from here on). Instead, regression models are adopted.

To facilitate this analysis, the model area is divided into 50 districts. Figure 9-23 shows the relative amounts of off-campus HBU trips produced in each district.

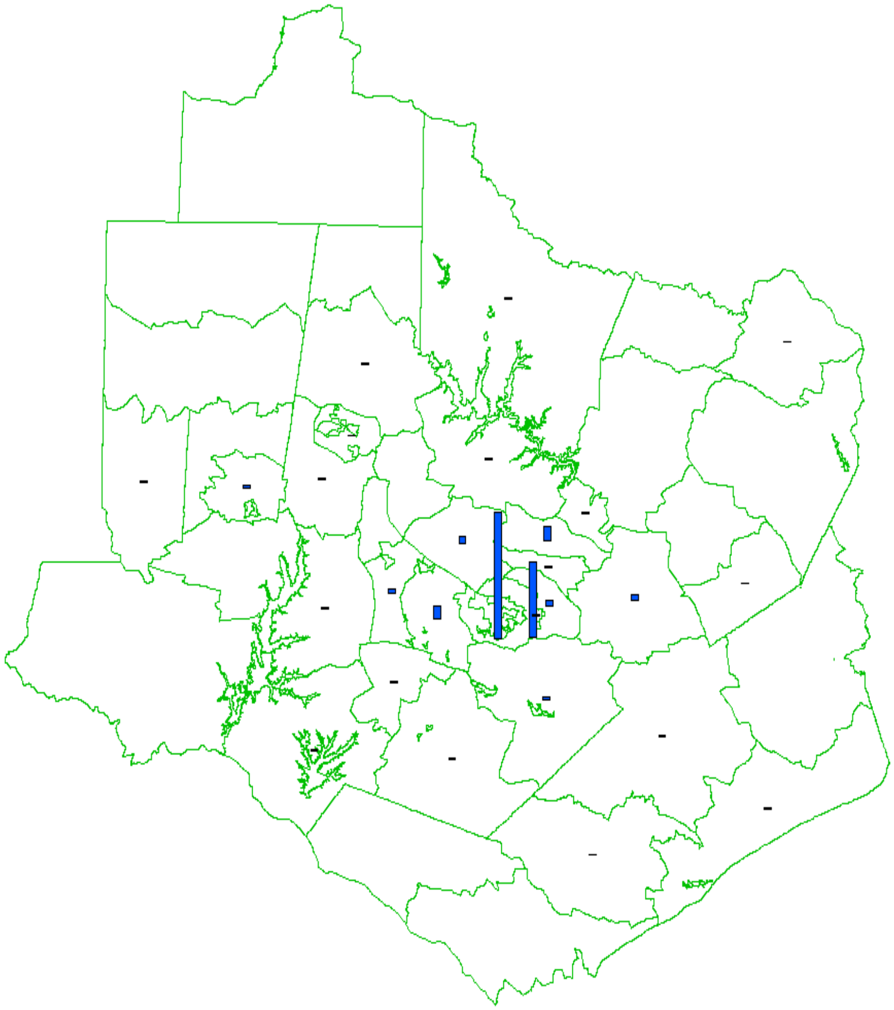


Figure 9-23 Off-campus HBU trips produced in each district

Figure 9-23 shows that off-campus HBU productions are concentrated around NCSU, and the further a district is from NCSU, the fewer off-campus HBU trips it produces. A detailed look at trips produced near NCSU is shown in Figure 9-24.

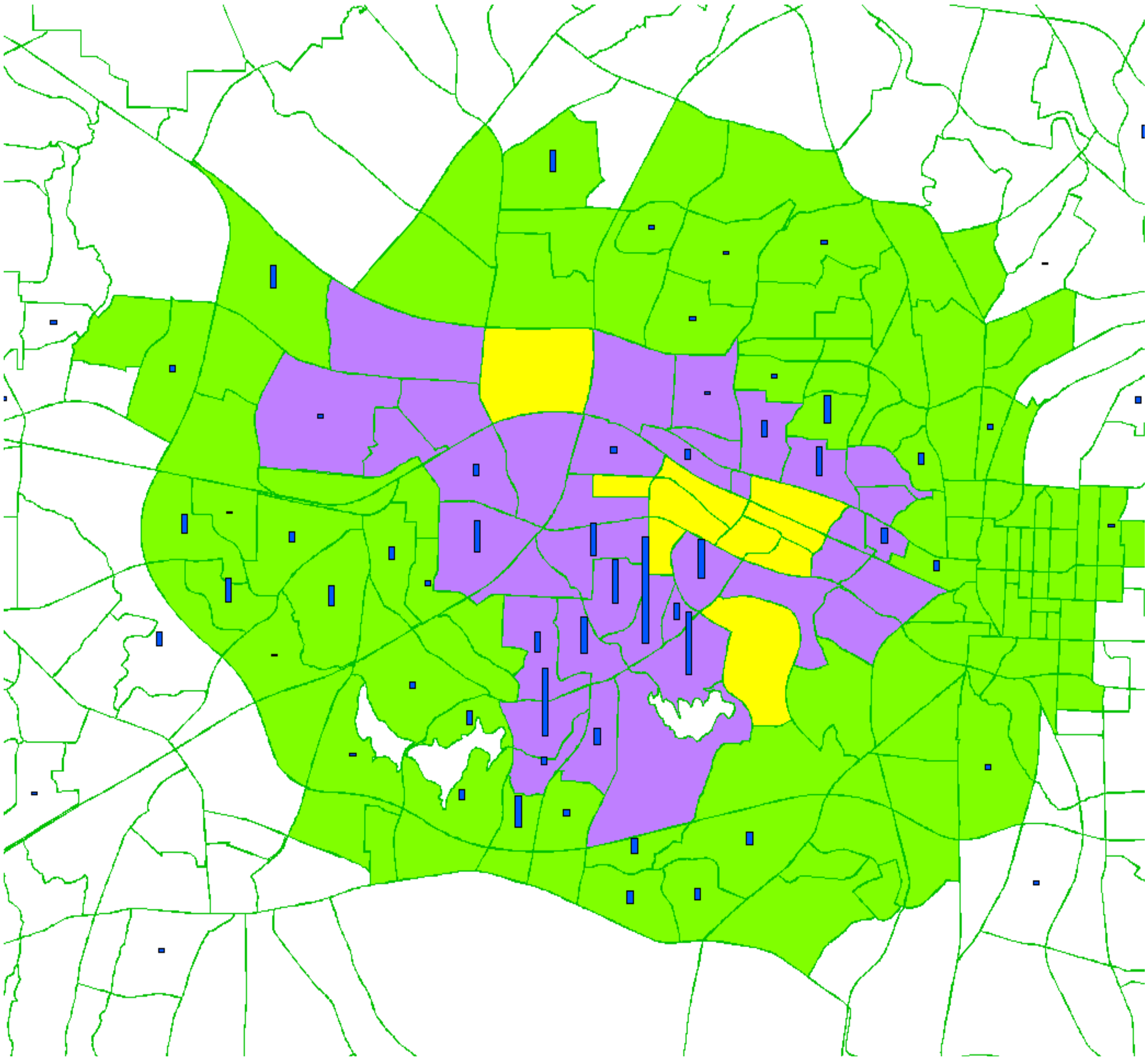


Figure 9-24 Off-campus HBU trips produced in TAZs around NCSU

In Figure 9-24, TAZs are color-coded to show four different areas. Yellow TAZs are completely on the NCSU campus, and do not produce any off-campus HBU trips, since no off-campus students live in these TAZs. Purple TAZs touch the "short walk" area (0.25-mile buffer) around Wolfline bus routes (NCSU's transit system). Green TAZs are within a two-mile buffer of Wolfline bus routes. The fourth, uncolored area consists of all TAZs outside of the first three categories. Table 9-83 summarizes off-campus HBU trips produced in each of these areas.

Table 9-83 Summary of off-campus HBU trip productions

	Number of TAZs	Off-Campus HBU Productions	Percent
NCSU campus TAZs (yellow)	10		0%

Short walk (0.25-mile buffer) to Wolfline (purple)	37	16,338	46%
Two-mile buffer of Wolfline (green)	118	9,798	27%
The rest (no color)	2,692	9,555	27%

Figure 9-24 and Table 9-83 indicate that the 37 TAZs in the "short walk to Wolfline" area produced 46% of the off-campus HBU trips in the 2001 NCSU Student Survey. Within this area, the distance to the NCSU campus does not seem to be a dominating factor in determining off-campus HBU productions. The 118 TAZs in the "two-mile buffer of Wolfline" area produces a smaller proportion of off-campus HBU trips than the short-walk area (27%), which is still more than the combined off-campus HBU productions of the 2,692 TAZs that are more than two miles from any Wolfline route.

Based on Figure 9-23 and Figure 9-24, it seems that off-campus HBU productions have different patterns in the three areas of "short walk to Wolfline," "two-mile buffer of Wolfline," and everywhere else. To better model off-campus HBU productions, it was suggested to develop three separate regression models.

A set of candidate explanatory variables was developed, and those variables were tested using the software package "JMP." Three linear regression models were selected, as shown in Table 9-84, based on statistical performance and reasonableness. Refer to Section 9.2.2.2.1 to see all of the candidate explanatory variables.

Table 9-84 Summary of linear regression formulas for off-campus HBU trip productions

	Formula	t-value	R^2
Short walk to Wolfline	$HBU_{off}^{P} = 0.873 \times Pop$	9.02	0.693
Two-mile buffer of Wolfline	$HBU_{off}^{P} = 0.183 \times Pop$	6.70	0.548
The rest	$HBU_{off}^{P} = 4.768 \times Pop/OP\_TT^2$	10.97	0.728

where

HBU_{off}^{P} = off-campus HBU trip productions,

Pop = population, and

OP_TT^2= the square of off-peak travel time to the NCSU main campus.

It is worth mentioning that the regressions in Table 9-84 were conducted based on different geographic units: the "short walk to Wolfline" regression is based on the 37 purple TAZs shown in Figure 9-24; the "two-mile buffer of Wolfline" regression is based on the 38 TAZ groups shown in Figure 9-25, as opposed to the 118 individual TAZs shown in green in Figure 9-24; and the third regression is based on 46 of the larger districts shown in Figure 9-23. This was done to mitigate the impact of under-sampling issues. The 2001 NCSU Student Survey sampled about 3% of NCSU students. It is possible for a TAZ to produce off-campus HBU trips even if no one from that TAZ was surveyed, meaning that the number of off-campus HBU productions in that TAZ is zero according to the survey. The impact of such issues is much less if two or more similar TAZs are grouped together and analyzed as one unit. However, grouping TAZs may also average out their differences, making it difficult to find relationships between dependent and explanatory variables. Therefore, appropriate geographic units should be selected for different analyses. Off-campus HBU trips were concentrated around NCSU, so under-sampling is not a big issue in near-campus areas, meaning that TAZs or small groups of TAZ can be used in that context. In areas farther from NCSU, there were very few off-campus HBU trips, so larger geographic units (the districts shown in Figure 9-23) are used.

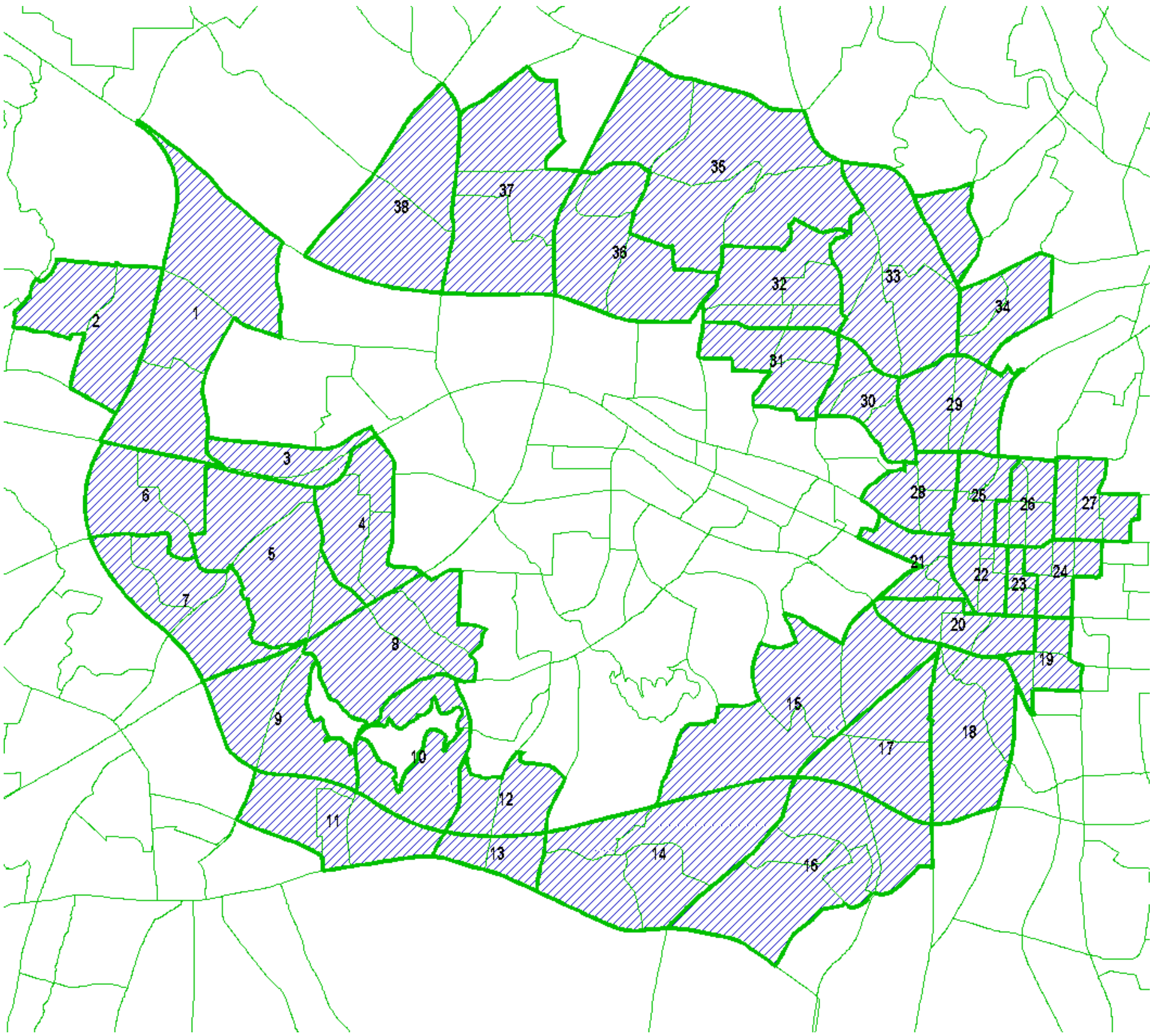


Figure 9-25 TAZ groups in two-mile buffer around Wolfline

In Table 9-84, population is used as an explanatory variable. To test the value of using this explanatory variable, the TRMSB compared the regression results for it to those for the previously discussed variable of "Stud_OFF." In the TRMv5 2010 SE table, "Stud_OFF" is the number of off-campus students residing in each TAZ who attend any of the region's four major universities, and the file "HBU Trip Campus Allocation Percentages.dbf," in the folder "input\Univ," was used to identify what percent of those off-campus students attend any given university. Based on these two files, the TRMSB calculated numbers of NCSU off-campus students in each TAZ, and used them as the explanatory variable in a linear regression model for the "short walk to Wolfline" area. Figure 9-26 compares regression plots based on the two different explanatory variables just discussed (population and calculated NCSU off-campus students living in each TAZ, as defined in the TRMv5 SE table).

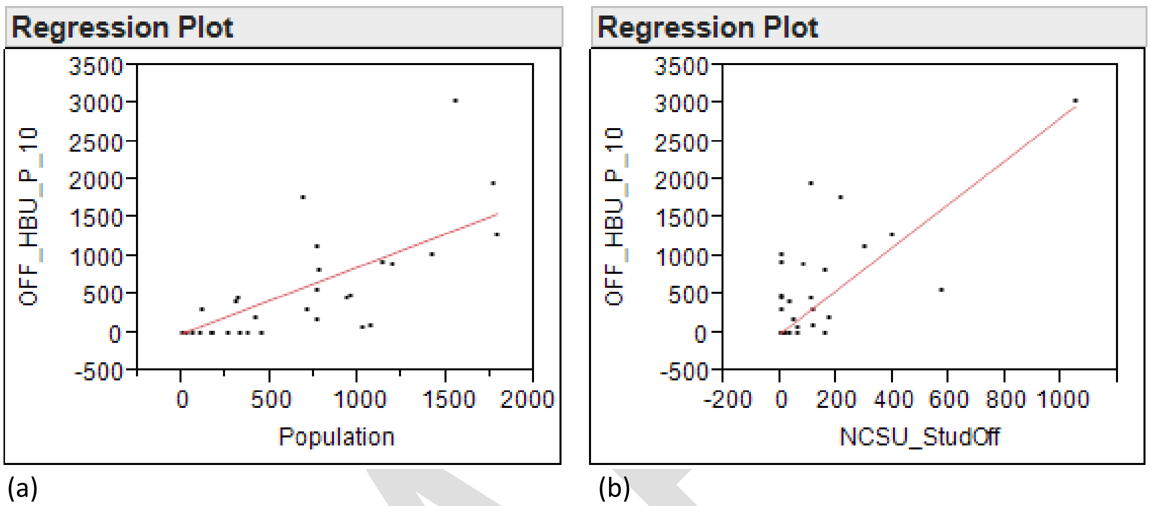


Figure 9-26 Comparison of regression plots for the "short walk to Wolfline" area, (a) using population as an explanatory variable, and (b) using NCSU off-campus students as an explanatory variable.

In Figure 9-26a, where the explanatory variable of the regression plot is population, the R^2 value is 0.693, slightly higher than the 0.627 R^2 value in Figure 9-26b, where the explanatory variable is NCSU off-campus students. Population also shows stronger correlation with off-campus HBU productions than does the calculation of NCSU off-campus students. This comparison indicates that the TRMv5 variable of "Stud_OFF" would not necessarily yield better performance than other explanatory variables.

9.2.2.1.3 How to Estimate the Number of Off-Campus Students in Each TAZ

Section 9.2.2.1.2 shows how to estimate off-campus HBU trips produced in a given TAZ, which does not require knowing the number of off-campus students in each TAZ. However, numbers of off-campus students are still needed for the model, for the following two reasons:

- The TRMv6 will model university students and the general population separately, so numbers of off-campus students must be subtracted from the total population of each TAZ in order to determine its non-student population.
- Numbers of off-campus students are needed to estimate HBO trips produced in each TAZ that are made by off-campus students (called "off-campus HBO trips").

It was suggested to estimate numbers of off-campus students in each TAZ according to the following steps:

- Step 1: Calculate numbers of off-campus HBU trips produced in each TAZ, using the formulas in Table 9-84.
- Step 2: Divide off-campus HBU trips produced in each TAZ by the appropriate trip rates from the 2001 NCSU Student Survey. Depending on the location of the TAZ, one of the three trip rates shown in Table 9-85 is to be used.

Table 9-85 Off-campus HBU trip rates by locations

	Off-Campus HBU Trip Rates
Short walk to Wolfline	2.60
Two-mile buffer of Wolfline	2.08
The rest	1.19

This method was used to estimate off-campus NCSU students in each TAZ. It is still not clear whether this method and the numbers from the NCSU Student Survey work well for UNC, NCCU, and Duke. The TRMSB checked the reasonableness of the results based on available datasets, and made adjustments when necessary.

9.2.2.2 Trip Attraction Models

Following normal practices, regression models were used to determine university student trip attractions.

9.2.2.2.1 Development of Candidate Explanatory Variables

A set of candidate explanatory variables was developed. Some are based on the SE table, some are based on newly collected data, and some are based on the network skim, as listed in Table 9-86, Table 9-87, and Table 9-88, respectively. The network skim files used were based on new free-flow speed procedures developed for the TRMv6.

Table 9-86 Candidate explanatory variables from the SE table

		Definition	Note
1	POP	Population from the SE table	
2	POP_Density	Population density	= POP/Area
3	Mean_INC	Mean household income from the SE table	
4	HH	Number of households	
4	Area_Type	Area type, based on the SE data	1=CBD, 2=Urban, 3=Suburban, and 4=Rural
5	CBD	Dummy variable if area type is CBD	
6	Urban	Dummy variable if area type is Urban	
7	Suburb	Dummy variable if area type is Suburban	
8	Rural	Dummy variable if area type is Rural	
9	Service_RateLow	Employment in service with lower attraction rate	
10	Service_RateHigh	Employment in service with higher attraction rate	
11	Retail	Employment in retail	

12	Industry	Employment in industry	
13	Office	Employment in office	
14	Emp	Total employment	= sum of variables 9 through 13
15	NonRetail	Employment not in retail	= Emp - Retail

Table 9-87 Candidate explanatory variables based on newly collected data

		Definition	Note
1	Stud_ON_2001	Number of on-campus students in 2001	
2	Stud_ON_2010	Number of on-campus students in 2010	
3	Building_Area_Service	Floor area of on-campus buildings used for service, including classrooms, gyms, libraries, dining halls, and other service facilities	The unit is 1000 square feet. For year 2001.
4	Building_Area_Office	Floor area of on-campus buildings used for office purposes, including research, administration, offices, and maintenance	The unit is 1000 square feet. For year 2001.
5	Building_Area_Residence	Floor area of on-campus buildings used for residence (on-campus housing)	The unit is 1000 square feet. For year 2001.
6	Building_Area_Other	Floor area of on-campus buildings not used for service, office, or residence	The unit is 1000 square feet. For year 2001.
7	Building_Area_S+O	Floor area of on-campus buildings used for service or office	The unit is 1000 square feet. For year 2001.

Table 9-88 Candidate explanatory variables based on the network skim

		Definition	Note
1	Dist	Highway distance to NCSU (the central campus, TAZ 1490)	Used “Distance” in OPLOV2.mtx
2	OP_TT	Auto travel time to NCSU (TAZ 1490) in the off-peak time period	Used “Time” in OPLOV2.mtx
3	OP_Local	Local bus composite travel time to NCSU (TAZ 1490) in the off-peak time period. The formula is ([Local_W]+([Walk_W]+[CBDWalk_W]+[Wait1_W]+[Wait2_W])*2+[Fare_W]/0.2)/100	Based on OPL.mtx. The maximum value is 341.75. Changed all 0 values to 10,000.
4	OP_EXP	Express bus composite travel time to NCSU (TAZ 1490) in the off-peak time period. The formula is ([Local_W]+[Exp_W]+([Walk_W]+[CBDWalk_W]+[Wait1_W]+[Wait2_W])*2+[Fare_W]/0.2)/100	Based on OPP.mtx. The maximum value is 394.83. Changed all 0 values to 10,000.

5	OP_Transit	The minimum of OP_Local_to_NCSU and OP_EXP_to_NCSU	
6	Accessible_Local	Dummy variable. Is equal to 1 if OP_Local <10,000.	
7	Accessible_EXP	Dummy variable. Is equal to 1 if OP_EXP <10,000.	
8	Accessible_Transit	Dummy variable. Is equal to 1 if OP_Transit <10,000.	

Interaction variables were also tested for explanatory power in the model development process, consisting of composites of two or more of the variables listed in Table 9-86 through Table 9-88. Table 9-89 only lists those interaction variables that are used in the final regression models.

Table 9-89 Interaction variables

		Formula
1	POP/OP_TT	=POP/OP_TT
2	POP/OP_TT_sqr	=POP/(OP_TT)^2
3	POP/OP_TT_3	=POP/(OP_TT)^3
4	POP/Dist_sqr	=POP/Dist^2
5	Retail/Dist	=Retail/Dist
6	Retail/Dist_sqr	=Retail/Dist^2
7	Retail/OP_TT_2	=Retail/(OP_TT)^2
8	Retail/OP_TT_3	=Retail/(OP_TT)^3
9	Retail/OP_TT_4	=Retail/(OP_TT)^4
10	Emp/OP_TT_3	=Emp/(OP_TT)^3

Intuitively, many explanatory variables could impact the trip attractions of university students, and Table 9-86 through Table 9-89 list many of them. To decide which explanatory variable should be included in the final models, the following things were considered:

- The regression model should have no intercept.
- The regression model should not be able to generate negative values. For example, in a regression model that includes only “POP” and “Rural” as the explanatory variables, if “Rural” has a negative coefficient, the number of trip attractions will be negative for a TAZ with “POP”=0 and “Rural”=1. In this example, “Rural” should be removed from the regression model.
- Due to the special characteristics of university student trips (most trip productions are on campus or near campus), the interaction variables shown in Table 9-89 are likely to provide better explanatory power than other variables.

9.2.2.2.2 Trip Attraction Models for HBU Trips Made by On-Campus Students

The attraction ends of HBU trips made by on-campus students (called “on-campus HBU trips”) are on-campus TAZs. There are only 20 TAZs that contain NCSU buildings, and they are the only TAZs that could attract HBU trips. Therefore, the regression was conducted based on these 20 TAZs. Table 9-90 shows the regression model for on-campus HBU attractions.

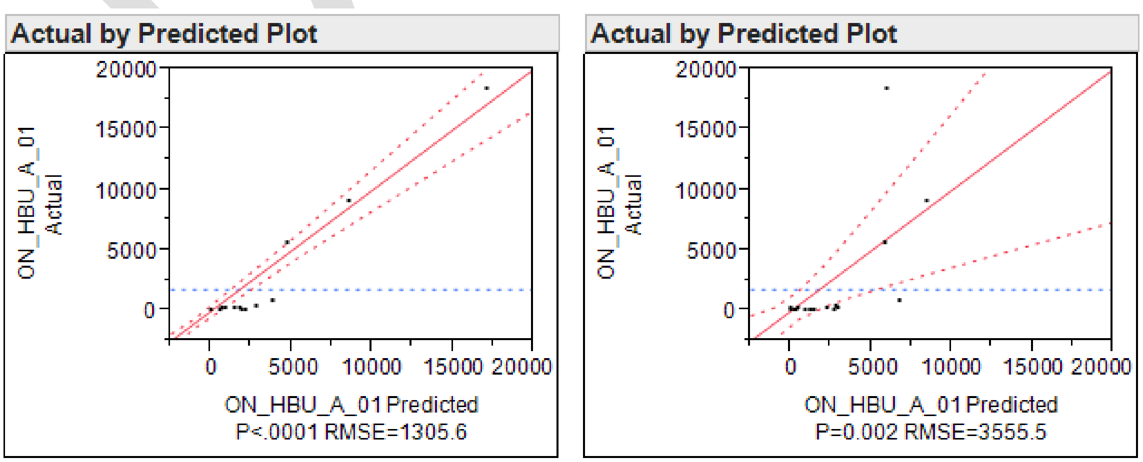
Table 9-90 Regression model for on-campus HBU attractions

Formula	StudOn_HBU_A = 6.406 * Building_Area_Service + 1.991 * Stud_ON
t-value for "Building_Area_Service"	12.91
t-value for "Stud_ON"	5.21
R^2	0.93
Note	Based on the 20 TAZs with NCSU buildings

To create the formula in Table 9-90, StudOn_HBU_A was set as the number of on-campus HBU attractions in 2001 (that is, the survey data were weighted and expanded using 2001 factors). To be consistent, Building_Area_Service and Stud_ON were also set to 2001 numbers. It is possible to use 2010 numbers for all three of these variables, but weighted and expanded 2010 on-campus HBU attractions might not reflect actual 2010 on-campus HBU attractions, since the NCSU Student Survey was conducted in 2001. Given the fast development of the NCSU campus between 2001 and 2010, especially on the NCSU Centennial Campus, it is better to base the analysis on 2001 numbers. When the regression model in Table 9-90 is applied, 2010 university building floor area for service and 2010 on-campus student numbers can be used to yield estimated 2010 on-campus HBU attractions.

Table 9-90 shows that on-campus HBU attractions can be explained using university building floor area for service and numbers of on-campus students, which is an expected result. Service buildings, such as those containing classrooms, gyms, libraries, and dining halls, are major on-campus attractors. Tests showed that building floor area for office is not a significant explanatory variable. Although building floor area for residence has significant explanatory power, it is highly correlated with Stud_ON, and data for Stud_ON are easier to collect.

A test was performed to see if employment could replace building floor area in the regression model, so as to remove the need to collect and predict building floor areas. Figure 9-27 compares regression plots based on these different explanatory variables.



(a) (b)

Figure 9-27 Comparison of on-campus HBU attraction regression plots, (a) using service building floor area as an explanatory variable, and (b) using employment as an explanatory variable.

In Figure 9-27a, where service building floor area is an explanatory variable, the R^2 value is 0.93, and the corresponding regression formula is shown in Table 9-90. In Figure 9-27b, where employment is an explanatory variable, the R^2 value is much lower (0.50), and the formula is StudOn_HBU_A = 2.229 * Office + 2.771 * Stud_ON. This comparison indicates that building floor area is a much better explanatory variable than employment, so it was deemed worthwhile to collect building-floor-area information.

9.2.2.2.3 Trip Attraction Models for HBO Trips Made by On-Campus Students

The attraction ends of HBO trips made by on-campus students (called "on-campus HBO trips") are off-campus TAZs. There are many such TAZs, but, intuitively, most on-campus HBO attractions in the NCSU Student Survey should be around NCSU. Figure 9-28 shows on-campus HBO attractions in each TAZ around NCSU. Figure 9-29 shows the same for each district of the overall model area.

The TRMSB tried to develop a single regression model for on-campus HBO trip attractions, based on the districts shown in Figure 9-29. However, since the district that is closest to the NCSU campus (the purple area in Figure 9-28) has much higher on-campus HBO attractions than other districts, one regression model does not seem adequate to model these trip attractions well. Therefore, two separate regression models were suggested, as shown in Table 9-91 and Table 9-92.

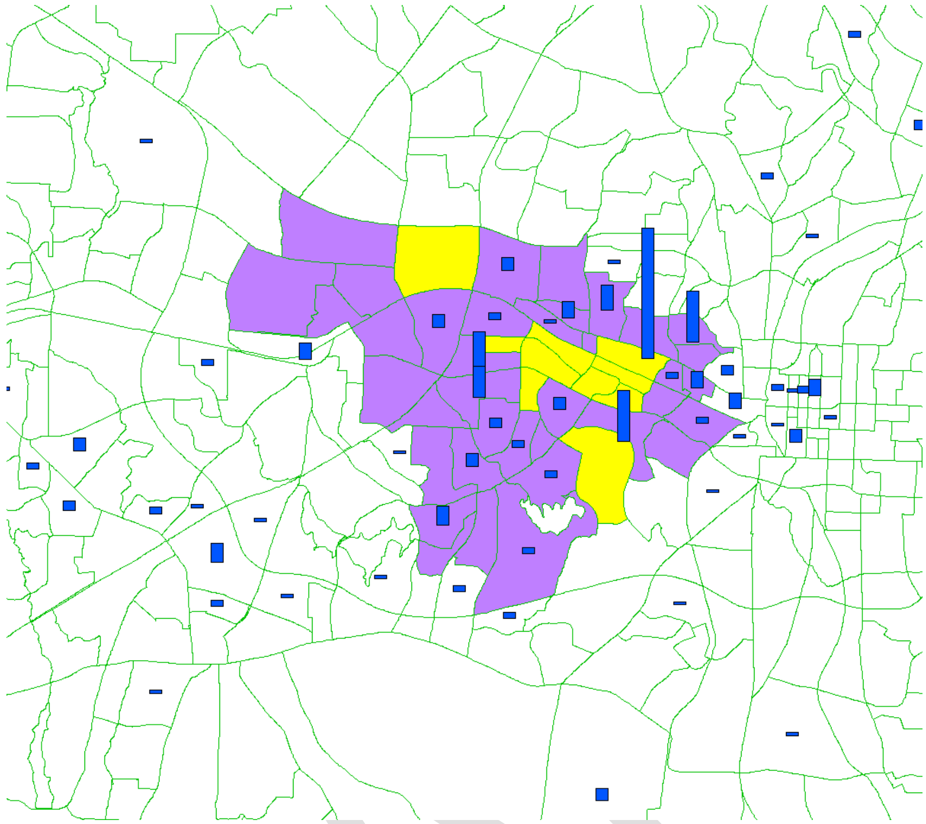


Figure 9-28 On-campus HBO attractions in each TAZ around NCSU

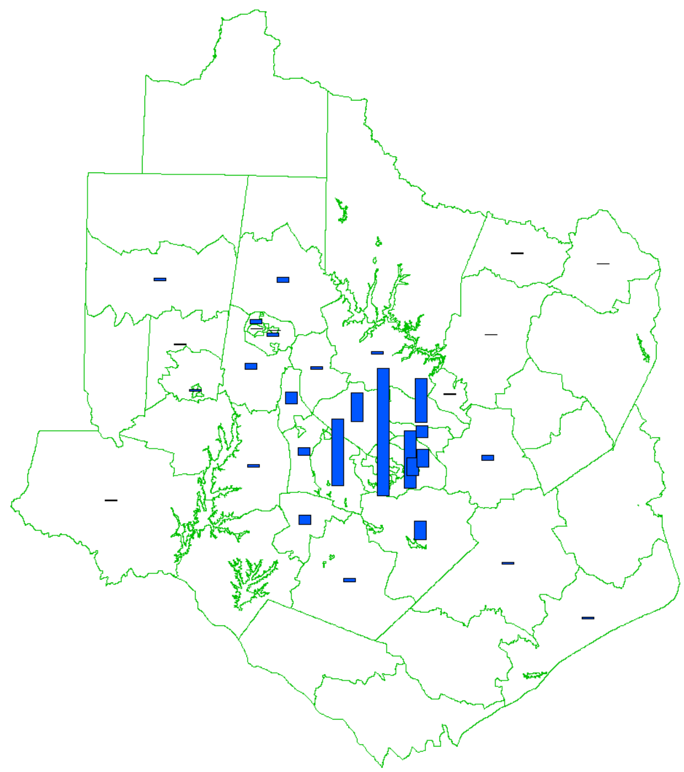


Figure 9-29 On-campus HBO attractions in each district of the overall model area

Table 9-91 Regression model for on-campus HBO attractions around NCSU

Formula	StudOn_HBO_A = 0.6428 * Retail/Dist + 0.1579 * POP/Dist_sqr
t-value for “Retail/Dist”	5.87
t-value for “POP/Dist_sqr”	3.26
R^2	0.63
Note	Based on the 37 TAZs in the “short walk to Wolfline” area. 49.8% of on-campus HBO trips were attracted to these 37 TAZs.

Table 9-92 Regression model for on-campus HBO attractions not around NCSU

Formula	StudOn_HBO_A = 199.5473 * Retail/OP_TT_3
t-value for “Retail/OP_TT_3”	16.48
R^2	0.85
Note	Based on 48 districts (excluding the NCSU district and the “short walk to Wolfline” district). 50.2% of on-campus HBO trips were attracted to these 48 districts.

The analysis shown in Table 9-91 and Table 9-92 is based on values for the year 2010. Since the NCSU Student Survey was conducted in 2001, travel pattern information collected from that survey reflect 2001 travel patterns, and expanding the survey to 2010 does not necessarily produce information reflective of 2010. Therefore, it would be preferable if a regression analysis could be conducted on the basis of 2001 values. However, the only available 2001 data are for the floor areas of on-campus buildings and numbers of on-campus students. Neither a 2001 SE table nor a 2001 network skim is available. As a result, "StudON_HBO_A" was expanded to 2010 and the regression analysis was conducted for 2010. This practice is similar to what was done for the Household Travel Survey: the survey was conducted in 2006, but it was expanded to 2010 and all analyses were conducted for 2010.

9.2.2.2.4 Trip Attraction Model for UBNH Trips Made by On-Campus Students

The attraction ends of UBNH trips made by on-campus students (called "on-campus UBNH trips") can be on-campus TAZs or off-campus TAZs. Examples of on-campus UBNH trips include trips from one classroom to another or from a university library to an off-campus restaurant. These are usually short trips, and the average trip distance is only 0.79 miles. Most on-campus UBNH trips end on-campus (84%) or around campus (9% in the "short walk to Wolfline" area), with almost no trips outside of those areas.

The TRMSB developed a single regression model based on the 50 districts of the model area discussed above. One regression model was deemed sufficient to catch all variations among districts. This regression model is shown in Table 9-93.

Table 9-93 Regression model for on-campus UBNH attractions

Formula	StudOn_UBNH_A = 3.1926 * Building_Area_Service + 47.4604 * Retail/OP_TT_3
t-value for "Building_Area_Service"	302.36
t-value for "Retail/OP_TT_3"	7.84
R^2	0.999
Note	Based on all 50 districts in the model area.

In Table 9-93, "StudOn_UBNH_A" is on-campus UBNH attractions in 2001 (that is, the survey data were weighted and expanded using 2001 factors). To be consistent, the values used for Building_Area_Service were also from 2001. Unfortunately, 2001 "Retail" and "OP_TT" data were unavailable, so 2010 numbers were used, instead. This inconsistency likely does not skew the results too much, since the first term (Building_Area_Service) dominates.

9.2.2.2.5 Trip Attraction Model for NHNU Trips Made by On-Campus Students

The attraction ends of NHNU trips made by on-campus students (called "on-campus NHNU trips") are off-campus TAZs. An example of an on-campus NHNU trip is traveling from an off-campus restaurant to an off-campus shopping center. As shown in Table 9-82, on-campus students make few NHNU trips, with a trip rate of only 0.21. Most on-campus NHNU trips in the NCSU Student Survey are in the area around the NCSU campus, as shown in Figure 9-30.

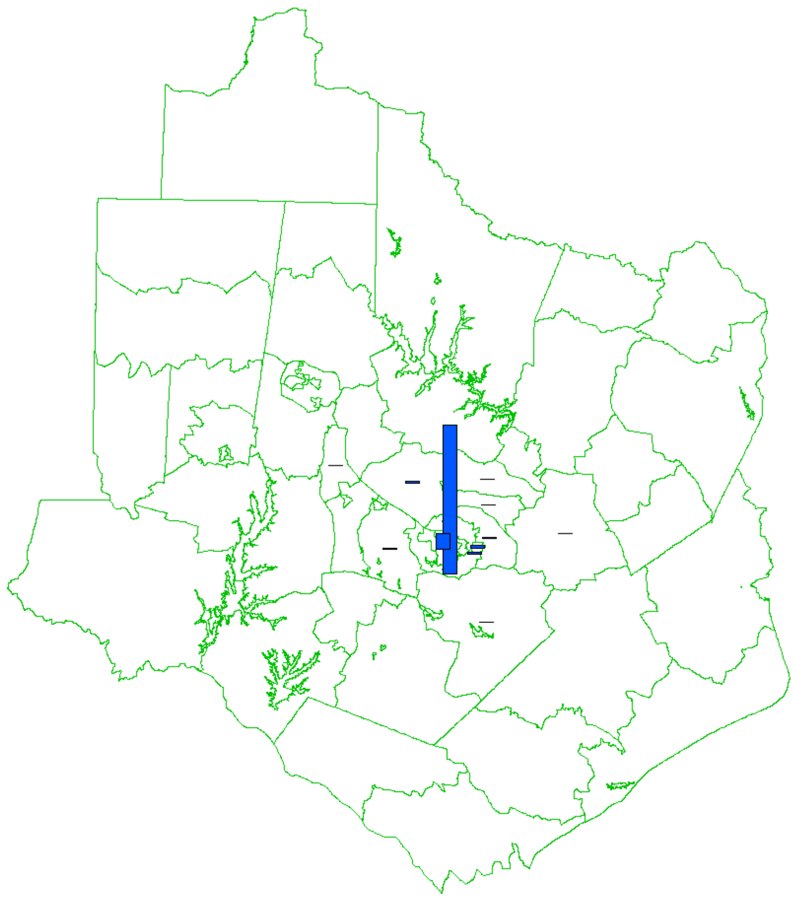


Figure 9-30 On-campus NHNU attractions in each district of the overall model area

One regression model was developed for on-campus NHNU trip attractions, based on districts, as shown in Table 9-94.

Table 9-94 Regression model for on-campus NHNU attractions

Formula	StudOn_NHNU_A = 2.5636 * Retail/OP_TT_sqr + 544.3458 * Retail/OP_TT_4
t-value for "Retail/OP_TT_sqr"	3.65
t-value for "Retail/OP_TT_4"	6.45
R^2	0.84
Note	Based on 49 districts (excluding the NCSU district).

9.2.2.2.6 Trip Attraction Model for HBU Trips Made by Off-Campus Students

The attraction ends of HBU trips made by off-campus students (called "off-campus HBU trips") are on-campus TAZs. There are only 20 TAZs that contain NCSU buildings, and they are the only TAZs that could attract HBU trips. Therefore, the regression was based on these 20 TAZs. Table 9-95 shows the regression model for off-campus HBU attractions.

Table 9-95 Regression model for off-campus HBU attractions

Formula	StudOff_HBU_A = 9.2009 * Building_Area_Service
t-value for "Building_Area_Service"	16.89
R^2	0.94
Note	Based on the 20 TAZs with NCSU buildings. The analysis was based on values for 2001.

9.2.2.2.7 Trip Attraction Model for HBO Trips Made by Off-Campus Students

The attraction ends of HBO trips made by off-campus students (called "off-campus HBO trips") are off-campus TAZs. Compared to other university-student trip purposes, off-campus HBO trips are more dispersed, since they start from off-campus homes, which are not necessarily close to campus, and also end at off-campus locations. Figure 9-31 shows off-campus HBO attractions in each district of the overall model area.

The TRMSB was able to develop only one regression model, based on the districts in Figure 9-31, as shown in Table 9-96.

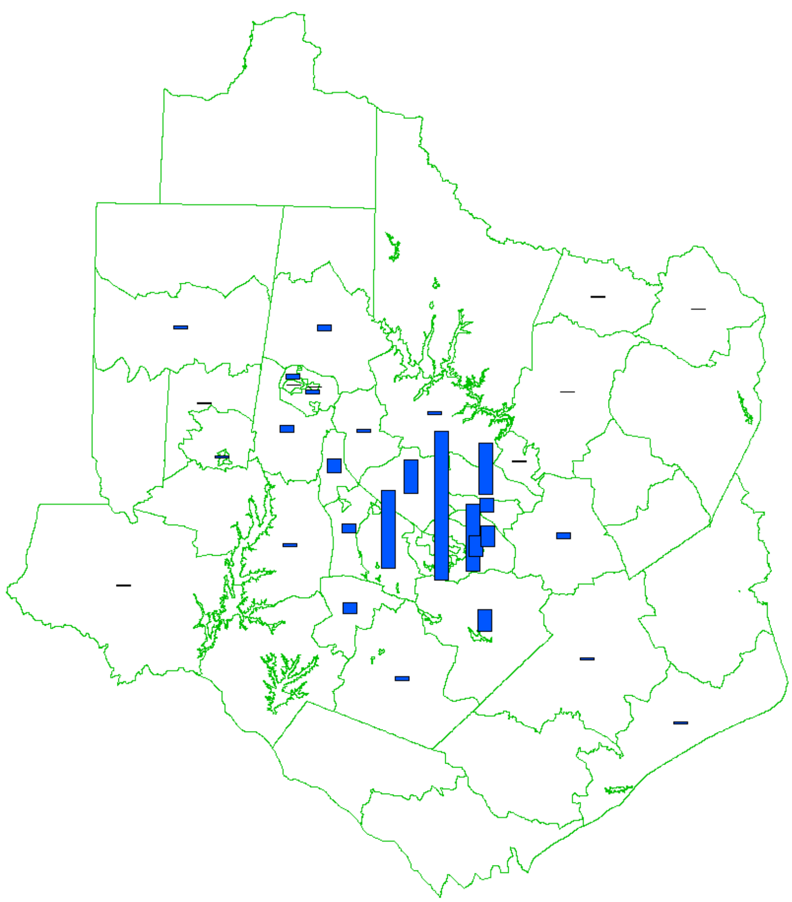


Figure 9-31 Off-campus HBO attractions in each district of the overall model area

Table 9-96 Regression model for off-campus HBO attractions

Formula	StudOff_HBO_A = 4.283 * POP/OP_TT_sqr + 7.917 * Retail/Dist_sqr
t value for "POP/OP_TT_sqr"	4.04
t value for "Retail/Dist_sqr"	9.74
R^2	0.90
Note	Based on 49 districts (excluding the NCSU district).

9.2.2.2.8 Trip Attraction Models for UBNH Trips Made by Off-Campus Students

The attraction ends of UBNH trips made by off-campus students (called "off-campus UBNH trips") can be on-campus TAZs or off-campus TAZs. Although both off-campus and on-campus UBNH trips start from campus, their average distances are different (1.92 miles vs. 0.79 miles). A possible reason for this difference is that off-campus students are more likely to make trips by car, making it easier to have long trip distances.

Most off-campus UBNH trips stay on campus (58%) or around campus (24% in the "short walk to Wolfline" area). Figure 9-32 shows off-campus UBNH attractions in each TAZ around NCSU. Figure 9-33 shows the same in each district of the overall model area.

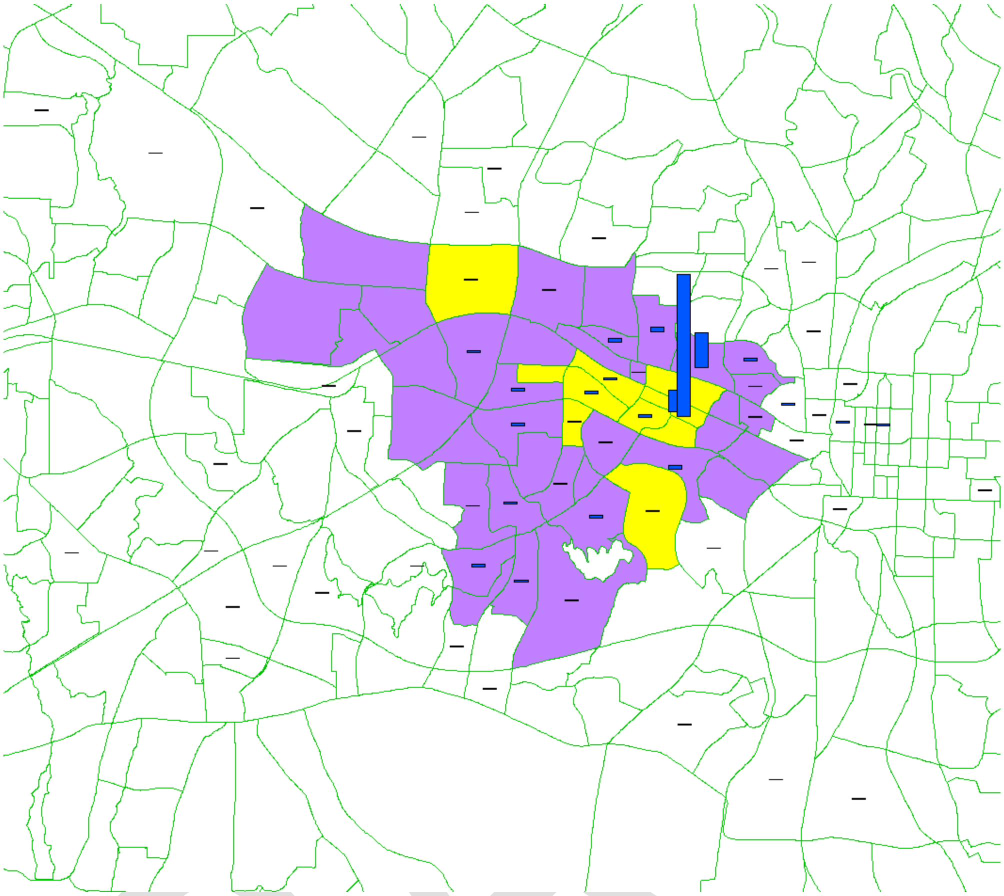


Figure 9-32 Off-campus UBNH attractions in each TAZ around NCSU

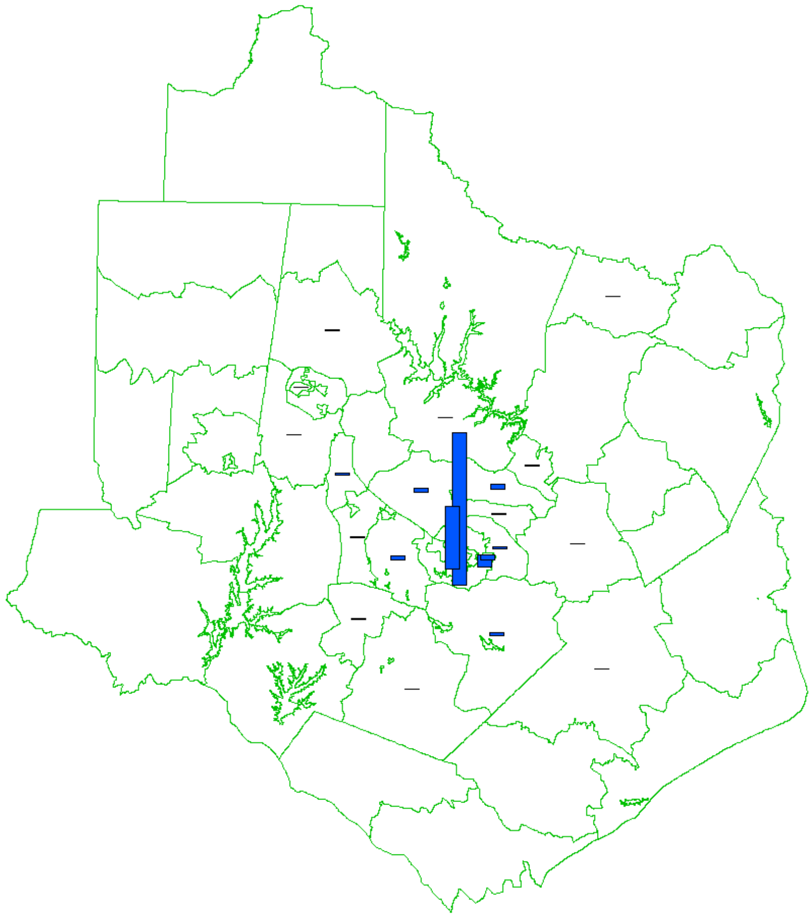


Figure 9-33 Off-campus UBNH attractions in each district of the overall model area

Two regression models were developed, one based on 47 TAZs around NCSU, and the other based on the 48 districts that constitute the rest of the model area. These regression models are shown in Table 9-97 and Table 9-98.

Table 9-97 Regression model for off-campus UBNH attractions around NCSU

Formula	StudOff_UBNH_A = 5.449 * Building_Area_Service + 1.7918 * Retail/Dist_sqr
t-value for "Building_Area_Service"	17.62
t-value for "Retail/Dist_sqr"	2.07
R^2	0.88
Note	Based on 47 TAZs on the NCSU campus or in the "short walk to Wolfline" area. 81.5% of off-campus UBNH trips were attracted to these 47 TAZs.

Table 9-98 Regression model for off-campus UBNH attractions not around NCSU

Formula	StudOff_UBNH_A = 27.4485 * POP/OP_TT_3 + 13.4887 * Emp/OP_TT_3
t-value for "POP/OP_TT_3"	8.77
t-value for "Emp/OP_TT_3"	4.82
R^2	0.88
Note	Based on 48 districts (excluding the NCSU district and the "short walk to Wolfline" district). 18.5% of off-campus UBNH trips were attracted to these 48 districts.

9.2.2.2.9 Trip Attraction Model for NHNU Trips Made by Off-Campus Students

The attraction ends of NHNU trips made by off-campus students (called "off-campus NHNU trips") are off-campus TAZs. Off-campus NHNU trips are similar to off-campus HBO trips, in that they are more dispersed than most other university-student trip purposes. Figure 9-34 shows off-campus NHNU attractions in each district of the overall model area. The TRMSB was able to develop only one regression model, based on the districts in Figure 9-34, as shown in Table 9-99.

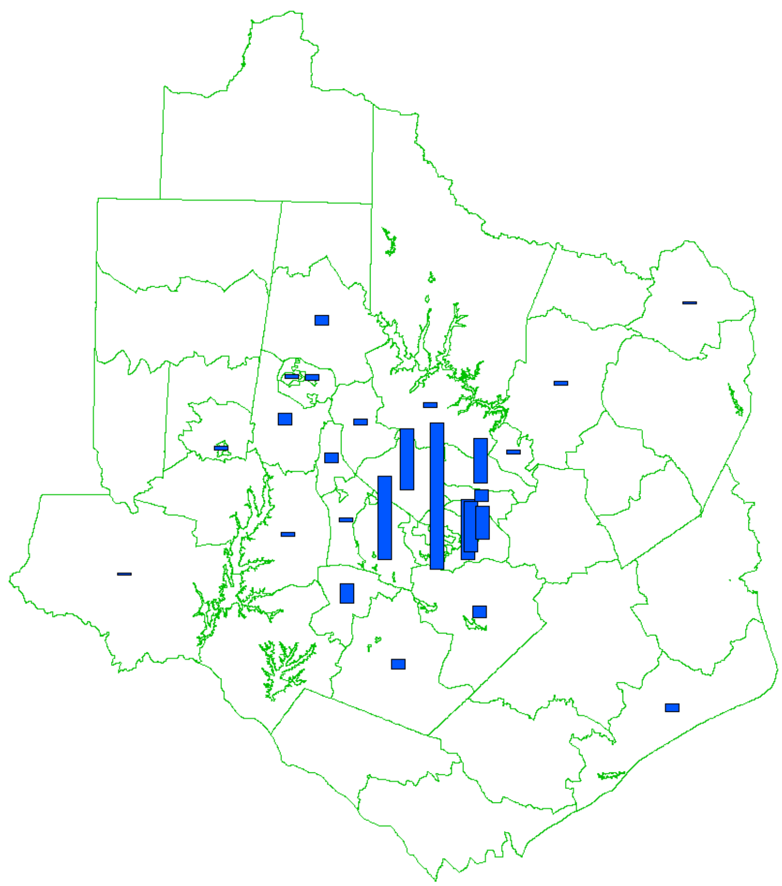


Figure 9-34 Off-campus NHNU attractions in each district of the overall model area

Table 9-99 Regression model for off-campus NHNU attractions

Formula	StudOff_NHNU_A = 0.0457 * POP/OP_TT + 3.2152 * Retail/Dist_sqr
t-value for "POP/OP_TT"	3.74
t-value for "Retail/Dist_sqr"	20.63
R^2	0.94
Note	Based on 49 districts (excluding the NCSU district).

9.2.3 Trip Distribution

9.2.3.1 Model Estimation

This section documents the university student destination choice model used in the TRMv6. It covers the preparation of the estimation dataset and the estimation results.

9.2.3.1.1 Data Preparation

To estimate coefficients for the destination choice models, estimation files were generated based on the 2001 NCSU Student Survey. These files include, for each observed trip, impedance and socioeconomic variables for the actual attraction TAZ and for all other potential attraction TAZs. In theory, all internal TAZs in the TRMv6 are potential choices. However, to make the estimation files manageable, only a sample of these TAZs is selected. The university student destination-choice models in the TRMv6 use similar sampling method as those in the TRMv5. This section details the procedure used to select sample TAZs, and how impedances and the values of socioeconomic variables were calculated. Matlab was used to prepare the estimation dataset.

Sampling Procedure

Selection Weight

In the TRMv5, for each trip observation in the 2006 Household Travel Survey (2006 HTS), 20 TAZs were sampled as candidate TAZs. The goal of the sampling method was to select a representative sample set of the location choices (TAZs) available for each trip. The process to calculate the selection weight was as follows:

For each trip record whose production TAZ is i in the 2006 HTS, calculate the selection weight of destination TAZ j (for all 2579 internal TAZs in the TRMv5) using the equation

$$W_{ij} = A_j \times e^{\left(-2\times\frac{D_{ij}}{D_{avg}}\right)} \quad (9\text{-}9)$$

where

W_{ij} = selection weight of attraction TAZ j for a trip whose production TAZ is i,
A_j = trip attractions for the studied trip purpose in TAZ j,

D_{ij} = highway distance from production TAZ i to attraction TAZ j, and
D_{avg} = regional average trip distance for the studied trip purpose, based on the 2006 HTS.

Equation 9-9 shows that the probability of a given TAZ being selected depends on its attractiveness (i.e., attraction or employment) and accessibility (i.e., distance from the production TAZ).

In the development of the university student model for the TRMv6, the TRMSB studied the travel behaviors of university students at North Carolina State University (NCSU), as reported in the 2001 NCSU Student Survey. For most trip purposes, the production ends were at NCSU, such as in the case of University Based Non Home (UBNH) trips. Likewise, the attraction ends of university-student trips were more likely to be distributed on or around the NCSU campus than elsewhere. Therefore, when trip attraction models were developed, distance or travel time to the NCSU campus was included in the linear regression models (refer to the section on university-student trip generation, 9.2.2, for more details). As a result, for a trip produced in an NCSU on-campus TAZ i, the probability of a student choosing TAZ j for a destination depends only on the attractiveness (attractions) of TAZ j (since accessibility has already been included as part of attractiveness). The selection weight should then be

$$W_{ij} = A_j \quad (9\text{-}10)$$

A study was conducted on how the selection weights determined via Equations 9-9 and 9-10 affect model estimation and application results. This study showed that Equation 9-10 yields more representative samples, so it was used in the sampling procedure.

Selection Probability

Selection probability was calculated based on the equation

$$P_{ij} = \frac{W_{ij}}{\sum_{k=1}^{N} W_{ik}} \quad (9\text{-}11)$$

where

P_{ij} = selection probability of attraction TAZ j for a trip whose production TAZ is i, and
N = total number of internal TAZs in the TRMv6 (2,857 TAZs).

Selection Process

In this step, 19 TAZs were selected randomly with replacement (i.e., a given TAZ may be selected multiple times), based on the calculated selection probability P_{ij}. For each trip record in the 2001 NCSU Student Survey, the cumulative weights of all attraction TAZs (all 2,857 internal TAZs) were calculated first. Each attraction TAZ had a low limit and a high limit – the low limit was the sum of the weights before the weight of that particular attraction TAZ was added and the high limit was equal to the low limit plus the weight of the attraction TAZ in question. Matlab was used to generate random numbers uniformly distributed between zero and the sum of all weights (for all 2857 internal TAZs). If an attraction TAZ's low limit was less than or equal to one of these randomly-generated number and its high limit was greater than that number, that TAZ was selected into the sample set. This process was repeated until 19 TAZs were selected, with the possibility of duplicates.

Because the actual attraction TAZ was also selected into the sample set by default, the final sample size was 20 for any given trip in the survey.

Selection Frequency

For the actual attraction TAZ and the 19 randomly-selected TAZs, the TRMSB counted the number of times each TAZ was selected, defined as selection frequency F_j. Since TAZs are selected with replacement, some TAZs may have an F_j greater than one. The range of F_j is from 1 to 20.

Correction Factor

Since only a subset of all potential TAZs was used in model estimation, it was necessary to account for the possible bias introduced by the sampling of TAZs.[14] Correction factors were calculated as

$$CF_{ij} = -ln\left(\frac{P_{ij}}{\frac{F_{ij}}{n}}\right) \tag{9-12}$$

where

CF_{ij} = correction factor of attraction TAZ j for a trip whose production TAZ is i,
F_{ij} = selection frequency of attraction TAZ j for a trip whose production TAZ is i, and
n = number of selected TAZs (20 TAZs).

These correction factors were only used in the model estimation as a linear term (more like a constant term) in the utility function for each selected TAZ. They are not a part of the true model, and are not used in model application.

If the selection probability P_{ij} is equal to $\frac{F_{ij}}{n}$, the correction factor is zero. However, if a TAZ is selected more frequently than the selection probability suggests, it has a positive correction factor, and consequently a lower base utility in the utility function.

It is possible for P_{ij} to be zero in Equation 9-12, which leads to an infinity CF value. Based on the selection process described in above, a TAZ with a selection probability P_{ij} of zero can never be selected into the sample set. However, the actual attraction TAZ, which is also in the sample set by default, could have a selection probability of zero. This happens if, for a given trip purpose, the trip generation model shows that a particular TAZ has no attractions, but some survey respondents reported that that TAZ was an attraction TAZ. That is to say, inconsistency between the model and the survey data makes infinity CF values possible. Table 9-100 summaries these infinity correction factors.

Table 9-100 Summary of infinity correction factors

Student type	Trip purpose	Total records	Records with infinity correction factors	Records without infinity correction factors
	HBU	1,846	6	1,840

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[14] Ben-Akiva M. and Lerman S. (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge.

On-campus	HBO	323	35	288
	UBNH	988	30	958
	NHNU	79	8	71
Off-campus	HBU	693	0	693
	HBO	565	16	549
	UBNH	651	2	649
	NHNU	203	5	198

Trip records with infinity correction factors were removed from the estimation file, since Biogeme does not work with infinity correction factors and such records usually only account for a small percentage of all records, as shown in Table 9-100.

Estimation Data Set

Eight estimation files were created, one for each combination of student type and trip purpose, such as on-campus-student HBU trips. Only internal-to-internal (I-I) trips were considered, including intrazonal trips and trips by all modes. The number of records in each estimation file can be found in the last column of Table 9-100. There are 327 columns in each estimation file. The structure of the estimation files is shown in Table 9-101.

Table 9-101 Destination choice model estimation file structure

Column	Variable	Description
1	Trip_ID	Trip ID in the 2001 NCSU Student Survey
2	Weight	2010 trip weight
3	Choice	Always equal to one, since the actual TAZ the respondent selected is always put as the first TAZ.
4	P_TAZ	Production TAZ ID
5	A_TAZ	Attraction TAZ ID
6	Strata	Residence status (1=on-campus, 2=off-campus)
7	PK	Peak (PK) trip (=1) or off-peak (OP) trip (=0)
8	TAZ1	The first TAZ option. It is always the actual TAZ the respondent selected. Therefore, it is always equal to A_TAZ.
9	CF1	Correction factor for TAZ1. Should be included in the utility function for TAZ1 (like a constant term) in model estimation.
10	NMD1	Non-motorized distance between P_TAZ and TAZ1
11	MCT1	Motorized composite time between P_TAZ and TAZ1
12	StudGQ1	Number of NCSU students living in group quarters in 2001 in TAZ1
13	BAS2001_1	NCSU building floor area for service in TAZ1 in 2001 (Unit: 1000 square feet)
14	SerL1	“Service Rate Low” employment in TAZ1 in 2010
15	SerH1	“Service Rate High” employment in TAZ1 in 2010
16	Ret1	“Retail” employment in TAZ1 in 2010
17	Ind1	“Industry” employment in TAZ1 in 2010

18	Off1	"Office" employment in TAZ1 in 2010
19	HH_Pop1	Household population in TAZ1 in 2010 (=HH POP in the SE file)
20	TOT_EMP1	Total employment in TAZ1 (=SerL1 + SerH1 + Ret1 + Ind1 + Off1)
21	MINC1	Mean household income in TAZ1 in 2010 (=MEANINC in the SE file)
22	TOT_POP1	Total population in TAZ1 (=HH_Pop1 + StudGQ1 + Other_NonInst_GQ in the 2010 SE file)
23	ShortWalk1	Dummy variable, whether TAZ1 is in the short-walk-to-campus-transit area
24-327		Similar to columns 8-23, for TAZ2 through TAZ20

PK

PK is a variable to show if a surveyed trip is a peak (PK) or off-peak (OP) trip. The peak periods defined for the TRM model are from 6:00 AM to 10:00 AM and from 3:30 PM to 7:30 PM. The off-peak periods are the remainder of the day. A trip is classified as a PK or OP trip based on the midpoint of the trip's duration: if the midpoint is in a PK period, it is classified as a PK trip; otherwise, it is classified as an OP trip.

NMD

NMD is the non-motorized distance between a production TAZ (P_TAZ) and a given attraction TAZ. To calculate NMD, freeways, expressways, and their associated ramps were excluded from the network before the skim of distance was created. Specifically, links with a "Special" value of 1, 2, 3, 5, 21, 22, 23, 24, 25, 41, 42, or 43 were excluded, and intrazonal distances were calculated using three neighboring zones and factored by 0.5. To be consistent, NMD was calculated based on the corresponding script in "TRMv6_TC50_Script.rsc."

It was found that TAZ 2166 had "null" values in the NMD matrix. The reason is that all centroid connectors in TAZ 2166 were connected to freeways or expressways, which were removed in the calculation of non-motorized distance. When preparing NMD figures for the model estimation process, highway distances were used when non-motorized distances were "null."

MCT

MCT is the Motorized Composite Time to travel between P_TAZ and a given attraction TAZ. If the surveyed trip is a peak-period trip (according to the variable "PK"), the peak-period MCT is used; otherwise, the off-peak MCT is used.

MCT was calculated as a combination of composite travel times by the auto and transit modes, using the same formulas as in the TRMv5. It was created for both peak and off-peak time periods and for different trip purposes and student types, on account that transit shares vary by time of day, by trip purpose, and by student type. The time and distance skim matrices in AMLOV2.mtx and OPLOV2.mtx were used to calculate auto mode composite travel times, while the walk-access transit skim matrices in AML.mtx, AMP.mtx, OPL.mtx, and OPP.mtx were used for the transit mode. These skim matrices were created on 4/23/2013, after assigning TRMv5 OD tables to the TRMv6 network with TRMv6 free-flow speeds and capacities.

Transit shares were calculated as the number of transit trips divided by the number of overall motorized trips, based on the 2001 NCSU Student Survey. These transit shares are shown in Table 9-102.

Table 9-102 University student transit shares by trip purpose, time period, and student type

	Peak		Off-Peak	
	On-Campus Student	Off-Campus Student	On-Campus Student	Off-Campus Student
HBU	42.53%	9.90%	36.36%	13.48%
HBO	6.32%	0.88%	1.37%	0.43%
UBNH	30.23%	3.34%	24.56%	9.35%
NHNU	0.00%	3.22%	0.00%	2.32%

MCT was calculated based on the following equations:

$$MCT = 1/(1/CT_{auto} + TrnShare/CT_{trn}), \text{ if } CT_{trn} <> 0 \quad (9\text{-}13)$$
$$MCT = CT_{auto}, \text{ if } CT_{trn} = 0 \quad (9\text{-}14)$$

where

MCT = motorized composite time in minutes;
$TrnShare$ = transit share of all motorized trips by time of day, as shown in Table 3;
CT_{auto} = auto composite travel time in minutes, calculated using Equation 7; and
CT_{trn} = transit composite travel time in minutes, calculated using Equation 8.

$$CT_{auto} = TT_{auto} + TD_{auto} * 0.5 / 2 / 0.2 \quad (9\text{-}15)$$

where

TT_{auto} = auto highway travel time in minutes,
TD_{auto} = auto highway travel distance in miles,
0.5 = auto operating cost in dollars per mile,
2 = factor that assumes perceived cost is ½ of actual cost, and
0.2 = value of time used in the TRM, with units of dollars per minute.

In each of the two time periods (peak and off-peak), CT_{trn} is calculated for both local- and express-bus skims and the one with a lower value is used.

$$CT_{trn} = (IVT_{trn} + (T_{walk} + T_{init\ wait} + T_{xfer\ wait}) * 2 + F_{trn} / 0.2)/100 \quad (9\text{-}16)$$

where

IVT_{trn} = transit in-vehicle travel time in 1/100 minutes, from the [Local_W] matrix in AML.mtx or OPL.mtx for the local bus skim, and from [Local_W]+ [Exp_W] in AMP.mtx or OPP.mtx for the express bus skim;

T_{walk} = access, transfer, and egress walk times in 1/100 minutes, from [Walk_W]+ [CBDWalk_W] in AML.mtx, OPL.mtx, AMP.mtx, or OPP.mtx;
$T_{init\ wait}$ = initial wait time in 1/100 minutes, from the [Wait1_W] matrix in AML.mtx, OPL.mtx, AMP.mtx, or OPP.mtx;
$T_{xfer\ wait}$ = transfer wait time in 1/100 minutes, from the [Wait2_W] matrix in AML.mtx, OPL.mtx, AMP.mtx, or OPP.mtx;
F_{trn} = transit fare in 1/100 dollars, from the [Fare_W] matrix in AML.mtx, OPL.mtx, AMP.mtx, or OPP.mtx;
2 = factor derived by comparing IVT regression coefficients to those of the variables representing walk times and wait times;
0.2 = value of time used in the TRM, with units of dollars per minute; and
100 = factor to convert units to minutes.

9.2.3.1.2 Model Estimation by Trip Purpose

University-student destination-choice models were estimated using Biogeme software. Estimated model equations are presented below for each of four trip purposes and two student types.

On-Campus HBU Trips

On-campus HBU trips are Home Based University trips made by on-campus students. The production ends are on-campus residence halls, and the attraction ends are also on-campus locations, such as classrooms and libraries.

The following utility function was selected for on-campus HBU trips:

$$U_{ij} = bMCT * MCT_{ij} + ln(BAS_j + e^{bStudGQ} * StudGQ_j) \quad (9\text{-}17)$$

where

$bMCT$ = coefficient for motorized composite time,
MCT_{ij} = motorized composite time from production TAZ i to TAZ j,
BAS_j = university building floor area for service in TAZ j,
$bStudGQ$ = coefficient for student group-quarters population, and
$StudGQ_j$ = student group-quarters population in TAZ j.

The estimation results are shown in Table 9-103. The trip attraction model for on-campus HBU trips used Building_Area_Service (BAS) and Stud_ON as explanatory variables, whereas BAS and a variable similar to Stud_ON, Stud_GQ, are used in Equation 9-17 for the size term. The BAS value used for model estimation is from 2001, as opposed to2010. This is because the student survey was conducted in 2001 and NCSU constructed many new buildings (including classrooms and residence halls) between 2001 and 2010. 2001 travel behavior can better be explained using 2001 BAS values.

Similarly, it would have been better to use 2001 Stud_GQ values, but they were not readily available. The only major construction of NCSU residence halls between 2001 and 2010 was Wolf Village, which opened in 2005 in TAZ 1485. Therefore, the model estimation uses 2010 Stud_GQ values, with the value for TAZ 1485 set to zero.

In Equation 9-17, the coefficient for Stud_GQ is statistically significant, with a negative sign. Since $e^{bStudGQ}$ is used in the formula and $e^{-0.302} = 0.739$, this negative sign just means Stud_GQ contributes less to the attractiveness of a TAZ than does BAS. Motorized composite time (MCT) is used as an impedance term, in order to be consistent with other models. The MCT coefficient has a negative sign, meaning that a TAZ that is further from the production TAZ has a lower utility, which is expected.

Table 9-103 On-campus student HBU destination choice model

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.154	-3.88
Building Area for Service (BAS)	1	Fixed
Student Group-Quarters Population (Stud_GQ)	-0.302	-4.06
R^2: 0.002		
Initial log-likelihood: -5319.14		
Final log-likelihood: -5307.74		
Number of records: 1840		

The R^2 value in Table 9-103 is very low (0.002). However, R^2 is just a measure of the difference between the log-likelihood when all coefficients are zero and when the estimated coefficients are used. The initial log-likelihood is the log-likelihood for $U_{ij} = ln(BAS_j + StudGQ_j)$, and the final log-likelihood is the log-likelihood for $U_{ij} = -0.154 * MCT_{ij} + ln(BAS_j + e^{-0.302} * StudGQ_j)$. A low R^2 value indicates that the log-likelihoods of these two equations are close, which is not surprising. Both ends of on-campus HBU trips are on-campus and they are usually very short trips. Therefore, the impedance term (MCT) does not provide much explanatory power, relative to other models. The TRMSB carefully watched the performance of this model while applying it.

On-Campus HBO Trips

On-campus HBO trips are Home Based Other trips made by on-campus students. The production ends are on-campus residence halls, and the attraction ends are off-campus locations.

The following utility function was selected for on-campus HBO trips:

$$U_{ij} = bMCT * MCT_{ij} + bSW * ShortWalk_j + ln(Ret_j + e^{bNonRet} * NonRet_j + e^{bTotPop} * TotPop_j) \quad (9\text{-}18)$$

where

$bMCT$ = coefficient for motorized composite time,
MCT_{ij} = motorized composite time from production TAZ i to TAZ j,
bSW = coefficient for the dummy variable $ShortWalk_j$,
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area,
Ret_j = retail employment in TAZ j,
$bNonRet$ = coefficient for non-retail employment,
$NonRet_j$ = non-retail employment in TAZ j (including Off, Ind, SerH and SerL),
$bTotPop$ = coefficient for total population, and
$TotPop_j$ = total population in TAZ j (including HH_Pop, Stud_GQ, and Other_NonInst_GQ).

The estimation results are shown in Table 9-104. Total population (TotPop), retail employment (Ret), and non-retail employment (NonRet) are used in the size term. The coefficients for NonRet and TotPop are -3.29 and -2.82, respectively. $e^{-3.29} = 0.037$ and $e^{-2.82} = 0.060$, so both NonRet and TotPop have smaller impacts than Ret, which has a fixed coefficient of one. The coefficient for MCT is negative and the coefficient for the short-walk dummy variable is positive, as expected. The R^2 value is 0.334.

Table 9-104 On-campus student HBO destination choice model

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.0889	-10.27
Short Walk Dummy (ShortWalk)	1.48	8.02
Retail Employment (Ret)	1	Fixed
Non-Retail Employment (NonRet)	-3.29	-8.12
Total Population (TotPop)	-2.82	-11.92
R^2: 0.334		
Initial log-likelihood: -1277.66		
Final log-likelihood: -851.327		
Number of records: 323		

On-Campus UBNH Trips

On-campus UBNH trips are University Based Non Home trips made by on-campus students. The production ends are on-campus locations, and the attraction ends may be on-campus or off-campus. Intuitively, on-campus buildings used for service (such as classrooms, libraries, gyms, and dining halls) are major attractors of UBNH trips with on-campus attraction ends. Population and employment (especially retail employment, considering that university students make a lot of trips to restaurants or shops near campus) are the major attractors of UBNH trips with off-campus attraction ends. Therefore, BAS, population, and employment variables were tested for explanatory power, and the following utility function was selected for on-campus UBNH trips:

$$U_{ij} = bMCT * MCT_{ij} + bSW * ShortWalk_j + ln(BAS_j + e^{bRet} * Ret_j + e^{bSer} * Ser_j + e^{bHH\_Pop} * HH\_Pop_j + e^{bStudGQ} * StudGQ_j) \tag{9-19}$$

where

$bMCT$ = coefficient for motorized composite time,
MCT_{ij} = motorized composite time from production TAZ i to TAZ j,
bSW = coefficient for the dummy variable $ShortWalk_j$,
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area,
BAS_j = university building floor area for service in TAZ j,
$bRet$ = coefficient for retail employment,
Ret_j = retail employment in TAZ j,
$bSer$ = coefficient for service employment,
Ser_j = service employment in TAZ j (including SerH and SerL),
bHH_Pop = coefficient for household population,
HH_Pop_j = household population in TAZ j,
$bStudGQ$ = coefficient for student group-quarters population, and

$StudGQ_j$ = student group-quarters population in TAZ j.

The estimation results are shown in Table 9-105. University building floor area for service (BAS), household population (HH_Pop), student group-quarters population (Stud_GQ), retail employment (Ret), and service employment (Ser) are used in the size term. Non-retail employment (NonRet) was tested, but its coefficient was insignificant, so it was not included in the model. As in the on-campus HBU model, the BAS values used to create the on-campus UBNH model estimation were from 2001. The coefficient for MCT is negative. The R^2 value is 0.373.

Table 9-105 On-campus student UBNH destination choice model

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.177	-8.51
Short Walk Dummy (ShortWalk)	0.781	2.47
Building Area for Service (BAS)	1	Fixed
Retail Employment (Ret)	-0.35	-1.48
Service Employment (Ser)	-2.74	-2.73
Household Population (HH_Pop)	-3.48	-6.79
Student Group-Quarters Population (Stud_GQ)	0.323	2.71
R^2: 0.373		
Initial log-likelihood: -4071.861		
Final log-likelihood: -2555.067		
Number of records: 958		

On-Campus NHNU Trips

On-campus NHNU trips are Non Home Non University trips made by on-campus students. Both the production ends and the attraction ends are off-campus locations. Intuitively, population and employment are major attractors of NHNU trips. Therefore, population and employment variables were tested for explanatory power, and the following utility function was selected for on-campus NHNU trips:

$$U_{ij} = bOP\_MCT * OP\_MCT_{ij} + bOP\_MCT2 * OP\_MCT_{ij}^2 + ln(Ret_j + e^{bNonRet} * NonRet_j + e^{bTotPop} * TotPop_j) \qquad (9\text{-}20)$$

where

bOP_MCT = coefficient for off-peak motorized composite time,
OP_MCT_{ij} = off-peak motorized composite time from production TAZ i to TAZ j,
bOP_MCT2 = coefficient for the square of off-peak motorized composite time,
$OP\_MCT_{ij}^2$ = square of off-peak motorized composite time from production TAZ i to TAZ j,
Ret_j = retail employment in TAZ j,
$bNonRet$ = coefficient for non-retail employment,
$NonRet_j$ = retail employment in TAZ j (including Off, Ind, SerH, and SerL),
$bTotPop$ = coefficient for total population, and
$TotPop_j$ = total population in TAZ j (including HH_Pop, Stud_GQ, and Other_NonInst_GQ).

The destination choice models for both on-campus and off-campus NHNU trips use off-peak Motorized Composite Time (OP_MCT), regardless of the time of day. This is because the TRMSB determined that not enough on-campus or off-campus NHNU trips were recorded in the 2001 NCSU Student Survey to support the creation of separate peak and off-peak models, and the majorities of both on-campus and off-campus NHNU trips in that survey were off-peak trips, making off-peak MCT a better choice than peak-period MCT.

The estimation results are shown in Table 9-106. Total population (TotPop), retail employment (Ret), and non-retail employment (NonRet) are used in the size term. The coefficient for OP_MCT is negative, as expected, and the coefficient for OP_MCT^2 is positive and of a much smaller magnitude than the coefficient for OP_MCT. Technically, according to this model, a sufficiently large OP_MCT would result in an increase in utility, in contrast to what one would intuitively expect. However, because of the great difference between the coefficients for OP_MCT and OP_MCT^2, it would require an extremely high, and extremely unlikely, OP_MCT value to produce that unintuitive result. The R^2 value for this regression equation was not available at the time of this writing.

Table 9-106 On-campus student NHNU destination choice model

Utility Coefficients	Value	t-stat
Off-Peak Motorized Composite Time (OP_MCT)	-0.226	-
Off-Peak Motorized Composite Time Squared (OP_MCT^2)	0.00165	-
Retail Employment (Ret)	1	Fixed
Non-Retail Employment (NonRet)	-3.86	-
Total Population (TotPop)	-3.07	-
R^2: -		
Initial log-likelihood: -		
Final log-likelihood: -		
Number of records: 71		

Off-Campus HBU Trips

Off-campus HBU trips are Home Based University trips made by off-campus students. As the name suggests, the production ends are off-campus student home locations and the attraction ends are on-campus locations. However, data on off-campus student home locations were not available for the TRMv6, so it is difficult to determine trip productions. However, off-campus HBU attractions are easier to determine, consisting of the product of the off-campus HBU trip rate and the total number of off-campus students, distributed to each on-campus TAZ according to building floor area used for service. Therefore, for the destination-choice model for off-campus HBU trips, the TRMSB treated student home locations as attractions ends and on-campus TAZs as production ends. For this reason, this part of the model will henceforth be referred to as the residence choice model.

The residence choice model was also used to estimate where off-campus students live. This information was used to separate off-campus students from the general population, as well as to determine off-campus HBO trip productions. For these reasons, more time and effort were put into this part of the model than into others.

Off-campus students tend to live close to campus and in areas with good access to campus transit. Also, they are more likely to live in multi-unit housing than in single-unit housing. However, information on the split between multi-unit and single-unit housing was not available during model development. Off-campus students are generally low-income, so TAZs with lower mean household incomes may be correlated with the presence of more off-campus students. Because off-campus students are counted as part of household population (“HH_POP” in the SE table), “HH_POP” is the only variable used in the size term.

After considering all of the points made above, the following utility function was selected for off-campus HBU trips:

$$U_{ij} = bOP\_MCT * OP\_MCT_{ij} + bMINC * \frac{MINC_j}{MINC_{Region}} + bSW * ShortWalk_j + ln(HH\_Pop_j) \tag{9-21}$$

where

bOP_MCT = coefficient for off-peak motorized composite time;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$bMINC$ = coefficient for standardized mean household income;
$MINC_j$ = standardized mean household income in TAZ j;
$MINC_{Region}$ = regional mean household income, weighted by the number of households in each TAZ;
bSW = coefficient for the dummy variable $ShortWalk_j$;
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area; and
HH_Pop_j = household population in TAZ j.

In Equation 9-21, as in the equations for on-campus and off-campus NHNU trips, off-peak motorized composite time (OP_MCT) is used as a term, which means that for each trip in the 2001 NCSU Student Survey, the motorized composite time under off-peak travel conditions (i.e., free-flow conditions) is used to prepare the estimation file, regardless of whether the trip was actually made during the peak or off-peak period. In contrast, in the equations for other trip-purpose/student-type combinations, the regular MCT variable is used, which is calculated based on off-peak travel times for trips made in the off-peak period and on peak-period travel times for those made in the peak period. The reason for using OP_MCT in this case is that the residence choice model is used to separate off-campus students from the general population, for which purpose it is better to keep the model independent of peak travel times, so that changes in peak travel times do not affect the results. Because off-peak travel times are free-flow travel times, they are stable.

Figure 9-35 shows off-campus HBU trips produced in each TAZ around NCSU. The purple TAZs touch the “short walk” area (0.25-mile buffer around NCSU Wolfline bus routes). Most of the off-campus HBU trips in the NCSU Student Survey were produced in this short-walk area. Therefore, whether or not a TAZ intersects with this area is represented as a dummy variable in Equation 9-21 ($ShortWalk_j$).

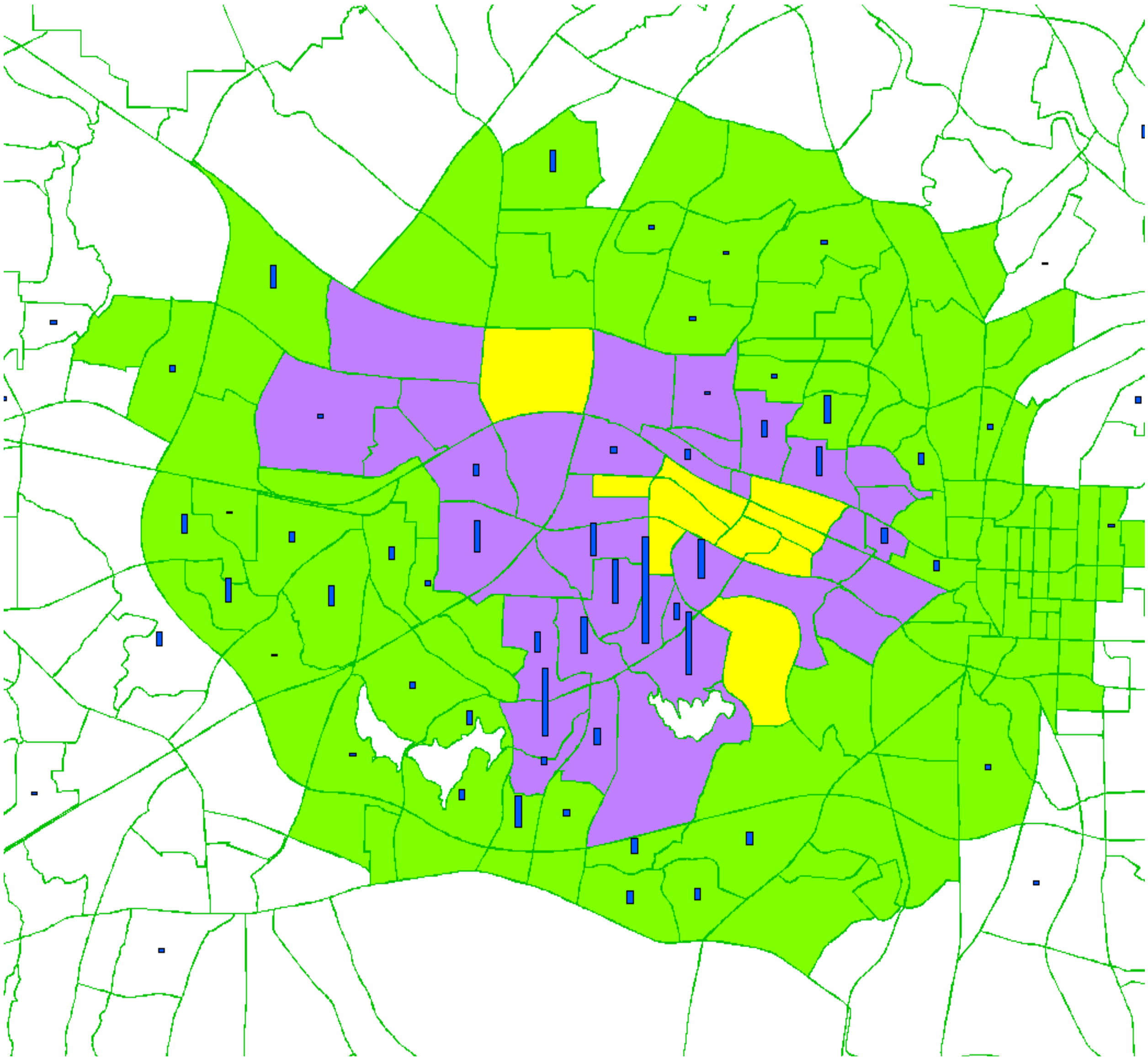


Figure 9-35 Off-campus HBU trips produced in each TAZ around NCSU

The estimation results are shown in Table 9-107. The coefficient for standardized mean household income (MINC) is significant and negative, meaning that off-campus students are less likely than the general population to live in TAZs with higher mean household incomes, which is expected. The coefficient for off-peak motorized composite time (OP_MCT) is negative, and it has a smaller magnitude than the coefficient for the regular MCT variable in the on-campus HBU equation, as shown in Table 9-103. This implies that on-campus students are more sensitive to MCT and live closer to campus than do off-campus students, as they would have to, by definition. The coefficient for the ShortWalk dummy variable is positive, indicating that off-campus students are more likely than the general population to live in the "short walk" TAZs. Population is the only variable in the size term. The R^2 value is 0.343.

Table 9-107 Off-campus student HBU destination choice model

Utility Coefficients	Value	t-stat
Off-Peak Motorized Composite Time (OP_MCT)	-0.0853	-20.49
Standardized Mean Household Income (MINC)	-0.707	-6.1
Short Walk Dummy (ShortWalk)	1.26	11.59
Population (Pop)	1	Fixed
R^2: 0.343		
Initial log-likelihood: -3273.411		
Final log-likelihood: -2151.119		
Number of records: 693		

Off-Campus HBO Trips

Off-campus HBO trips are Home Based Other trips made by off-campus students. Both the production ends and the attraction ends are off-campus locations. Whereas only one destination choice model was estimated for on-campus HBO trips, separate models were estimated for peak-period and off-peak-period off-campus HBO trips. The TRMSB chose to do this because it was observed in the 2001 NCSU Student Survey that the average distance of an off-campus HBO trip was significantly greater in the peak period than in the off-peak period (7.296 miles vs. 4.960 miles), and the same survey had enough samples to support the estimation of both models: 275 trip samples in the peak period and 274 in the off-peak period. Intuitively, population and employment are major attractors of off-campus HBO trips, so population and employment variables were tested for explanatory power, and utility functions of the following form were selected for the peak and off-peak periods:

$$U_{ij} = bMCT * MCT_{ij} + ln(Ret_j + e^{bNonRet} * NonRet_j + e^{bTotPop} * TotPop_j) \tag{9-22}$$

where

$bMCT$ = coefficient for motorized composite time,
MCT_{ij} = motorized composite time from production TAZ i to TAZ j,
$bRet$ = coefficient for retail employment,
Ret_j = retail employment in TAZ j,
$bNonRet$ = coefficient for non-retail employment,
$NonRet_j$ = retail employment in TAZ j (including Off, Ind, SerH, and SerL),
$bTotPop$ = coefficient for total population, and
$TotPop_j$ = total population in TAZ j (including HH_Pop, Stud_GQ, and Other_NonInst_GQ).

The estimation results are shown in Table 9-108 and Table 9-109. Total population (TotPop), retail employment (Ret), and non-retail employment (NonRet) are used in the size terms. Testing showed that the coefficients for the four individual non-retail employment variables were very close, so they were consolidated for the purposes of these models. The coefficients for MCT are negative. The R^2 values are 0.334 for the peak-period model and 0.414 for the off-peak model.

Table 9-108 Off-campus student HBO destination choice model (peak)

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.0912	-15.77
Retail Employment (Ret)	1	Fixed

Non-Retail Employment (NonRet)	-1.91	-6.75
Total Population (TotPop)	-2.64	-9.92
R^2: 0.334		
Initial log-likelihood: -887.994		
Final log-likelihood: -590.969		
Number of records: 275		

Table 9-109 Off-campus student HBO destination choice model (off-peak)

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.157	-17.11
Retail Employment (Ret)	1	Fixed
Non-Retail Employment (NonRet)	-2.7	-7.35
Total Population (TotPop)	-2.91	-11.59
R^2: 0.414		
Initial log-likelihood: -1051.607		
Final log-likelihood: -615.899		
Number of records: 274		

Off-Campus UBNH Trips

Off-campus UBNH trips are University Based Non Home trips made by off-campus students. The production ends are on-campus locations and the attraction ends may be on-campus or off-campus. Off-campus UBNH trips are very similar to on-campus UBNH trips. However, whereas only one destination choice model was estimated for on-campus UBNH trips, separate models were estimated for peak-period and off-peak-period off-campus UBNH trips. The TRMSB chose to do this because it was observed in the 2001 NCSU Student Survey that the average distance of an off-campus UBNH trip was significantly greater in the peak period than in the off-peak period (2.978 miles vs. 1.586 miles), and the same survey had enough samples to support the estimation of both models: 199 trip samples in the peak period and 450 in the off-peak period. Utility functions of the following form were selected for off-campus UBNH trips in the peak and off-peak periods:

$$U_{ij} = bMCT * MCT_{ij} + bSW * ShortWalk_j + ln(BAS_j + e^{bRet} * Ret_j + e^{bNonRet} * NonRet_j + e^{bHH\_Pop} * HH\_Pop_j + e^{bStudGQ} * StudGQ_j) \quad (9\text{-}23)$$

where

$bMCT$ = coefficient for motorized composite time,
MCT_{ij} = motorized composite time from production TAZ i to TAZ j,
bSW = coefficient for the dummy variable $ShortWalk_j$,
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area,
BAS_j = university building floor area for service in TAZ j,
$bRet$ = coefficient for retail employment,
Ret_j = retail employment in TAZ j,
$bNonRet$ = coefficient for non-retail employment,
$NonRet_j$ = retail employment in TAZ j (including Off, Ind, SerH, and SerL),
bHH_Pop = coefficient for household population,
HH_Pop_j = household population in TAZ j,

$bStudGQ$ = coefficient for student group-quarters population, and
$StudGQ_j$ = student group-quarters population in TAZ j.

The estimation results are shown in Table 9-110 and Table 9-111. University building floor area for service (BAS), household population (HH_Pop), student group quarters population (StudGQ), retail employment (Ret), and non-retail employment (NonRet) are used in the size terms. The coefficients for retail employment are larger than those for non-retail employment. The coefficients for MCT are negative, and the R^2 values are 0.355 for the peak-period model and 0.424 for the off-peak model.

Table 9-110 Off-campus student UBNH destination choice model (peak)

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.0684	-6.31
Short Walk Dummy (ShortWalk)	1.16	3.84
Building Area for Service (BAS)	1	Fixed
Retail Employment (Ret)	0.906	3.6
Non-Retail Employment (NonRet)	-2.43	-4.64
Household Population (HH_Pop)	-2.33	-4.97
Student Group-Quarters Population (Stud_GQ)	-1.19	-2.12
R^2: 0.355		
Initial log-likelihood: -832.045		
Final log-likelihood: -536.654		
Number of records: 199		

Table 9-111 Off-campus student UBNH destination choice model (off-peak)

Utility Coefficients	Value	t-stat
Motorized Composite Time (MCT)	-0.106	-8.87
Short Walk Dummy (ShortWalk)	1.84	7.78
Building Area for Service (BAS)	1	Fixed
Retail Employment (Ret)	0.729	4.27
Non-Retail Employment (NonRet)	-1.87	-6.13
Household Population (HH_Pop)	-1.73	-4.74
Student Group-Quarters Population (Stud_GQ)	-1.66	-3.6
R^2: 0.424		
Initial log-likelihood: -2224.03		
Final log-likelihood: -1280.791		
Number of records: 450		

Off-Campus NHNU Trips

Off-campus NHNU trips are Non Home Non University trips made by off-campus students. Both the production ends and the attraction ends are off-campus locations. Intuitively, population and employment are major attractors of NHNU trips. Therefore, population and employment variables were tested, and the following utility function was selected for on-campus NHNU trips:

$$U_{ij} = bOP\_MCT * OP\_MCT_{ij} + ln(Ret_j + e^{bNonRet} * NonRet_j + e^{bTotPop} * TotPop_j) \quad (9\text{-}24)$$

where

bOP_MCT = coefficient for off-peak motorized composite time,
OP_MCT_{ij} = off-peak motorized composite time from production TAZ i to TAZ j,
$bRet$ = coefficient for retail employment,
Ret_j = retail employment in TAZ j,
$bNonRet$ = coefficient for non-retail employment,
$NonRet_j$ = retail employment in TAZ j (including Off, Ind, SerH, and SerL),
$bTotPop$ = coefficient for total population, and
$TotPop_j$ = total population in TAZ j (including HH_Pop, Stud_GQ, and Other_NonInst_GQ).

The estimation results are shown in Table 9-112. Total population (TotPop), retail employment (Ret), and non-retail employment (NonRet) are used in the size term. The coefficient for OP_MCT, which is used for trips in both the peak and off-peak periods, is negative. The R^2 value is 0.427.

Table 9-112 Off-campus student NHNU destination choice model

Utility Coefficients	Value	t-stat
Off-Peak Motorized Composite Time (OP_MCT)	-0.131	-13.54
Retail Employment (Ret)	1	Fixed
Non-Retail Employment (NonRet)	-2.27	-5.99
Total Population (TotPop)	-2.82	-8.15
R^2: 0.427		
Initial log-likelihood: -706.43		
Final log-likelihood: -404.79		
Number of records: 198		

9.2.3.2 Calibration of the Residence Choice Model for Off-Campus HBU Trips

Off-campus HBU trips are Home Based University trips made by off-campus students. The production ends are off-campus student home locations, which are not available as an input to the TRMv6. However, the attraction ends are on-campus locations, all of which are in a small number of closely-clustered TAZs. Therefore, the TRMSB first determined off-campus HBU trip attractions to each on-campus TAZ, then distributed those trips to production ends (home ends). Such a model may be better understood as a residence choice model.

The off-campus-student residence choice model was calibrated through the following steps:

1. Calculate total off-campus HBU trips to the NCSU campus as the product of the number of off-campus students (for undergraduate and graduate students, separately) and the corresponding HBU trip rates;
2. Distribute off-campus HBU trips to each NCSU on-campus TAZ according to university building floor area for service (BAS) to determine the zonal attractions;
3. Apply estimated residence choice model to distribute off-campus HBU trips from attraction TAZs (university on-campus locations) to production TAZs (off-campus residence locations);
4. Compare the modeled average trip distance and duration with observed values from the 2001 NCSU Student Survey;
5. Add a new variable, highway distance, to the residence choice model and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 10%).

The BAS values used in Step 2, above, are from 2001, which is consistent with what was used during model estimation. If 2010 BAS values were used in Step 2, many off-campus HBU trips would be attracted to NCSU's Centennial Campus, where many new buildings were constructed between 2001 and 2010, even though the 2001 NCSU Student Survey shows that only a few off-campus HBU trips were attracted to the then-less-developed Centennial Campus in that year. Therefore, travel behaviors observed in the 2001 survey are best explained using 2001 BAS values. Because data from the 2001 NCSU Student Survey were the targets for model calibration, using 2001 values to model trip distribution minimized distortion caused by the input data and better represented real travel behaviors.

Ideally, all input data (including population, employment, and the transportation network) would be from 2001, but many of these data were not available, such as 2001 population and employment in the TAZs delineated for the TRMv6 TAZ system. However, these data likely do not affect the model results as much as BAS does. 2001 values were available for only two of the variables used in the calibration process: BAS and Stud_GQ (students living in group quarters).

The calibration results are shown in Table 9-113. The residence choice model after calibration is as follows:

$$U_{ij} = -0.03 \times Dist_{ij} - 0.0853 \times OP\_MCT_{ij} - 0.707 \times \frac{MINC_j}{MINC_{Region}} + 1.26 \times ShortWalk_j + ln(HH\_Pop_j) \quad (9\text{-}25)$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
$Dist_{ij}$ = highway distance from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$MINC_j$ = mean household income in TAZ j;
$MINC_{Region}$ = regional mean household income, weighted by households in each TAZ;
$ShortWalk_j$ = dummy variable for whether TAZ j is in short-walk-to-campus-transit area; and
HH_Pop_j = household population in TAZ j.

Table 9-113 Calibration results of the destination choice model for off-campus HBU trips

	Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Observed	12.605		5.228	
Before calibration	14.175	12.5%	5.579	6.7%
After calibration	13.370	6.1%	4.927	-5.8%

Figure 9-36 and Figure 9-37 show frequency distributions for the observed and modeled travel times and distances of off-campus HBU trips. As discussed in Section 9.2.3.1, the off-peak (OP) highway skim (i.e., the highway skim that assumes free-flow speeds) was used to estimate the residence choice model, because it would be used to distinguish off-campus students from the general population and is best kept independent of peak-period conditions, which could skew the results. Therefore, the results shown in Figure 9-36 and Figure 9-37 only reflect the off-peak highway skim. These two figures show a close conformity between modeled and observed trip-length frequency distributions.

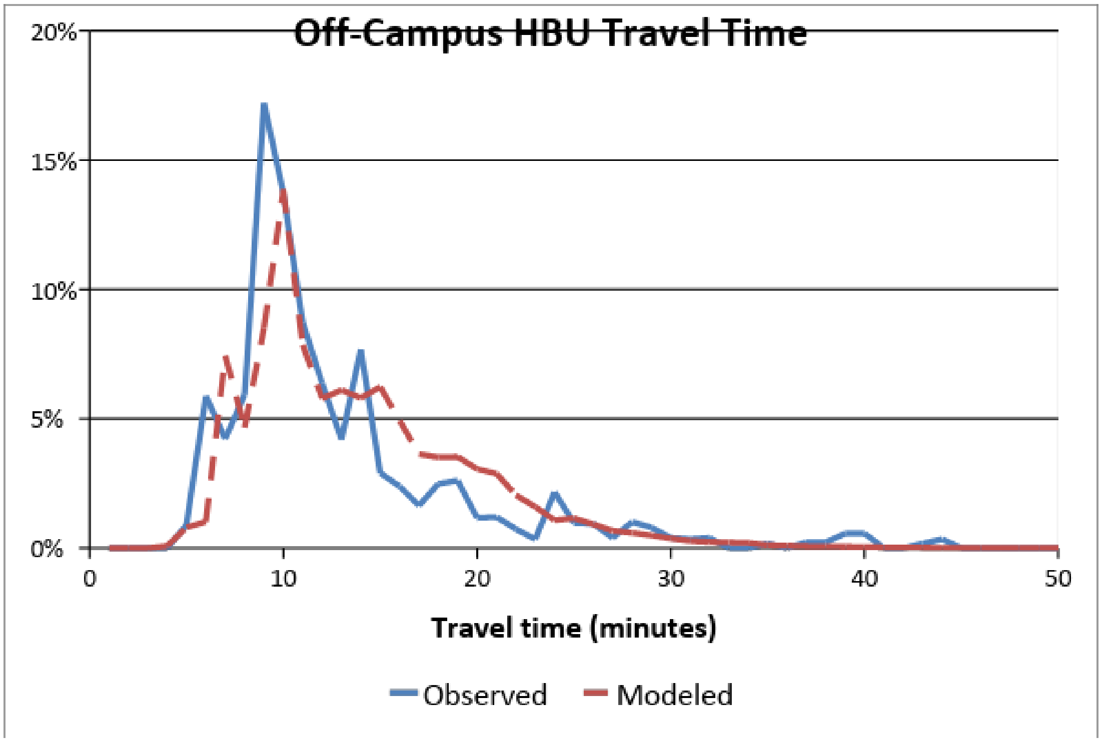


Figure 9-36 Off-campus HBU travel time frequency distribution

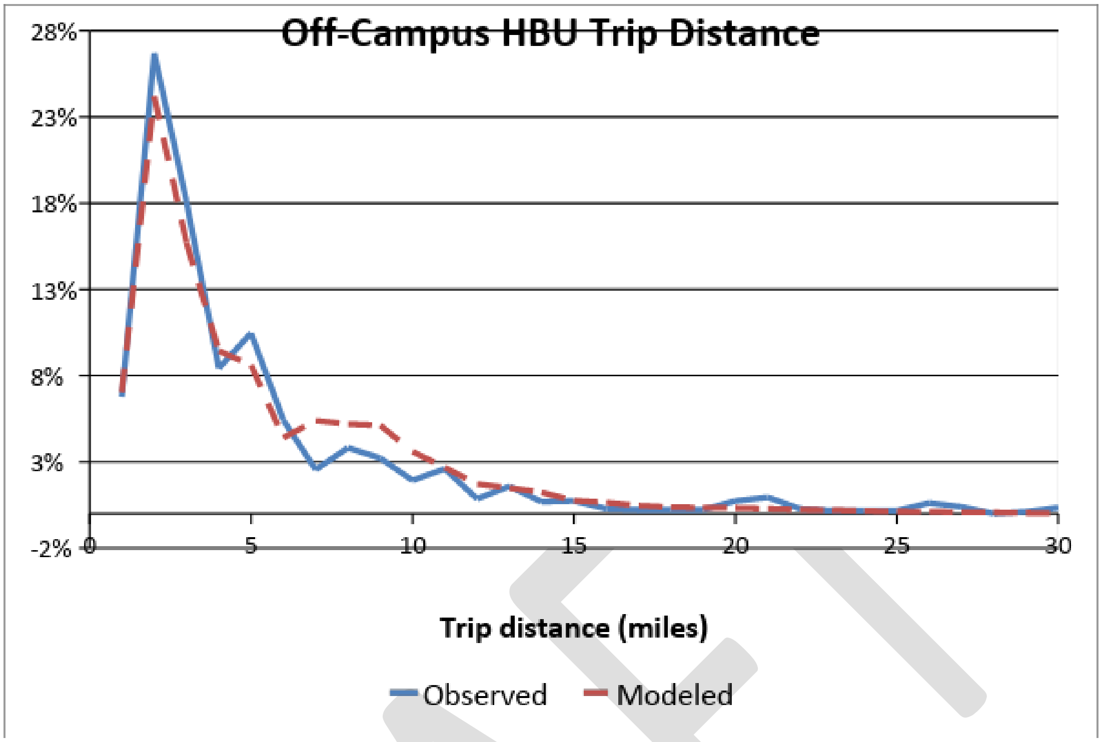


Figure 9-37 Off-campus HBU trip distance frequency distribution

Table 9-114 summarizes the coincidence ratios of the curves in Figure 9-36 and Figure 9-37. These coincidence ratios were calculated as

$$CR = \frac{\sum_i \quad min(obs_i, mod_i)}{\sum_i \quad max(obs_i, mod_i)} \quad (9\text{-}26)$$

where

CR = coincidence ratio,
obs_i = value on the observed distribution curve at time or distance i, and
mod_i = value on the modeled distribution curve at time or distance i.

Table 9-114 Summary of coincidence ratios for off-campus HBU trips

	Travel Time	Trip Distance
Off-Campus HBU	0.635	0.793

Figure 9-38 compares observed and modeled off-campus HBU productions (at the residence end) by district for travel to NCSU. Figure 9-39 compares the same data in an x-y coordinate system, with a linear regression line. Both of these figures show that observed and modeled off-campus HBU attractions are close at the scale of districts. A similar comparison at the more disaggregated TAZ level was also conducted. This comparisons showed larger differences between observed and modeled values, which was expected. Given that the observed values came from a survey of only about 400 students, they may not provide a reliable representation at the scale of TAZs, especially when only those survey results pertaining to off-campus HBU productions are considered.

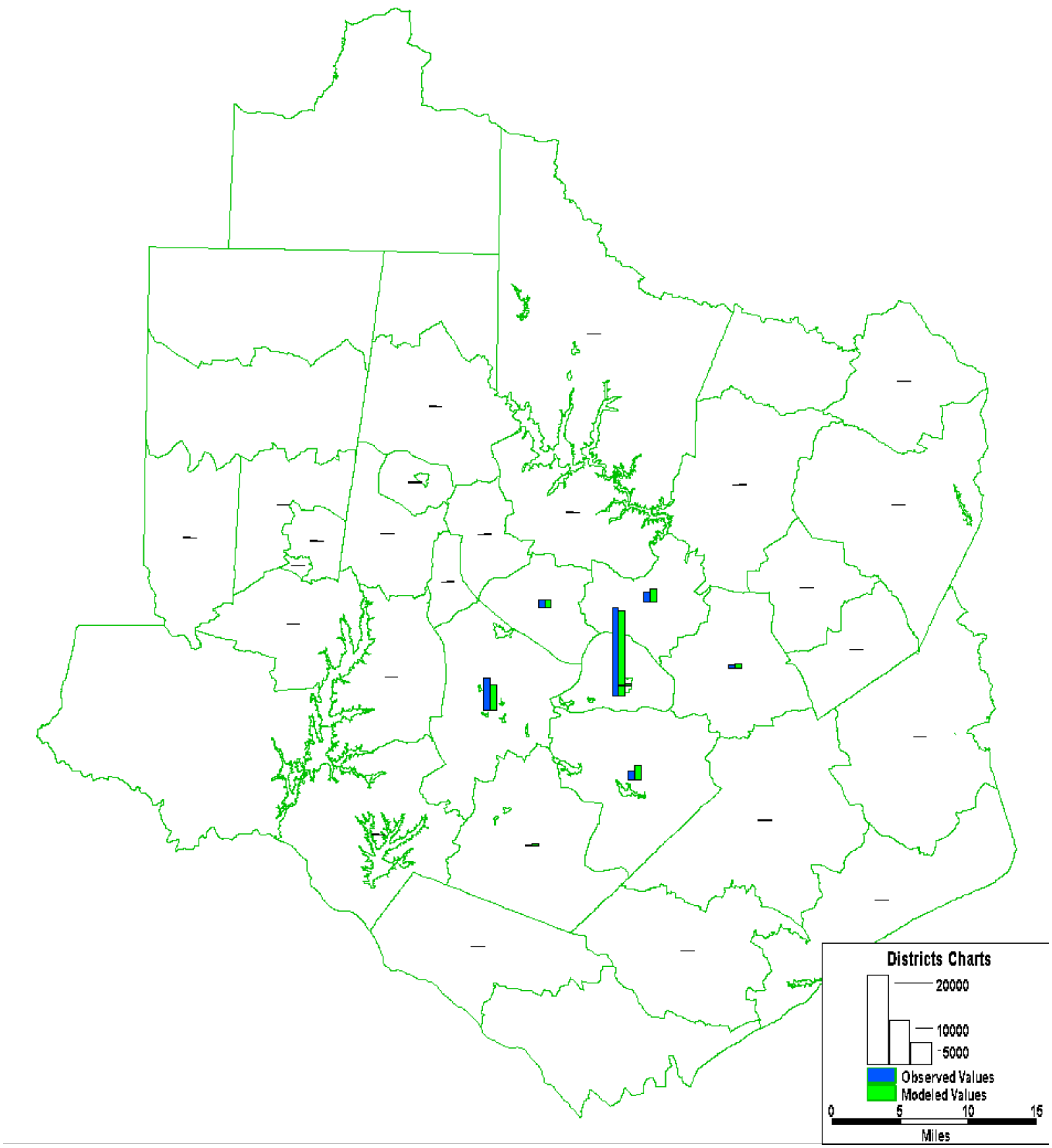


Figure 9-38 Comparison of observed and modeled off-campus HBU productions (at the residence end) by district for travel to NCSU

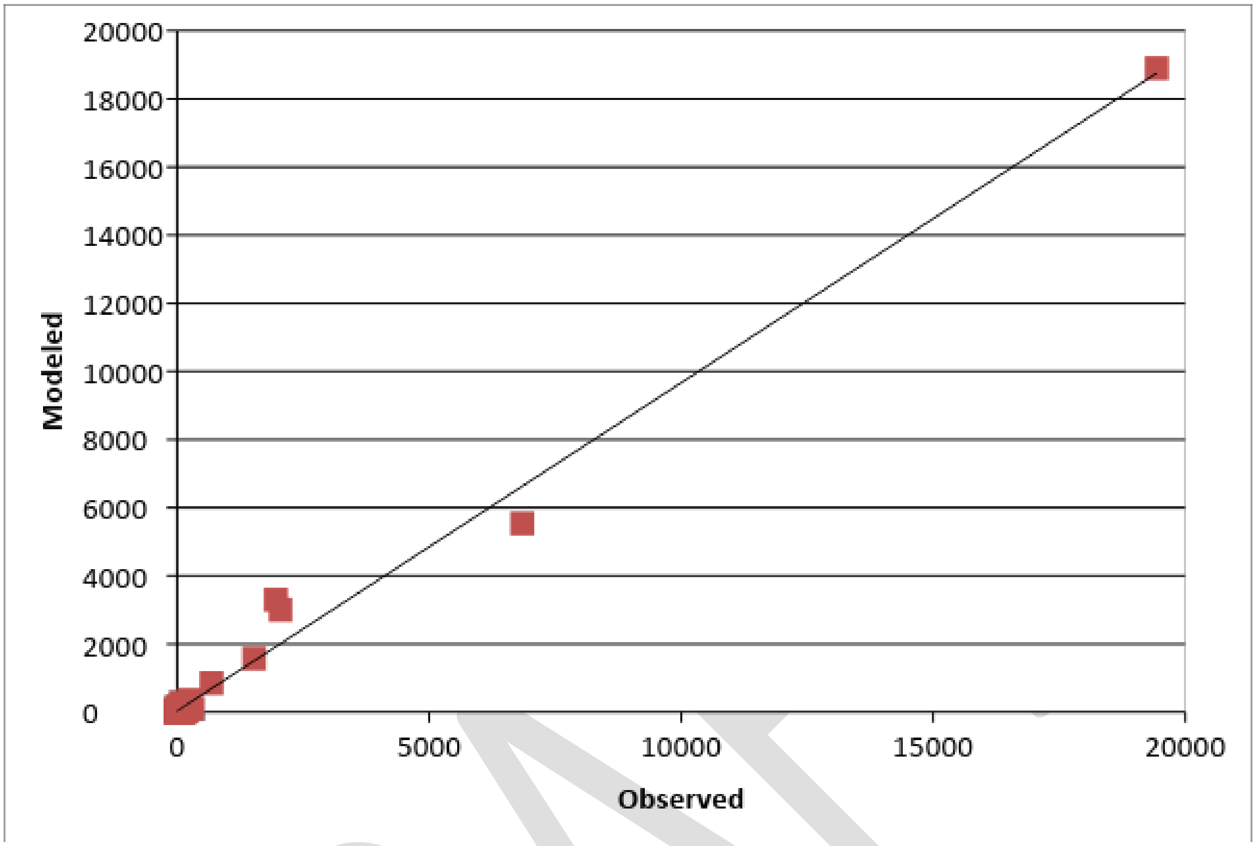


Figure 9-39 Plot of observed and modeled off-campus HBU productions (at the residence end) by district for travel to NCSU

9.2.3.3 Estimation of the Number of Off-Campus Students in Each TAZ

The residence choice model presented in Section 9.2.3.2 was used to estimate the number of off-campus students in each TAZ, which was then subtracted from the total population to get the non-university-student population of each TAZ. The basic idea can be expressed as the following equation:

$$Number\ of\ off\_campus\ students\ in\ TAZ\ i = \frac{Number\ of\ off\_campus\ HBU\ trips\ produced\ in\ TAZ\ i}{Off\_campus\ HBU\ trip\ rate\ in\ TAZ\ i}$$

9.2.3.3.1 Off-Campus HBU Trip Rate

The off-campus HBU trip rate is, intuitively, a function of distance to campus: an off-campus student makes more HBU trips if they live nearer to campus, as confirmed by an analysis of the 2001 NCSU Student Survey. Table 9-115 shows average off-campus HBU trip rates by distance to NCSU. TAZ 1490 (the TAZ in which the D. H. Hill Library is located) was selected as the center of the NCSU campus for the purpose of this analysis, and distances to NCSU were calculated as distances to the centroid of TAZ 1490.

Table 9-115 Off-campus HBU trip rates by distance to NCSU

Distance to NCSU	Weighted number of HBU trips	Weighted number of off-campus students	Count of TAZs	Count of off-campus students sampled	Average off-campus HBU trip rate
In Short Walk	15,492	5,882	19	114	2.6340
(0, 2]	1,562	597	5	11	2.6168
(2,3]	1,223	767	9	16	1.5952
(3,4]	3,387	1,643	13	32	2.0618
(4,5]	3,642	1,742	11	34	2.0910
(5,6]	913	455	5	9	2.0079
(6,8]	2,647	1,446	23	28	1.8310
(8,10]	1,804	1,769	28	37	1.0198
(10,12]	1,498	1,566	23	30	0.9562
(12,15]	857	674	12	13	1.2716
(15,20]	650	800	17	18	0.8132
>20	831	1,435	28	30	0.5791

In Table 9-115, TAZs that are "In Short Walk" are those TAZs that have any part of them within a 0.25-mile buffer of any Wolfline route (the NCSU campus bus service). 19 TAZs are "In Short Walk," and the 2001 NCSU Student Survey collected responses from 114 off-campus students in those TAZs. Those 114 sampled students represented 5,882 off-campus students after weighting, accounting for 15,492 off-campus HBU trips. Therefore, the average off-campus HBU trip rate is 2.6340 for TAZs "In Short Walk." All other records in Table 9-115 are for TAZs not "In Short Walk," but within a given distance range of NCSU, inclusive of the upper end of the range but not the lower end. The sizes of these distance ranges are not uniform: for example, (2,3] is 1 mile, and (15, 20] is 5 miles. This was done to ensure each range encompasses enough student samples to yield reliable results.

Ten of the records in Table 9-115 (excluding "In Short Walk" and ">20") are plotted in Figure 9-40. The midpoint of each distance range is used as the x-coordinate. The points in this plot show a clear trend of off-campus HBU trip rates declining with distance from campus, to represent which a quadratic regression model was developed. The "In Short Walk" category was not included in the plot because it is defined by the distance to NCSU's Wolfline, instead of to the designated center of NCSU.

The equations in Table 9-116 were used to determine off-campus HBU trip rates based on a TAZ's distance to NCSU and whether it is within the "short walk" distance to the Wolfline.

Table 9-116 Equations for off-campus HBU trip rates

	Off-campus HBU trip rate	Applied to TAZ j
1	2.6340	If TAZ j is in "short walk" area
2	$0.0041 \times d_j^2 - 0.1708 \times d_j + 2.5743$	If TAZ j is not in short walk and $0 < d_j \leq 20\ miles$
3	0.5791	If TAZ j is not in short walk and $d_j > 20\ miles$

Note: d_j is the highway distance from the centroid of TAZ 1490 to TAZ j.

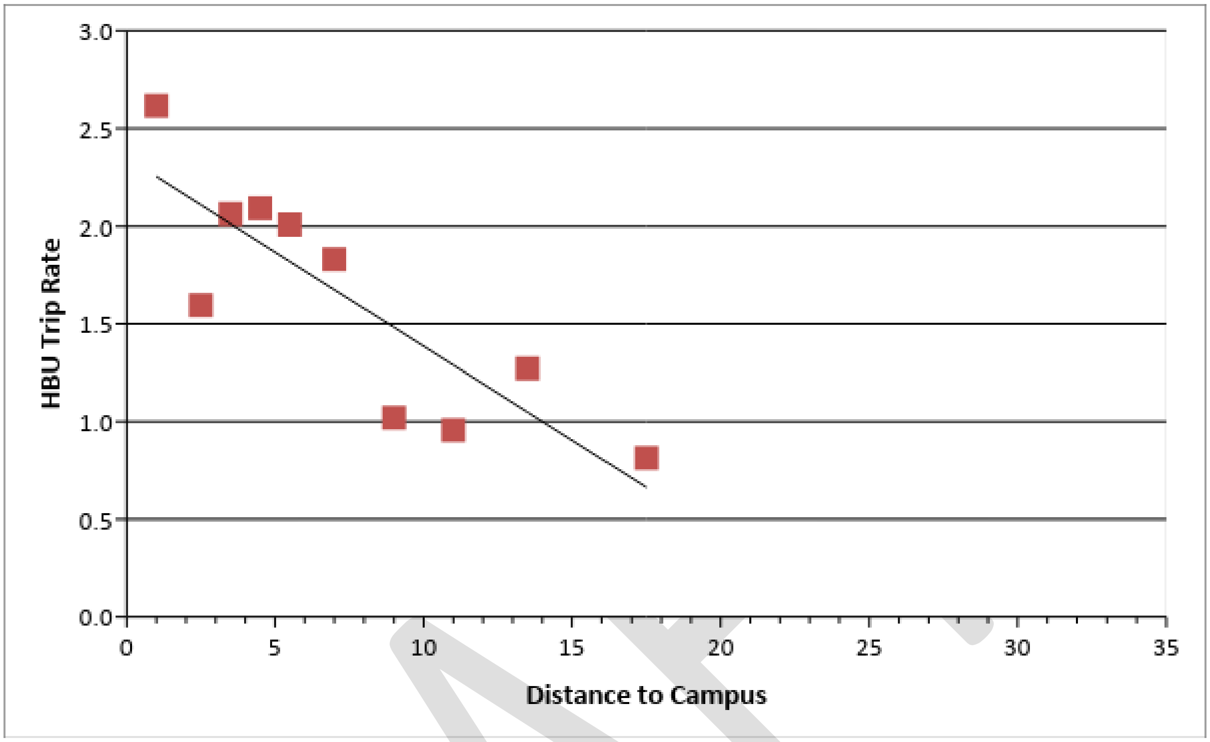


Figure 9-40 Relationship between off-campus HBU trip rates and distance to the NCSU campus

9.2.3.3.2 Estimating the Number of Off-Campus Students in each TAZ

GISDK code was developed to estimate the number of off-campus students attending each major university who live in any given TAZ, using the method described above. The sum of the resulting numbers of off-campus students associated with a particular university across all TAZs did not necessarily match the total number of off-campus students enrolled at the same university that was entered as input. Therefore, all modeled numbers of off-campus students living in each TAZ who attended a given university were multiplied by a factor that made their total equal the necessary total off-campus enrollment for that university.

Figure 9-41 through Figure 9-44 show modeled numbers of off-campus students associated with each university in the TAZs that surround them. Instead of absolute numbers, these figures show the off-campus-student percent of the household population (HH_POP), to provide a clearer idea of what fraction of the household population gets subtracted on the grounds of representing off-campus students.

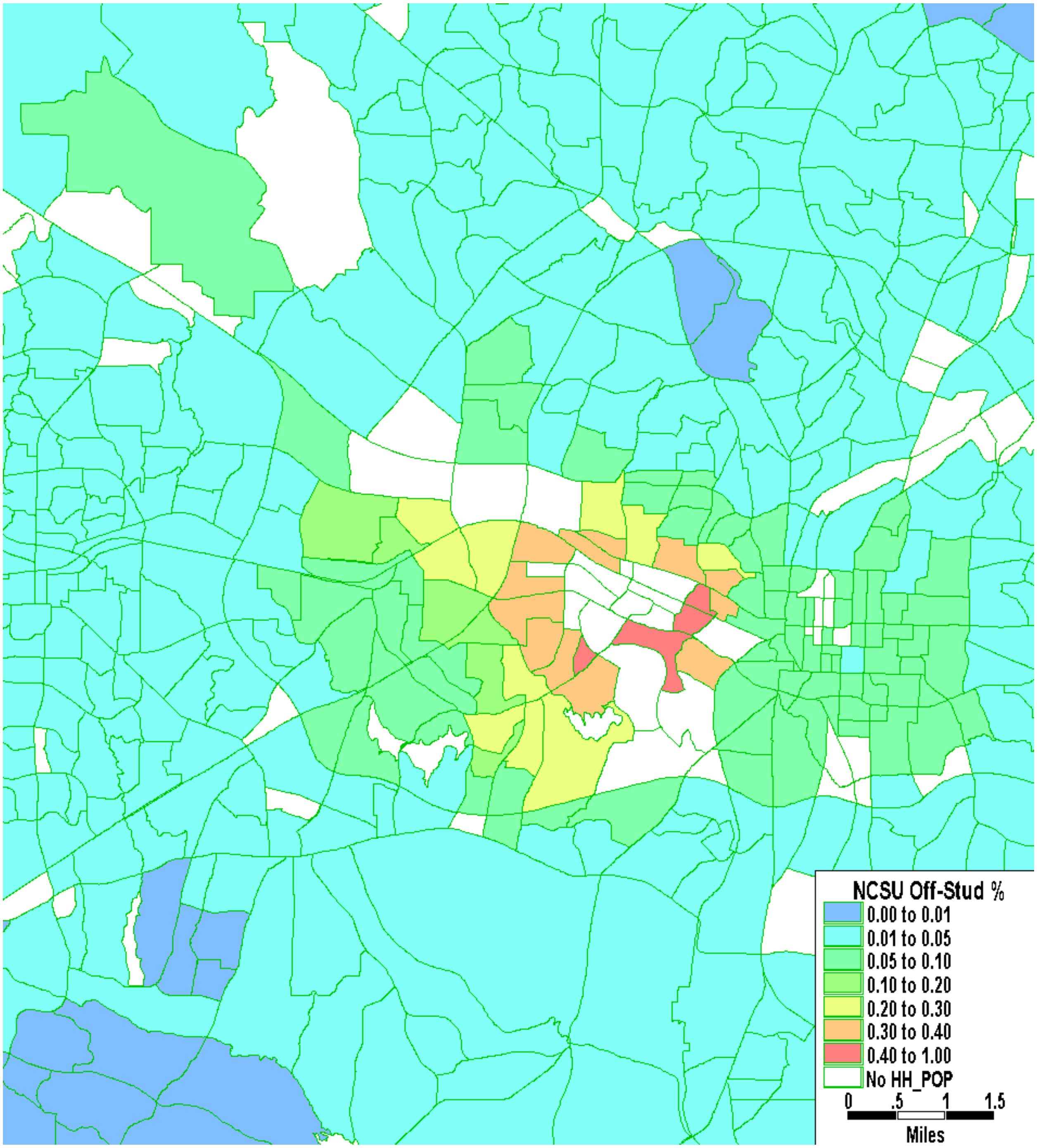


Figure 9-41 Percent of NCSU off-campus students in the household population

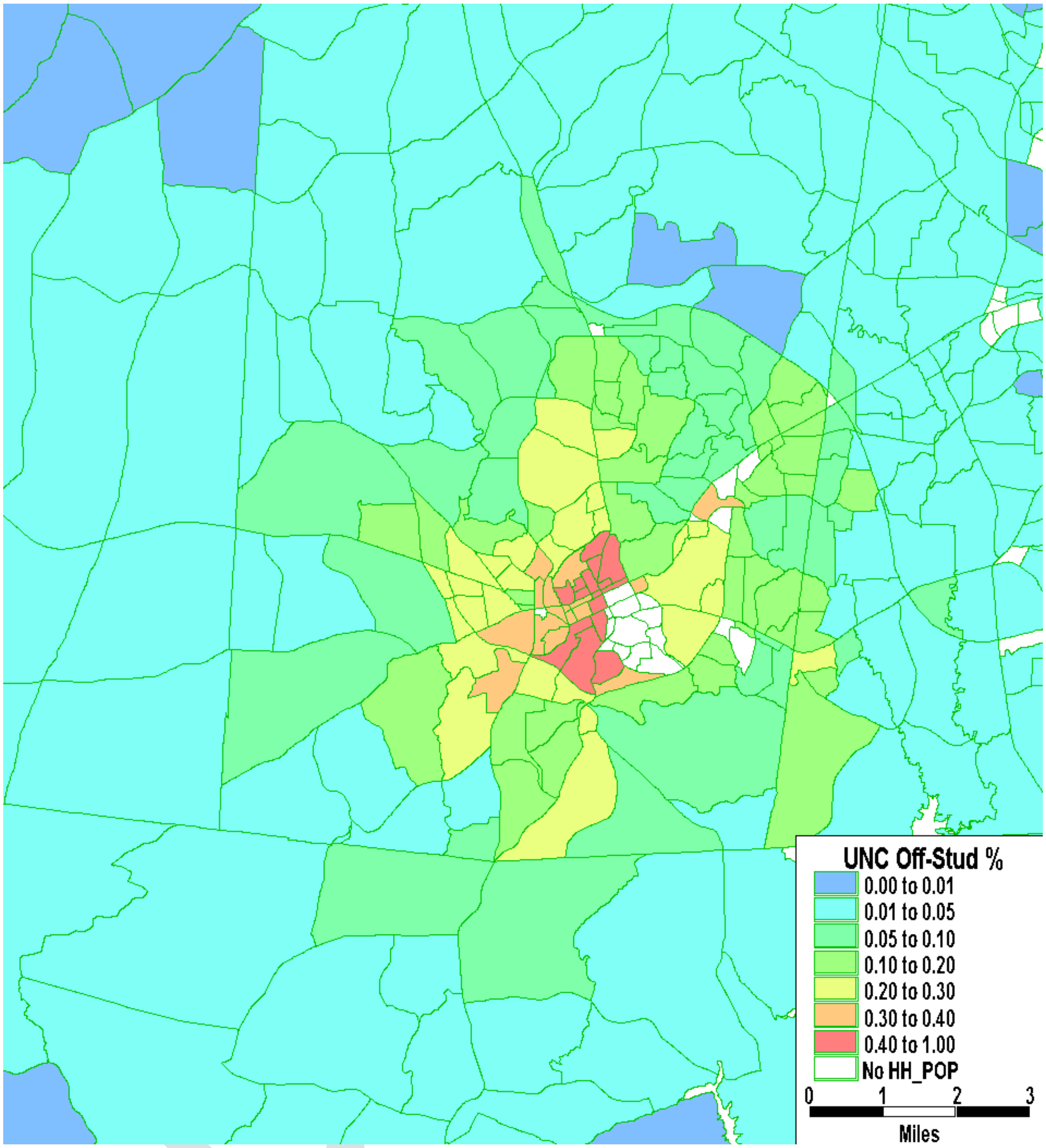


Figure 9-42 Percent of UNC off-campus students in the household population

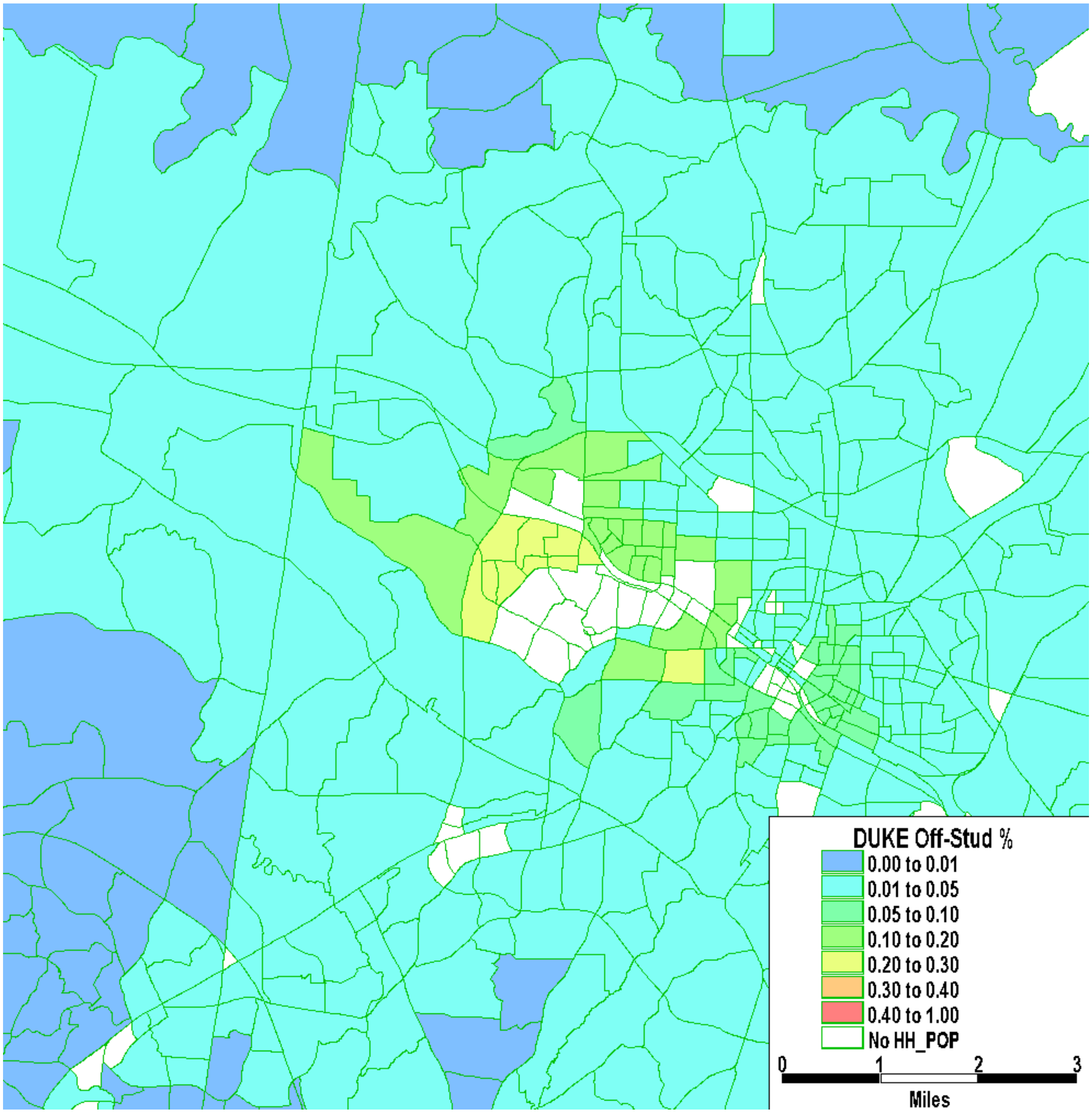


Figure 9-43 Percent of Duke off-campus students in the household population

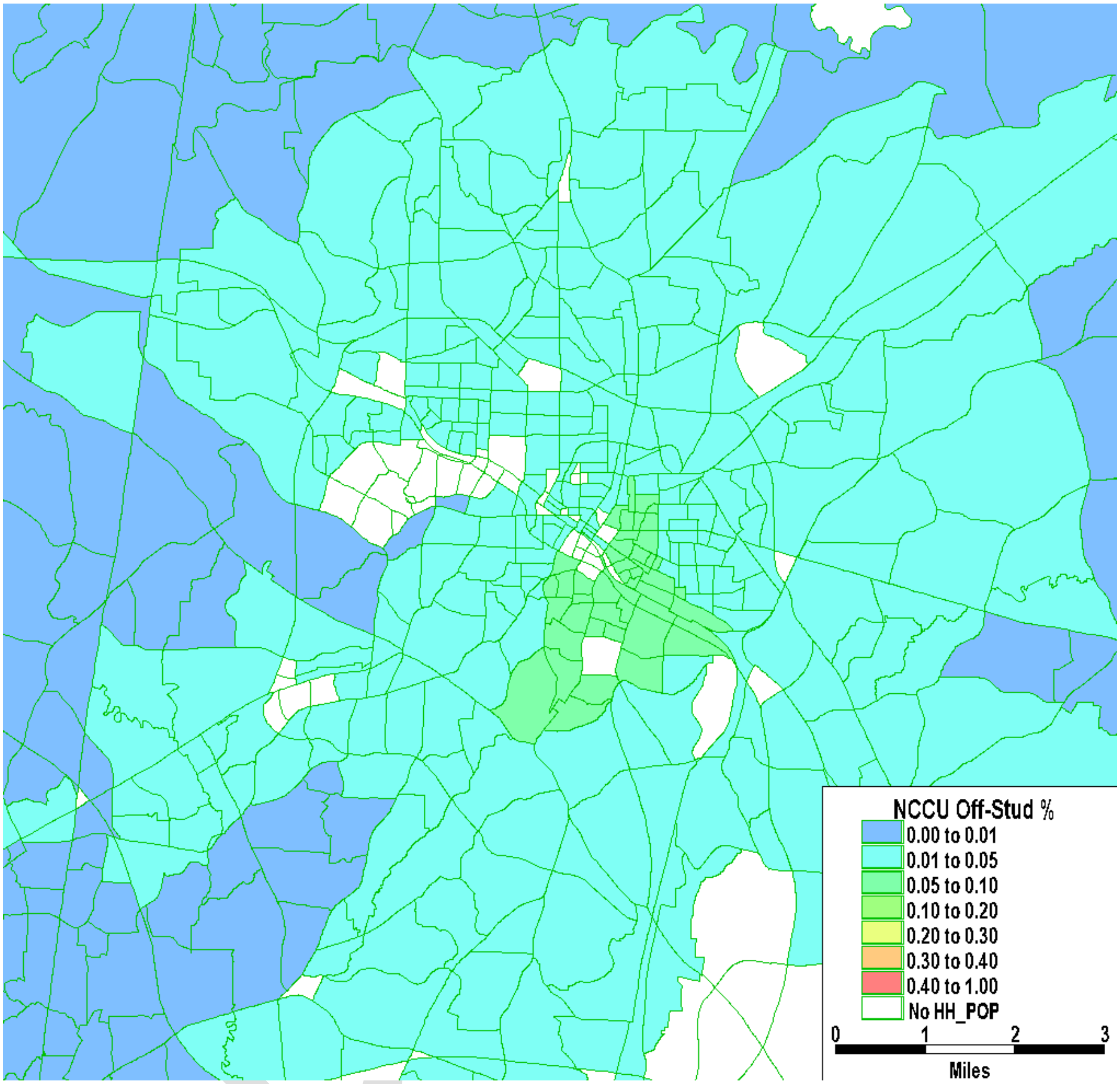


Figure 9-44 Percent of NCCU off-campus students in the household population

9.2.3.3.3 Validation of Numbers of Off-Campus Students for UNC

The 2011 UNC Campus Commuting Survey[15] was adopted to validate the numbers of off-campus students associated with UNC. The UNC Campus Commuting Survey was started in 1997 and repeated in 2001, 2004, 2007, and 2009. It is now conducted every other year. The purpose of the study is to survey both students and employees about the various travel modes they use to commute to campus, as well as their origins and destinations. In the 2011 survey, "the student population

[15] Martin / Alexiou / Bryson, P.C., UNC-Chapel Hill, *2011 UNC Campus Commuting Survey,* Project Report, November 2011.

consisted of all undergraduate, graduate, and professional students who lived off-campus during spring 2011. From this population, a random sample of 5,000 was drawn. A total of 484 responses were received for a response rate of 9.7%. The margin of error for the student survey is +/-4.4% at a confidence level of 95%."

Figure 9-45 compares trip length distributions from the 2011, 2009, and 2007 UNC Campus Commuting Surveys to the modeled results. This comparison indicates that the trip length distribution resulting from the modeled home locations of UNC off-campus students is generally consistent with the survey results, especially those from the 2007 survey.

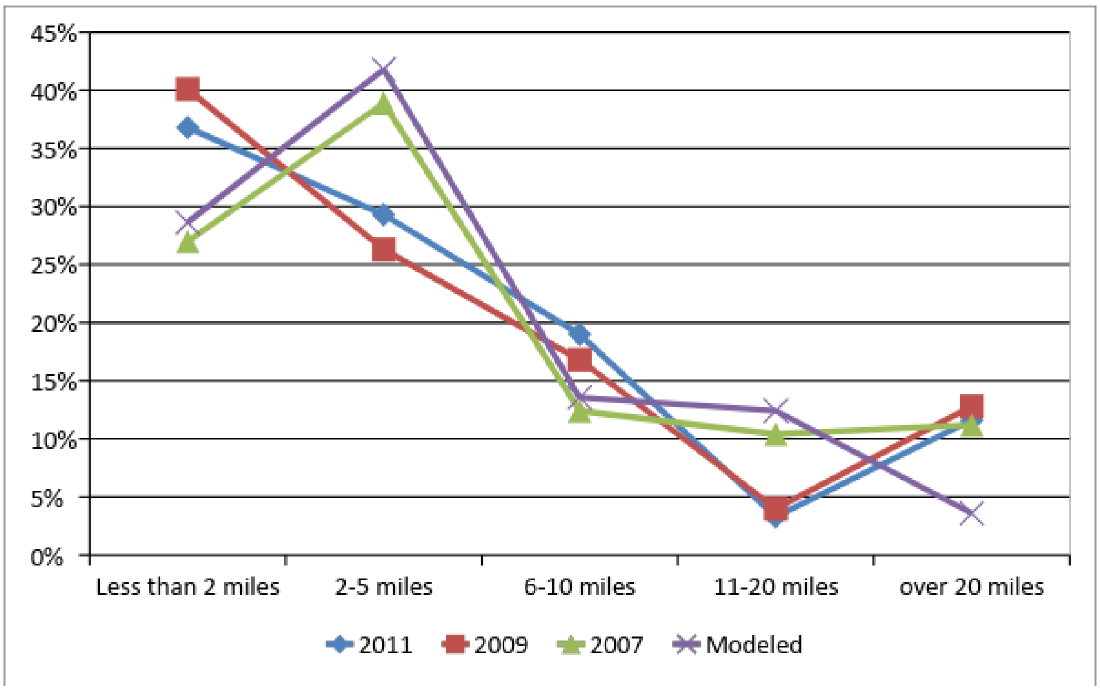


Figure 9-45 Validation of the trip length distribution for UNC

The trip length distribution presented in Figure 9-45 is based on highway trip distance (in miles). A similar analysis was also prepared based on travel time (in minutes), which showed more inconsistencies. However, the travel times derived from the model were all automobile travel times, since mode-choice information is not yet available in the trip distribution modeling step. In contrast, the travel times from the surveys may be automobile travel times, walk travel times, or bus travel times. Therefore, it would have been misleading to compare the model and survey results in terms of travel times.

Figure 9-46 presents percentages of off-campus students living in each of the ZIP Codes surrounding UNC, and a map of those ZIP Codes is shown in Figure 9-47. The modeled home locations of UNC off-campus students are generally distributed amongst the ZIP Codes in appropriate proportions, with the exception of ZIP Code 27516: the model locates more off-campus students in ZIP Code 27516 than do the surveys.

It is suspected that the model locates too many off-campus students in the rural buffer in ZIP Code 27516, which is a low-density residential area and less likely to attract off-campus-student residents. A detailed analysis showed that rural areas (based on the rural-area definition used in the TRM) account for 90% of the area of ZIP Code 27516, but only account for 12% of the off-campus students assigned to that ZIP Code by the model. Therefore, the results would not change much if a penalty were applied in the model to discourage off-campus students from living in rural areas.

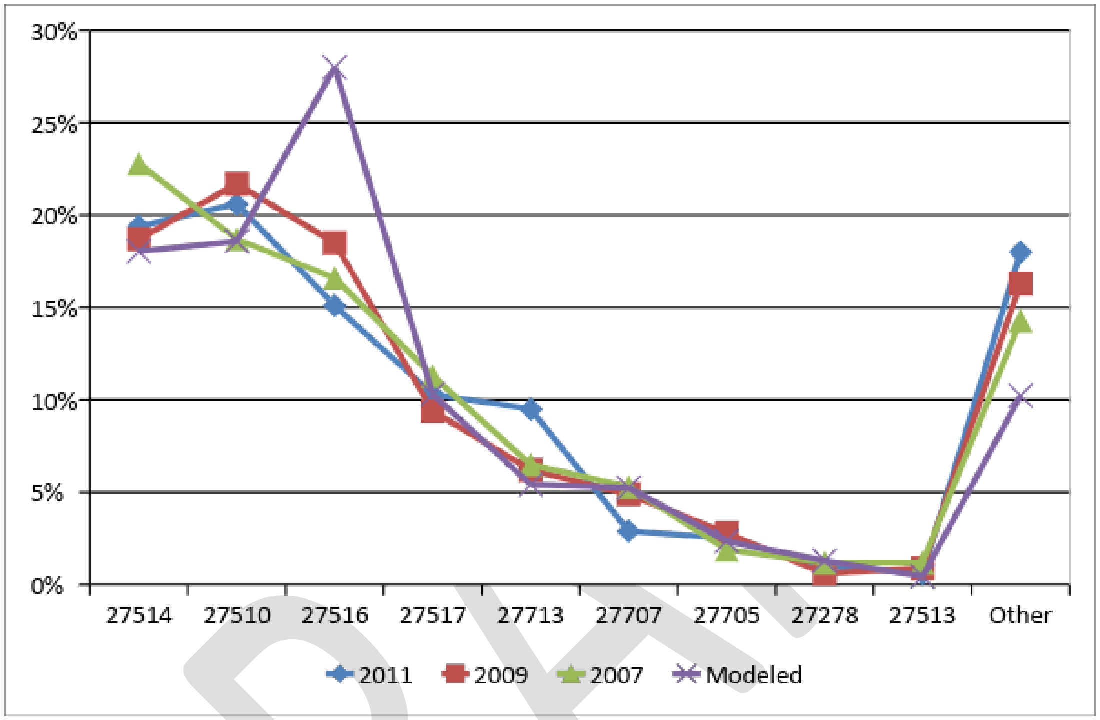


Figure 9-46 Validation of the ZIP Code distribution of UNC off-campus students

The model to locate off-campus student homes was developed using a survey conducted at NCSU in 2001, yet it is applied to yield the off-campus student home locations in 2010 for NCSU, UNC, NCCU, and Duke. Both the spatial and temporal adaptation of the model affect the comparison results shown in Figure 9-45 and Figure 9-46. Given that, the validation results are reasonable.

A possible future improvement of the model is to include single-unit/multi-family housing information in the residence choice model.

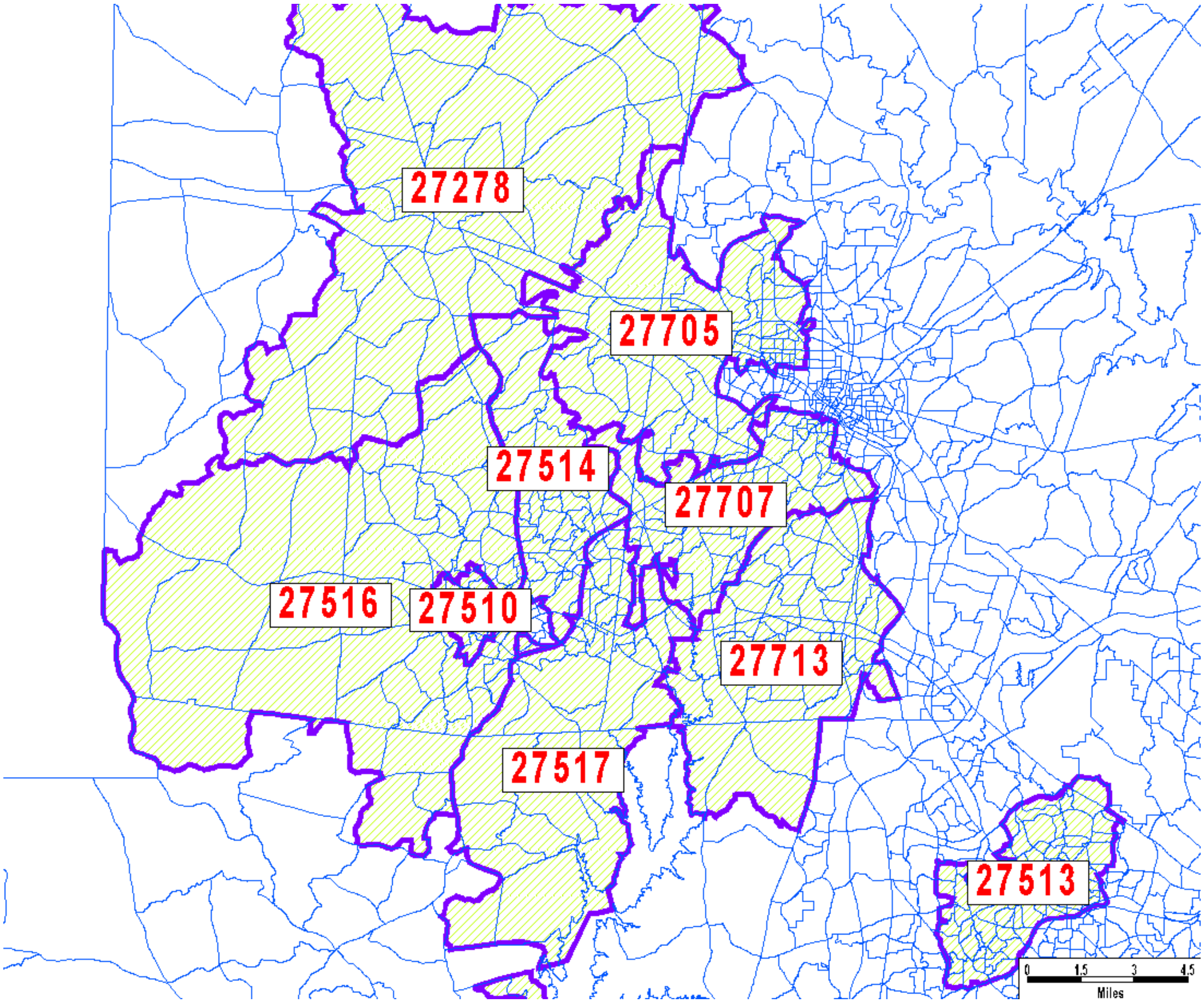


Figure 9-47 ZIP Code map around UNC

9.2.3.4 Calibration of Destination Choice Models for Other Trip Purposes

9.2.3.4.1 On-Campus HBU Trips

On-campus HBU trips are Home Based University trips made by on-campus students. Because their production and attraction ends are both on-campus locations, the distances of these trips are short. The model calibration was conducted by following these steps:

1. Calculate daily productions of on-campus HBU trips for each TAZ as the product of the number of on-campus students and the corresponding HBU trip rate;
2. Split daily on-campus HBU productions into peak and off-peak trips, based on a peak/off-peak factor developed from the 2001 NCSU Student Survey;
3. Apply the on-campus HBU destination choice model to distribute peak-period on-campus HBU trips from production TAZs to attraction TAZs;

4. Compare the modeled average trip distance and duration with observed values from the 2001 NCSU Student Survey;
5. Add a new variable, highway distance, to the peak-period destination choice model, and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 5%);
6. Repeat Steps 3 through 5 for off-peak trips.

The calibration results are shown in Table 9-117. The destination choice models after calibration are represented by Equations 9-27a and 9-27b. Equation 9-27a is for the peak period and Equation 9-27b is for the off-peak period. These two equations use university building floor area for service (BAS) and the number of on-campus students living in group quarters (Stud_GQ) in a logarithm term as the size variable, meaning that trip attractions can only be to TAZs with BAS > 0 or Stud_GQ > 0, which ensures that the attraction TAZs can only be on-campus TAZs.

$$U_{ij} = -0.3 \times Dist_{ij} - 0.154 \times PK\_MCT_{ij} + ln(BAS_j + e^{-0.302} \times Stud\_GQ_j) \tag{9-27a}$$

$$U_{ij} = -0.1 \times Dist_{ij} - 0.154 \times OP\_MCT_{ij} + ln(BAS_j + e^{-0.302} \times Stud\_GQ_j) \tag{9-27b}$$

where

U_{ij} = utility of travel from TAZ i to TAZ j,
$Dist_{ij}$ = highway distance from TAZ i to TAZ j,
PK_MCT_{ij} = peak motorized composite time from TAZ i to TAZ j,
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j,
BAS_j = university building floor area for service in TAZ j (unit: 1,000 square feet), and
$Stud\_GQ_j$ = on-campus students living in group quarters in TAZ j.

Table 9-117 Calibration results of the destination choice model for on-campus HBU trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Peak	Observed	7.735		0.684	
	Before calibration	7.453	-3.6%	0.764	11.7%
	After calibration	7.366	-4.8%	0.718	5.0%
Off-peak	Observed	7.603		0.719	
	Before calibration	7.246	-4.7%	0.767	6.6%
	After calibration	7.221	-5.0%	0.750	4.3%

Figure 9-48 through Figure 9-51 show frequency distributions for the observed and modeled travel times and distances of on-campus HBU trips: Figure 9-48 and Figure 9-49 are for the peak period and Figure 9-50 and Figure 9-51 are for the off-peak period. Because on-campus HBU trips are short, finer trip-duration and trip-distance bins are used in these figures than in those for off-campus HBU trips (Figure 9-36 and Figure 9-37). The coincidence ratios are shown in Table 9-118.

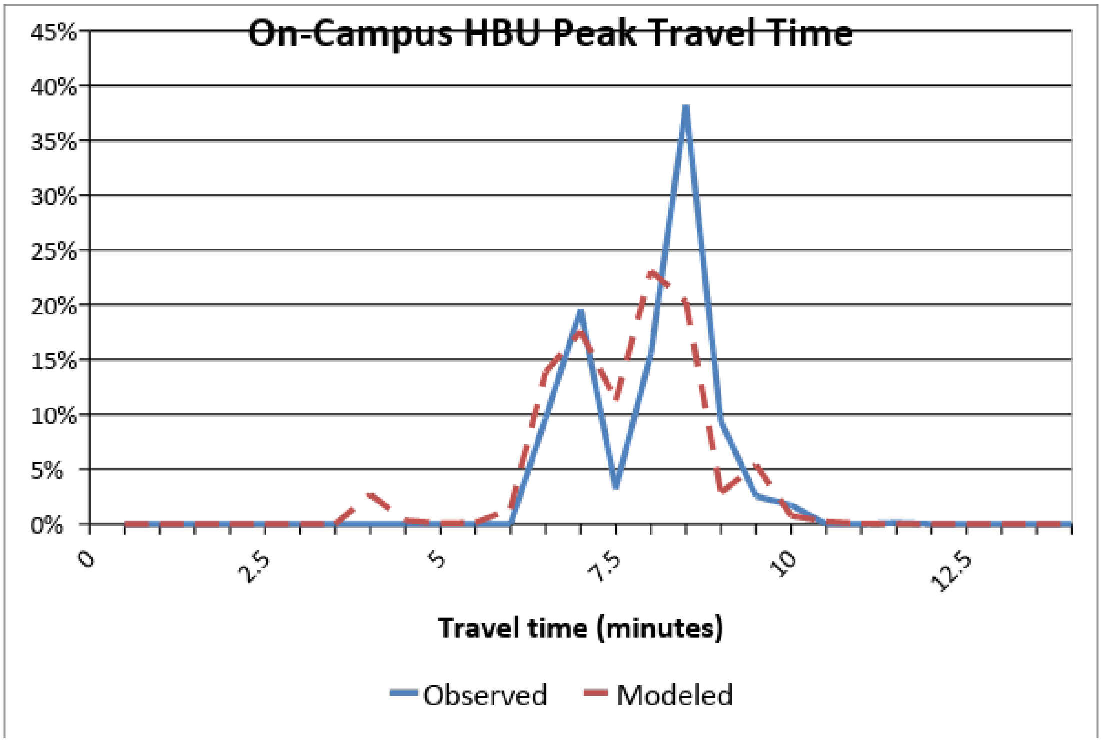


Figure 9-48 On-campus HBU trip duration frequency distribution (peak)

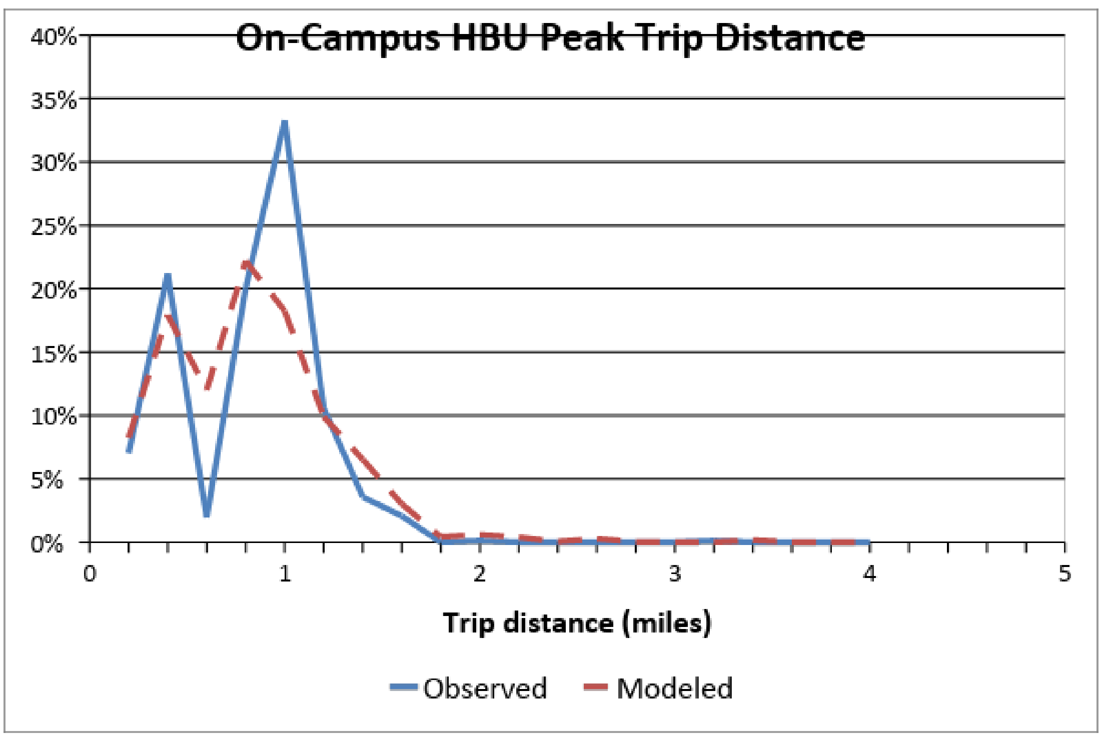


Figure 9-49 On-campus HBU trip distance frequency distribution (peak)

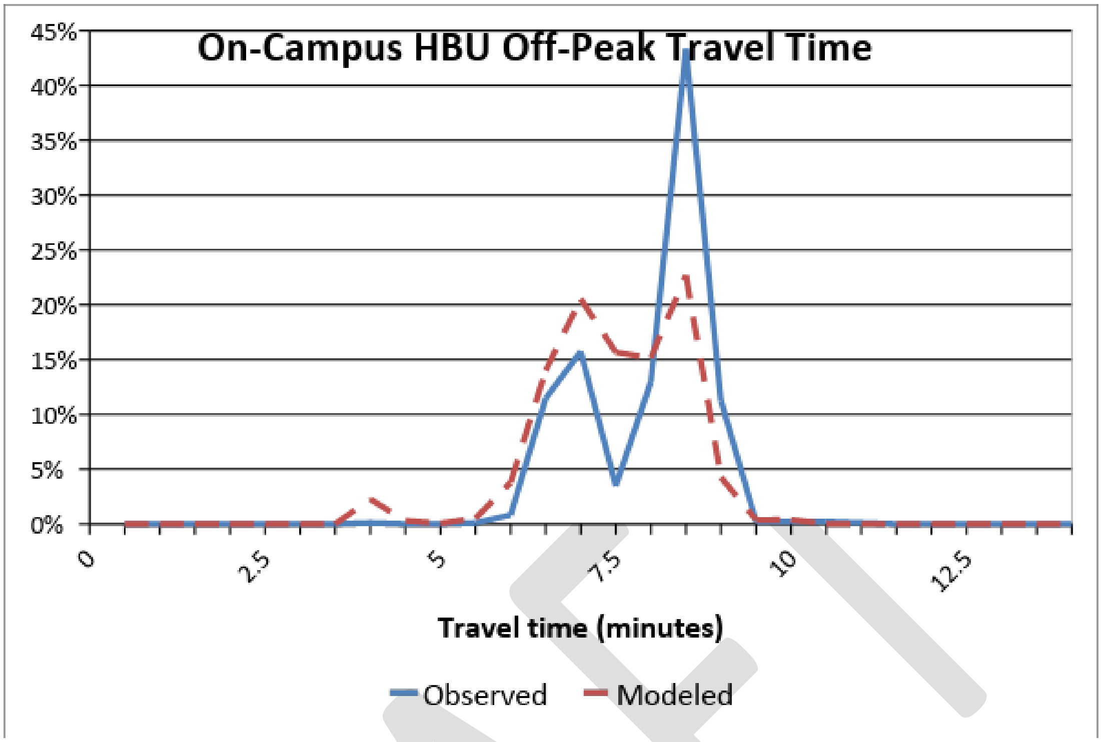


Figure 9-50 On-campus HBU trip duration frequency distribution (off-peak)

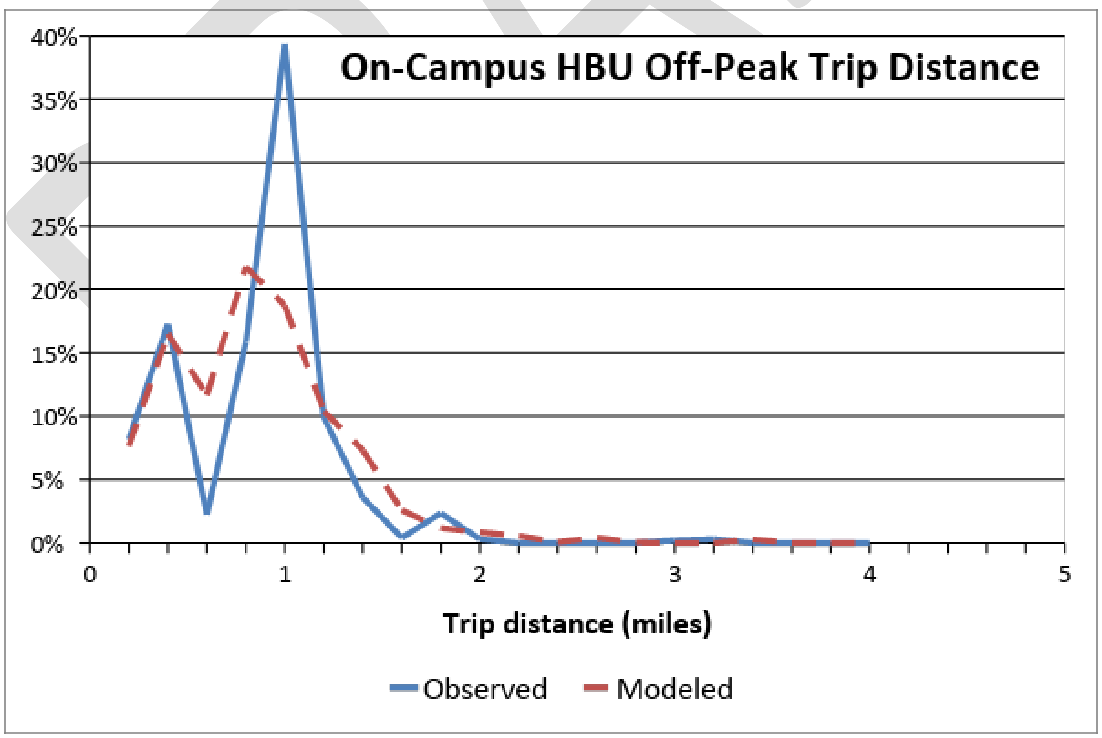


Figure 9-51 On-campus HBU trip distance frequency distribution (off-peak)

Table 9-118 Summary of coincidence ratios for on-campus HBU trips

	Travel Time	Trip Distance
On-Campus HBU Peak	0.569	0.679
On-Campus HBU Off-Peak	0.563	0.618

9.2.3.4.2 On-Campus HBO Trips

On-campus HBO trips are Home Based Other trips made by on-campus students, with on-campus production ends and off-campus attraction ends. The model calibration was conducted by following these steps:

1. Calculate daily productions of on-campus HBO trips in each TAZ as the product of the number of on-campus students living in the TAZ and the corresponding HBO trip rate;
2. Split daily on-campus HBO productions into peak and off-peak trips by using a peak/off-peak factor developed from the results of the 2001 NCSU Student Survey;
3. Apply the on-campus HBO destination choice model to distribute peak-period on-campus HBO trips from production TAZs to attraction TAZs;
4. Compare the modeled average trip distance and duration with observed values from the 2001 NCSU Student Survey;
5. Add a new variable, highway distance, to the peak-period destination choice model, and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 5%);
6. Repeat Steps 3 through 5 for off-peak trips.

The calibration results are shown in Table 9-119. The destination choice models after calibration are represented by Equations 9-28a and 9-28b. Equation 9-28a is for the peak period and Equation 9-28b is for the off-peak period. To ensure that all on-campus HBO trips are attracted to off-campus TAZs, the variables $Retail_j$, $NonRet_j$, and $TotPop_j$ in these equations were set to zero for on-campus TAZs during the model calibration and application steps.

$$U_{ij} = -0.025 \times Dist_{ij} - 0.0889 \times PK\_MCT_{ij} + 1.48 \times ShortWalk_j + ln(Retail_j + e^{-3.29} \times NonRet_j + e^{-2.82} \times TotPop_j) \quad \text{(9-28a)}$$

$$U_{ij} = -0.035 \times Dist_{ij} - 0.0889 \times OP\_MCT_{ij} + 1.48 \times ShortWalk_j + ln(Retail_j + e^{-3.29} \times NonRet_j + e^{-2.82} \times TotPop_j) \quad \text{(9-28b)}$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
$Dist_{ij}$ = highway distance from TAZ i to TAZ j;
PK_MCT_{ij} = peak-period motorized composite time from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area;
$Retail_j$ = retail employment in TAZ j;
$NonRet_j$ = non-retail employment in TAZ j; and

$TotPop_j$ = total population in TAZ j, including household population, student group quarters population, and other non-institutional group quarters population.

Table 9-119 Calibration results of the destination choice model for on-campus HBO trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Peak	Observed	11.813		4.173	
	Before calibration	12.502	5.8%	4.533	8.6%
	After calibration	11.921	0.9%	4.116	-1.4%
Off-peak	Observed	10.928		4.330	
	Before calibration	11.810	8.1%	4.842	11.8%
	After calibration	11.049	1.1%	4.214	-2.7%

Figure 9-52 through Figure 9-55 show frequency distributions for the observed and modeled travel times and distances of on-campus HBO trips: Figure 9-52 and Figure 9-53 are for the peak period and Figure 9-54 and Figure 9-55 are for the off-peak period. The coincidence ratios are shown in Table 9-120.

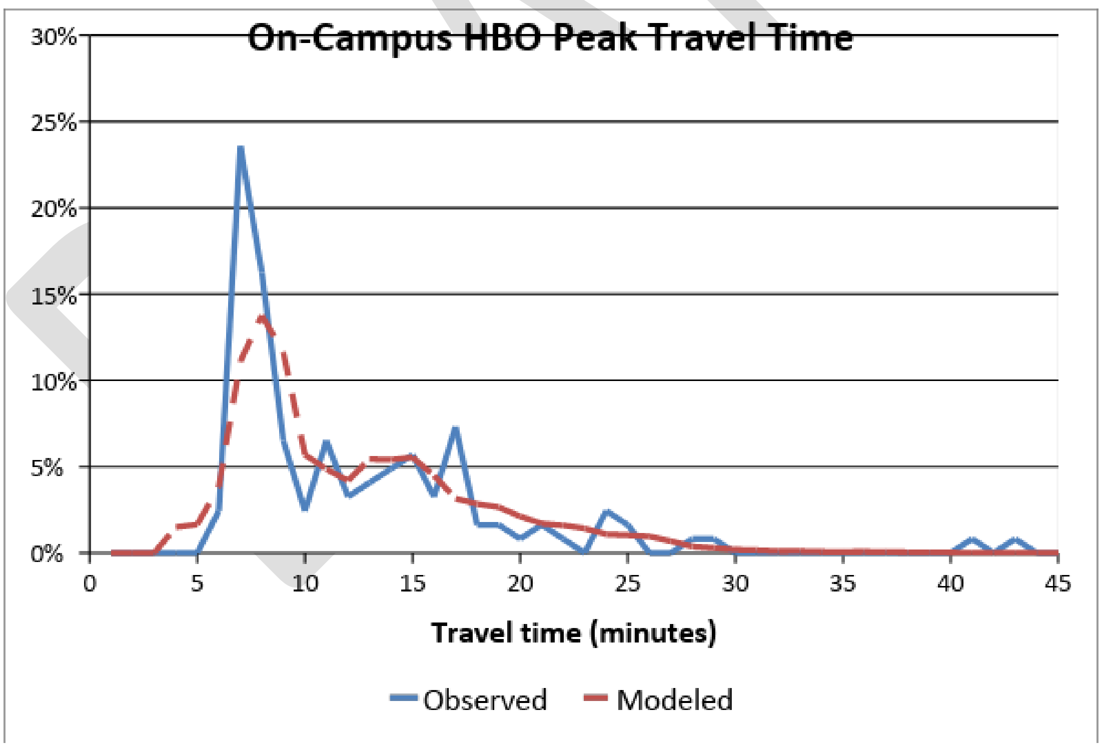


Figure 9-52 On-campus HBO trip duration frequency distribution (peak)

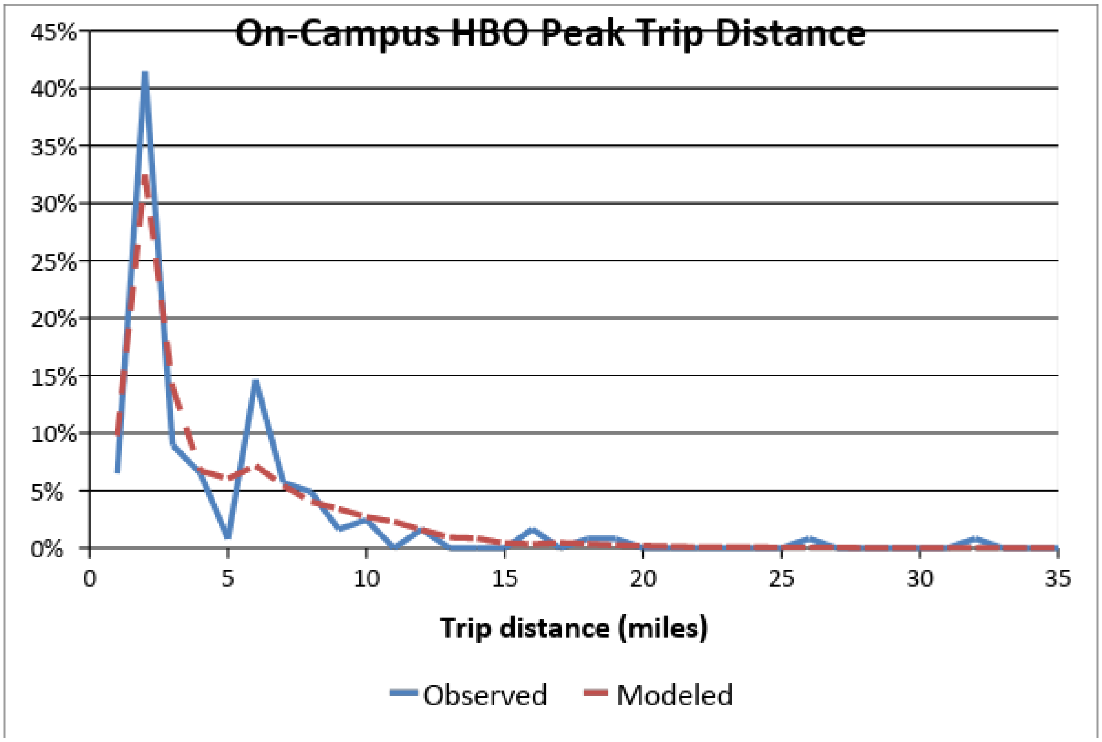


Figure 9-53 On-campus HBO trip distance frequency distribution (peak)

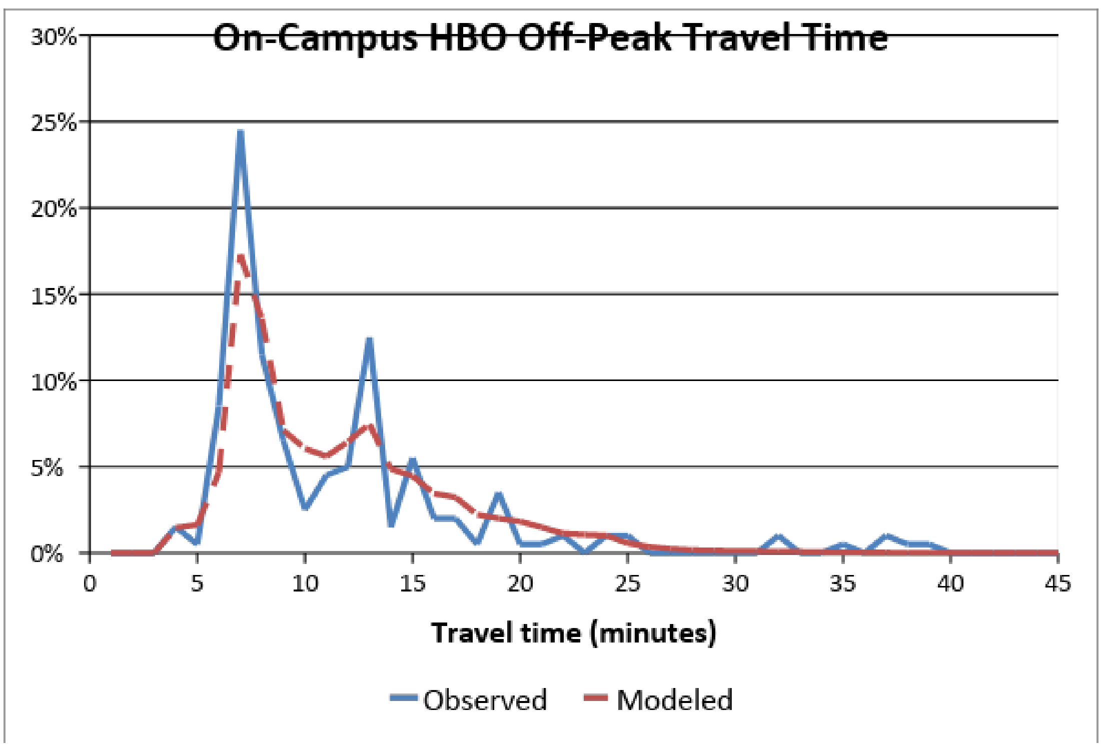


Figure 9-54 On-campus HBO trip duration frequency distribution (off-peak)

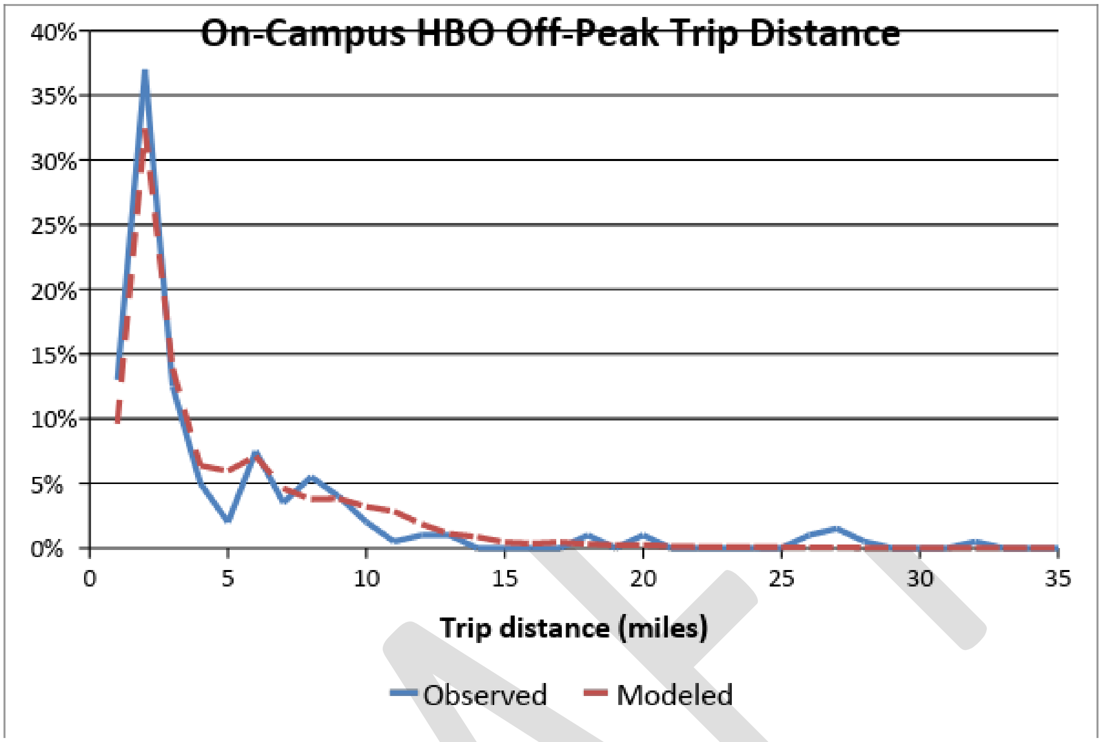


Figure 9-55 On-campus HBO trip distance frequency distribution (off-peak)

Table 9-120 Summary of coincidence ratios for on-campus HBO trips

	Travel Time	Trip Distance
On-Campus HBO Peak	0.594	0.646
On-Campus HBO Off-Peak	0.634	0.738

9.2.3.4.3 Off-Campus HBO Trips

Off-campus HBO trips are Home Based Other trips made by off-campus students. Both the production and attraction ends are off-campus locations. The model calibration was conducted by following these steps:

1. Obtain the number of off-campus students in each TAZ, using the method presented in Section 9.2.3.3;
2. Calculate daily productions of off-campus HBO trips in each TAZ as the product of the number of off-campus students living in the TAZ and the corresponding HBO trip rate;
3. Split daily off-campus HBO productions into peak and off-peak trips by using a peak/off-peak factor developed from the results of the 2001 NCSU Student Survey;
4. Apply the off-campus HBO destination choice model to distribute peak-period off-campus HBO trips from production TAZs to attraction TAZs;

5. Compare the modeled average trip duration and distance with observed values from the 2001 NCSU Student Survey;
6. adjust the coefficient for MCT, so that the modeled average peak-period trip distance and duration match observed values (within 5%); the variable of highway distance is not introduced in this model because it would have made modeled average trip lengths deviate further from observed values;
7. Repeat Steps 4 through 6 for off-peak trips.

The calibration results are shown in Table 9-121. The destination choice models after calibration are represented by Equations 9-29a and 9-29b. Equation 9-29a is for the peak period, and Equation 9-29b is for the off-peak period. To ensure that all off-campus HBO trips are attracted to off-campus TAZs, the variables $Retail_j$, $NonRet_j$, and $TotPop_j$ in these equations were set to zero for on-campus TAZs during the model calibration and application steps.

As shown in Table 9-121, off-campus HBO trip lengths are significantly different in the peak and off-peak periods: the average trip distance is 7.296 miles in the peak period and only 4.960 miles in the off-peak period. Therefore, two destination choice models were estimated, one for each time period. It was determined that there were enough samples in the 2001 NCSU University Student Survey to support estimating both of these models: 275 trip samples in the peak period and 274 in the off-peak period. After model estimation, the coefficient for PK_MCT_{ij} was -0.0912, and the coefficient for OP_MCT_{ij} was -0.157. Upon calibrating these two models, it was found that the initial modeled average travel times and trip distances were all smaller than the observed values, as shown in Table 9-121 (“before calibration”). As a result, if highway distance were introduced to calibrate the model, as was done for all other trip purposes, the coefficients for highway distance would have had to be positive, which is counter-intuitive. Therefore, it was decided to not introduce highway distance is a variable in this instance. Instead, the coefficient for MCT was adjusted. As a result of the calibration process, the coefficient for PK_MCT_{ij} was adjusted from -0.0912 to -0.08, and the coefficient for OP_MCT_{ij} was adjusted from -0.157 to -0.142.

$$U_{ij} = -0.08 \times PK\_MCT_{ij} + ln(Retail_j + \ e^{-1.91} \times NonRet_j + e^{-2.64} \times TotPop_j) \qquad \text{(9-29a)}$$

$$U_{ij} = -0.142 \times OP\_MCT_{ij} + ln(Retail_j + \ e^{-2.7} \times NonRet_j + e^{-2.91} \times TotPop_j) \qquad \text{(9-29b)}$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
PK_MCT_{ij} = peak-period motorized composite time from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$Retail_j$ = retail employment in TAZ j;
$NonRet_j$ = non-retail employment in TAZ j; and
$TotPop_j$ = total population in TAZ j, including household population, student group quarters population, and other non-institutional group quarters population.

Table 9-121 Calibration results of the destination choice model for off-campus HBO trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Peak	Observed	15.844		7.296	
	Before calibration	14.850	-6.3%	6.548	-10.3%
	After calibration	15.781	-0.4%	7.233	-0.9%
Off-peak	Observed	11.123		4.960	
	Before calibration	10.680	-4.0%	4.497	-9.3%
	After calibration	11.229	1.0%	4.917	-0.9%

Figure 9-56 through Figure 9-59 show frequency distributions for the observed and modeled travel times and distances of off-campus HBO trips: Figure 9-56 and Figure 9-57 are for the peak period and Figure 9-58 and Figure 9-59 are for the off-peak period. The coincidence ratios are shown in Table 9-122.

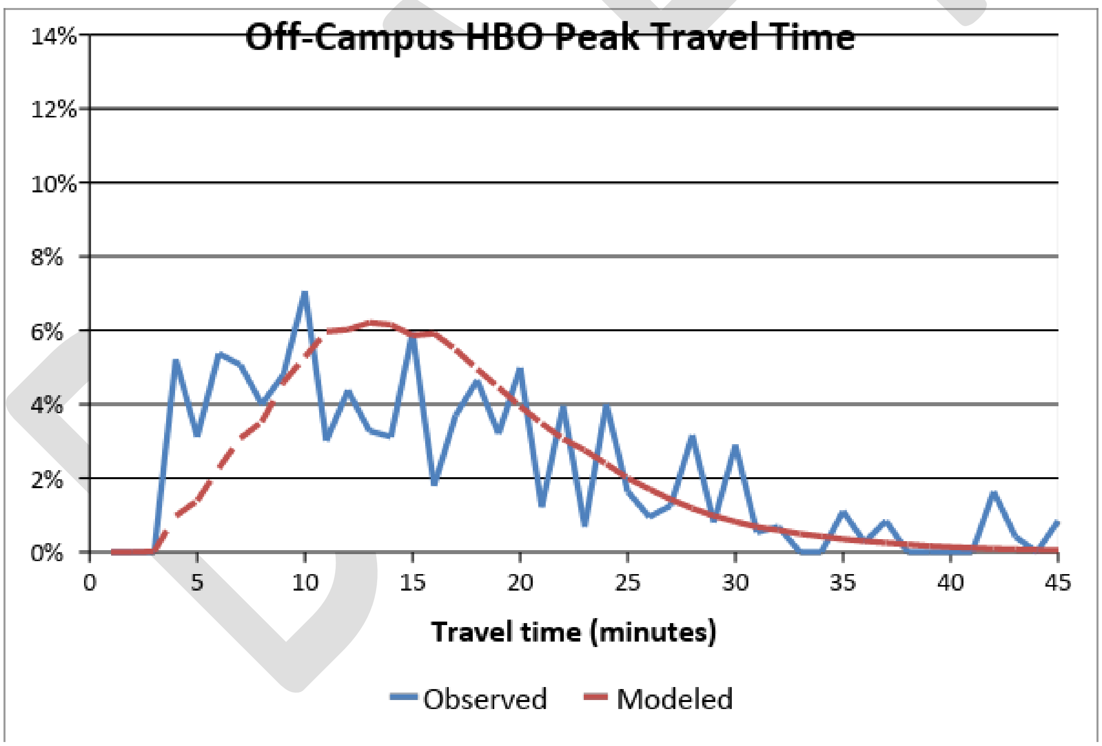


Figure 9-56 Off-campus HBO trip duration frequency distribution (peak)

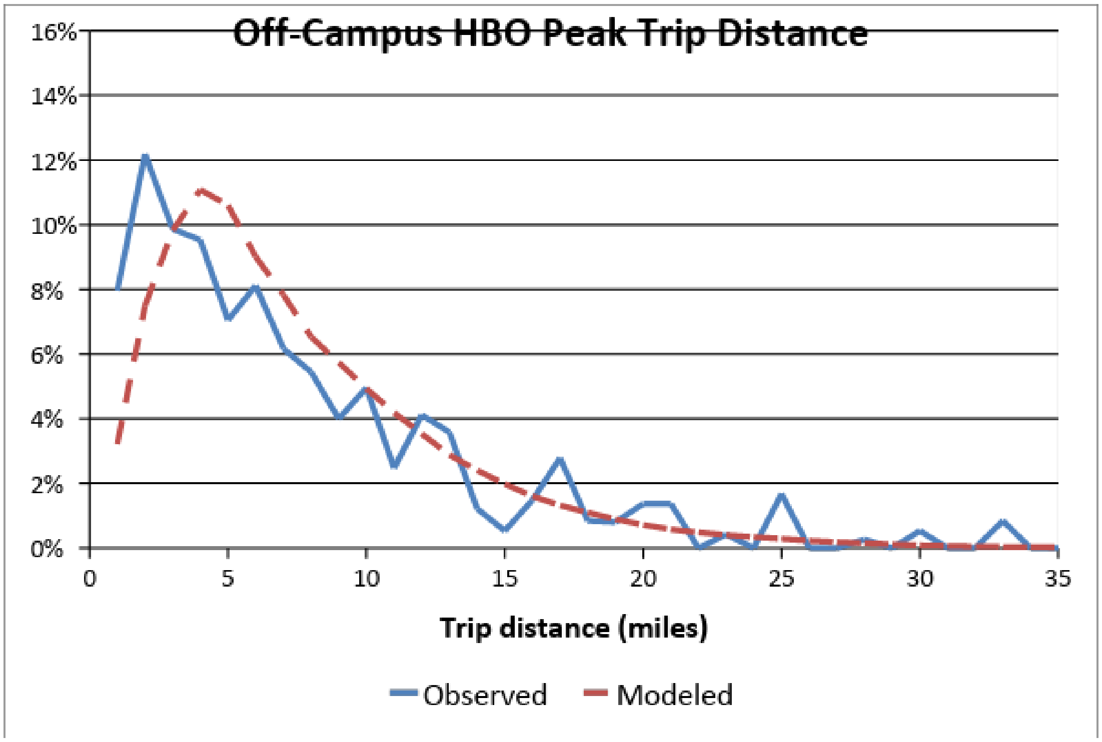


Figure 9-57 Off-campus HBO trip distance frequency distribution (peak)

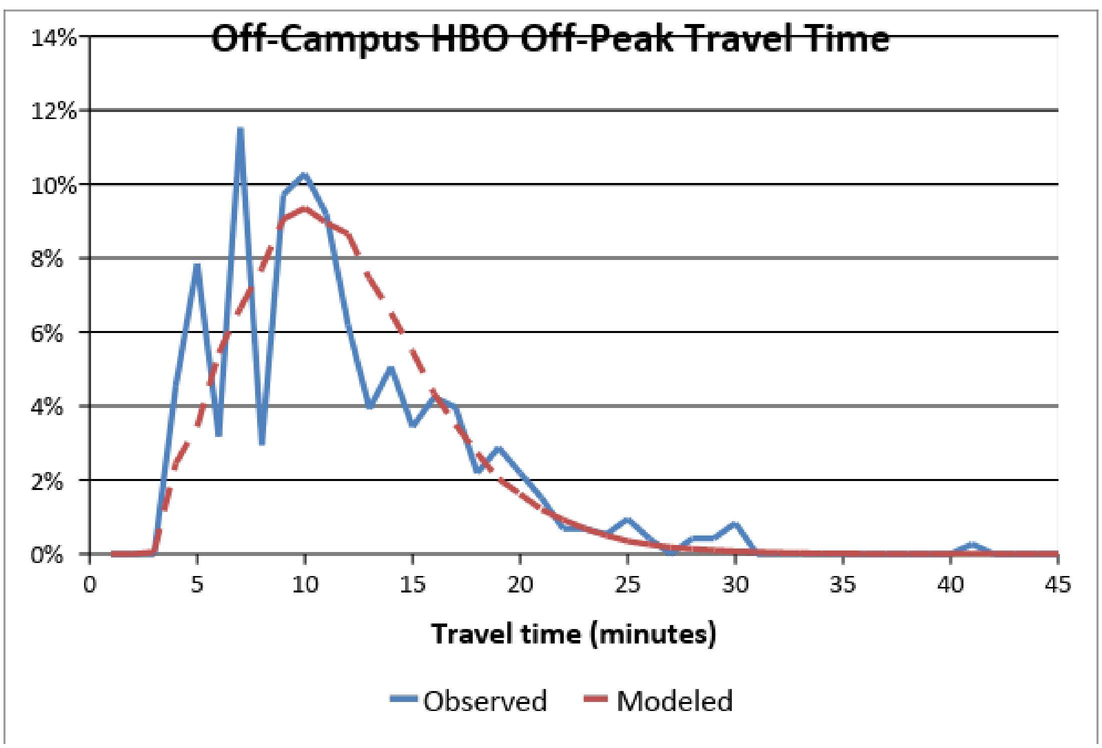


Figure 9-58 Off-campus HBO trip duration frequency distribution (off-peak)

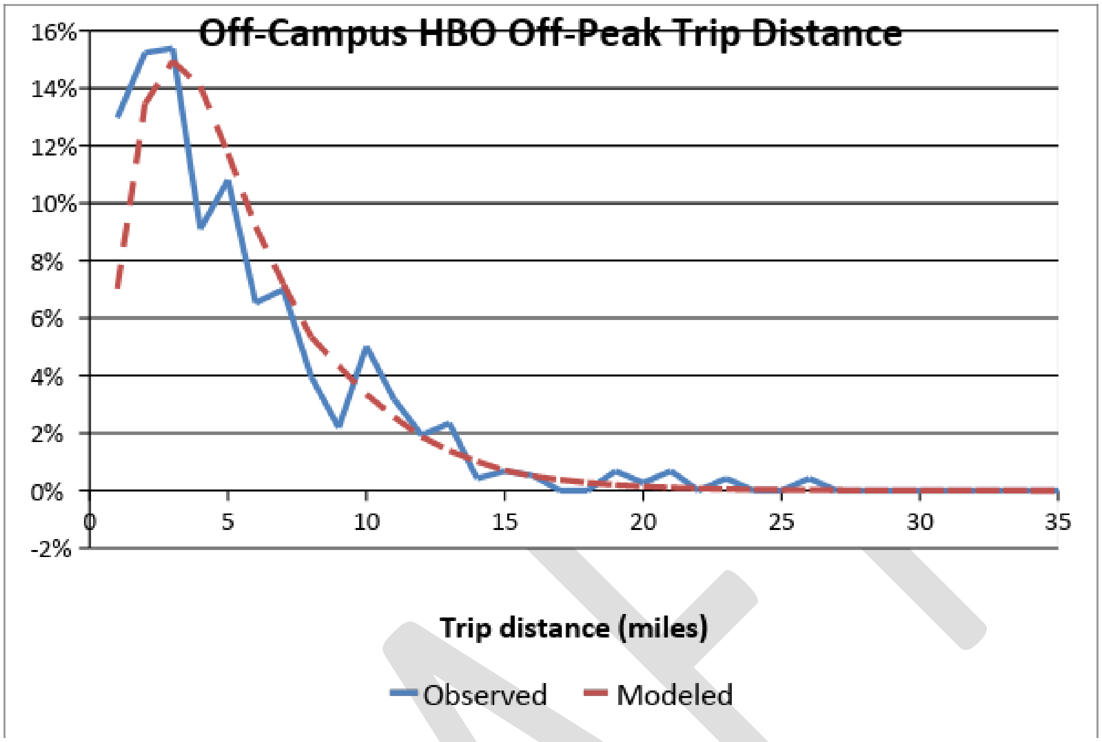


Figure 9-59 Off-campus HBO trip distance frequency distribution (off-peak)

Table 9-122 Summary of coincidence ratios for off-campus HBO trips

	Travel Time	Trip Distance
Off-Campus HBO Peak	0.590	0.711
Off-Campus HBO Off-Peak	0.698	0.759

9.2.3.4.4 On-Campus UBNH Trips

On-campus UBNH trips are University Based Non Home trips made by on-campus students, with on-campus production ends and attraction ends that may be either on-campus or off-campus locations. The model calibration was conducted by following these steps:

1. Calculate total on-campus UBNH trips by NCSU students as the product of the number of on-campus students living in the TAZ and the corresponding UBNH trip rate;
2. Distribute on-campus UBNH trips to each NCSU-campus TAZ in accordance with their university building floor area for service (such as classrooms and gyms) to get the zonal productions;
3. Split daily on-campus UBNH productions into peak and off-peak trips by using a peak/off-peak factor developed from the results of the 2001 NCSU Student Survey;
4. Apply the on-campus UBNH destination choice model to distribute peak-period on-campus UBNH trips from production TAZs to attraction TAZs;

5. Compare the modeled average trip duration and distance with observed values from the 2001 NCSU Student Survey;
6. Add a new variable, highway distance, to the peak-period destination choice model, and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 5%);
7. Repeat Steps 4 through 6 for off-peak trips.

The calibration results are shown in Table 9-123. The destination choice models after calibration are represented by Equations 9-30a and 9-30b. Equation 9-30a is for the peak period and Equation 9-30b is for the off-peak period.

$$U_{ij} = -0.5 \times Dist_{ij} - 0.177 \times PK\_MCT_{ij} + 0.781 \times ShortWalk_j + ln(BAS_j + e^{-0.35} \times Retail_j + e^{-2.74} \times Service_j + e^{-3.48} \times HH\_Pop_j + e^{0.323} \times Stud\_GQ_j) \quad \text{(9-30a)}$$

$$U_{ij} = -1.1 \times Dist_{ij} - 0.177 \times OP\_MCT_{ij} + 0.781 \times ShortWalk_j + ln(BAS_j + e^{-0.35} \times Retail_j + e^{-2.74} \times Service_j + e^{-3.48} \times HH\_Pop_j + e^{0.323} \times Stud\_GQ_j) \quad \text{(9-30b)}$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
$Dist_{ij}$ = highway distance from TAZ i to TAZ j;
PK_MCT_{ij} = peak-period motorized composite time from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area;
BAS_j = university building floor area for service in TAZ j (unit: 1,000 square feet);
$Retail_j$ = retail employment in TAZ j;
$Service_j$ = service employment in TAZ j, including service-rate-low and service-rate-high;
HH_Pop_j = household population in TAZ j; and
$Stud\_GQ_j$ = on-campus students living in group quarters in TAZ j.

Table 9-123 Calibration results of the destination choice model for on-campus UBNH trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Peak	Observed	7.721		0.919	
	Before calibration	8.402	8.8%	1.370	49.0%
	After calibration	7.675	-0.6%	0.932	1.4%
Off-peak	Observed	7.314		0.722	
	Before calibration	8.154	11.5%	1.421	96.8%
	After calibration	7.180	-1.8%	0.758	4.9%

Figure 9-60 through Figure 9-63 show frequency distributions for the observed and modeled travel times and distances of on-campus UBNH trips: Figure 9-60 and Figure 9-61 are for the peak period and

Figure 9-62 and Figure 9-63 are for the off-peak period. The coincidence ratios are shown in Table 9-124.

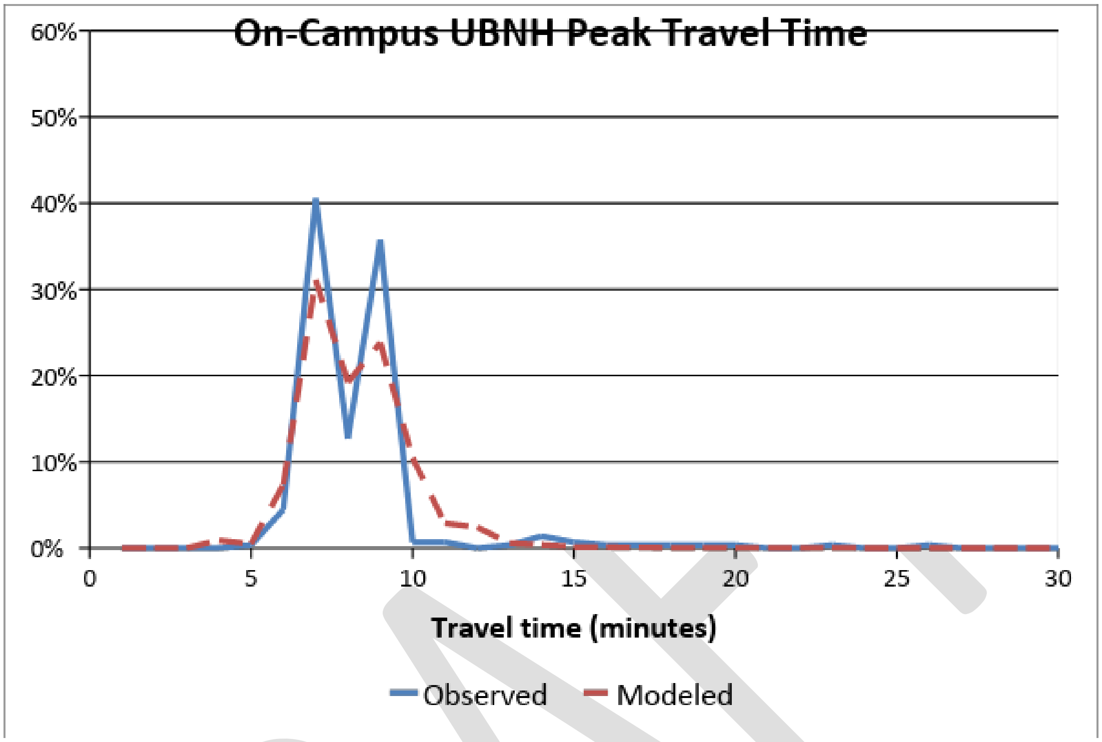


Figure 9-60 On-campus UBNH trip duration frequency distribution (peak)

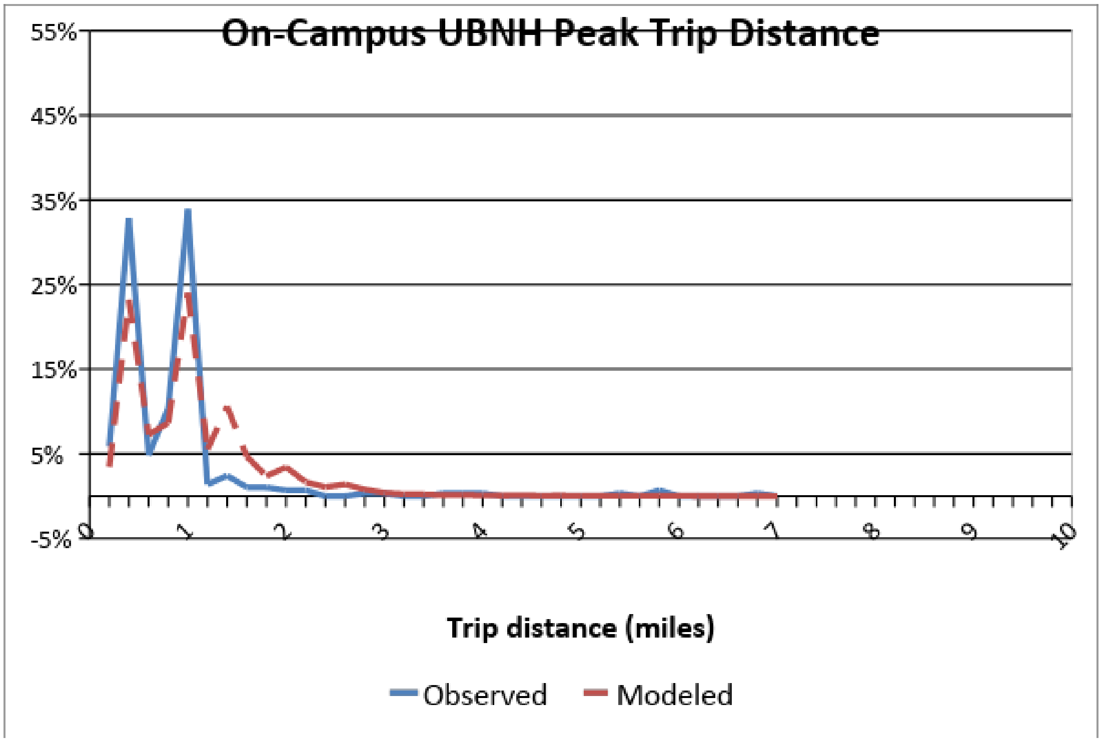


Figure 9-61 On-campus UBNH trip distance frequency distribution (peak)

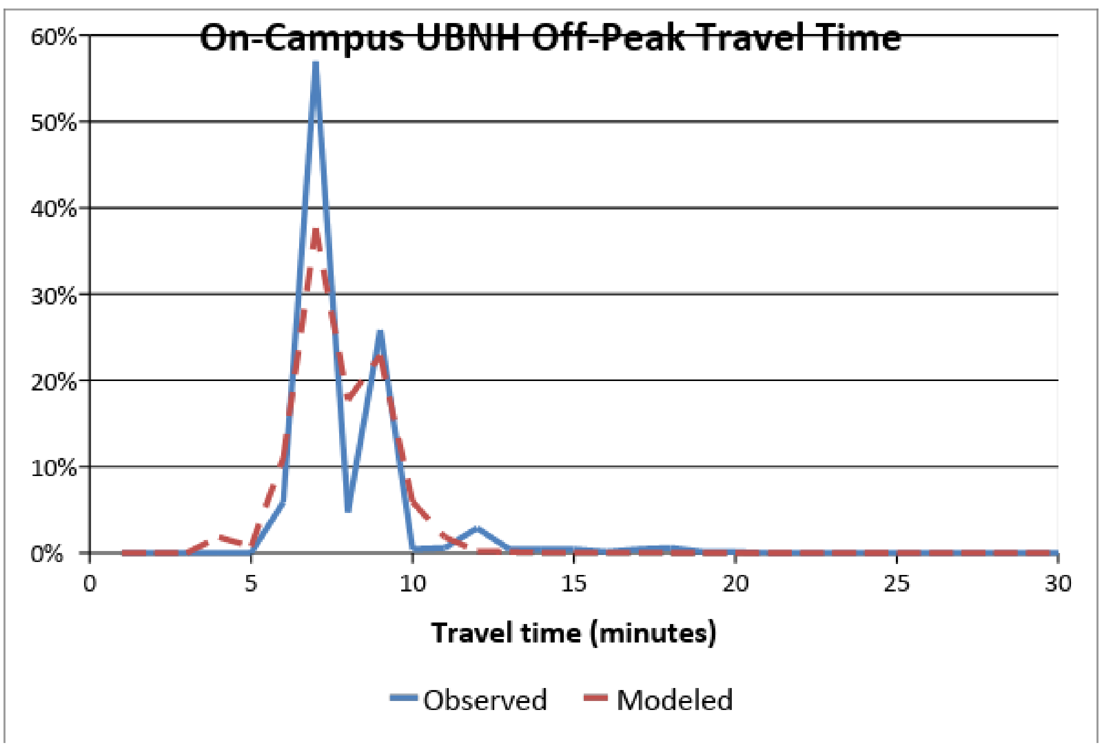


Figure 9-62 On-campus UBNH trip duration frequency distribution (off-peak)

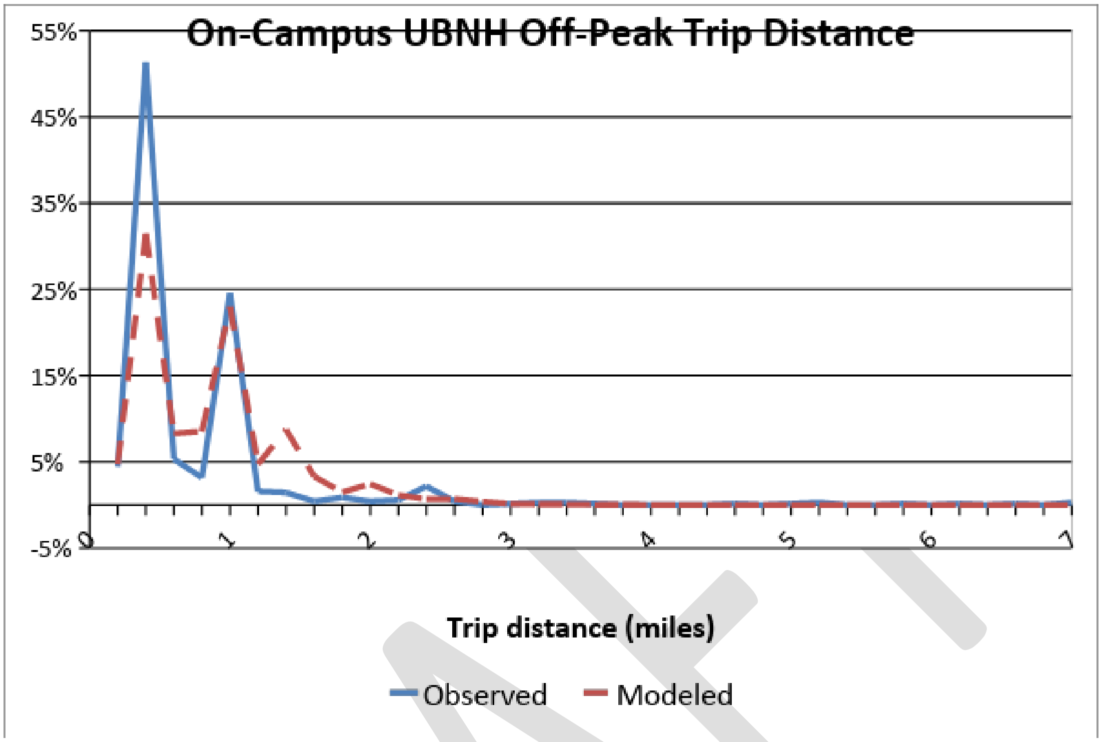


Figure 9-63 On-campus UBNH trip distance frequency distribution (off-peak)

Table 9-124 Summary of coincidence ratios for on-campus UBNH trips

	Travel Time	Trip Distance
On-Campus UBNH Peak	0.599	0.570
On-Campus UBNH Off-Peak	0.569	0.589

9.2.3.4.5 Off-Campus UBNH Trips

Off-campus UBNH trips are University Based Non Home trips made by off-campus students, with on-campus production ends and attraction ends that may be either on-campus or off-campus locations. The steps to calibrate off-campus UBNH trips were similar to those used for on-campus UBNH trips, as described in Section 9.2.3.4.4.

The calibration results are shown in Table 9-125. The destination choice models after calibration are represented by Equations 9-31a and 9-31b. Equation 9-31a is for the peak period and Equation 9-31b is for the off-peak period. As shown in Table 9-125, off-campus UBNH trip lengths are significantly different in the peak and off-peak periods: the average trip distance is 2.978 miles in the peak period and only 1.586 miles in the off-peak period. Therefore, two destination choice models were estimated, one for each time period. It was determined that there were enough samples in the 2001 NCSU University Student Survey to support estimating both of these models: 199 trip samples in the peak period and 450 in the off-peak period.

$$U_{ij} = -0.13 \times Dist_{ij} - 0.0684 \times PK\_MCT_{ij} + 1.16 \times ShortWalk_j + ln(BAS_j + e^{0.906} \times Retail_j + e^{-2.43} \times NonRet_j + e^{-2.33} \times HH\_Pop_j + e^{-1.19} \times Stud\_GQ_j) \quad (9\text{-}31a)$$

$$U_{ij} = -0.23 \times Dist_{ij} - 0.106 \times OP\_MCT_{ij} + 1.84 \times ShortWalk_j + ln(BAS_j + e^{0.729} \times Retail_j + e^{-1.87} \times NonRet_j + e^{-1.73} \times HH\_Pop_j + e^{-1.66} \times Stud\_GQ_j) \quad (9\text{-}31b)$$

where

U_{ij} = utility of travel from TAZ i to TAZ j,
$Dist_{ij}$ = highway distance from TAZ i to TAZ j,
PK_MCT_{ij} = peak-period motorized composite time from TAZ i to TAZ j,
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j,
$ShortWalk_j$ = dummy variable for whether TAZ j is in the short-walk-to-campus-transit area,
BAS_j = university building floor area for service in TAZ j (unit: 1,000 square feet),
$Retail_j$ = retail employment in TAZ j,
$NonRet_j$ = non-retail employment in TAZ j,
HH_Pop_j = household population in TAZ j, and
$Stud\_GQ_j$ = on-campus students living in group quarters in TAZ j.

Table 9-125 Calibration results of the destination choice model for off-campus UBNH trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Peak	Observed	10.582		2.978	
	Before calibration	13.518	27.7%	4.983	67.3%
	After calibration	10.635	0.5%	2.920	-2.0%
Off-peak	Observed	8.094		1.586	
	Before calibration	9.677	19.6%	2.849	79.6%
	After calibration	8.066	-0.3%	1.616	1.9%

Figure 9-64 through Figure 9-67 show frequency distributions for the observed and modeled travel times and distances of off-campus UBNH trips: Figure 9-64 and Figure 9-65 are for the peak period and Figure 9-66 and Figure 9-67 are for the off-peak period. The coincidence ratios are shown in Table 9-126.

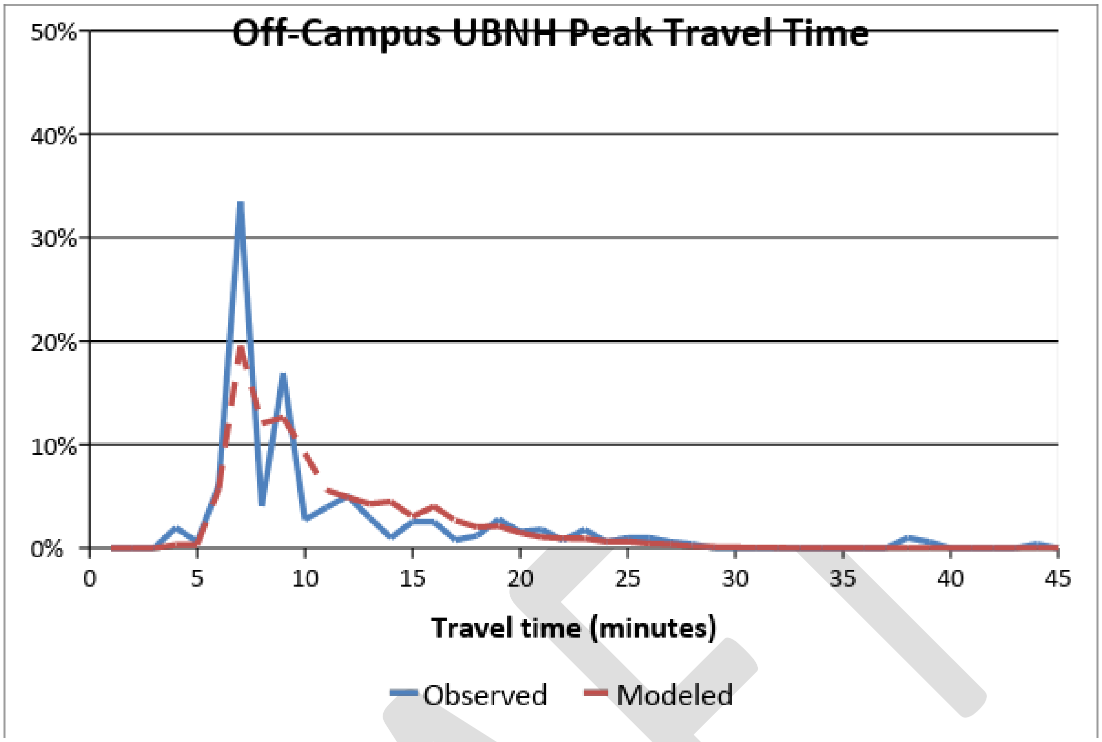


Figure 9-64 Off-campus UBNH trip duration frequency distribution (peak)

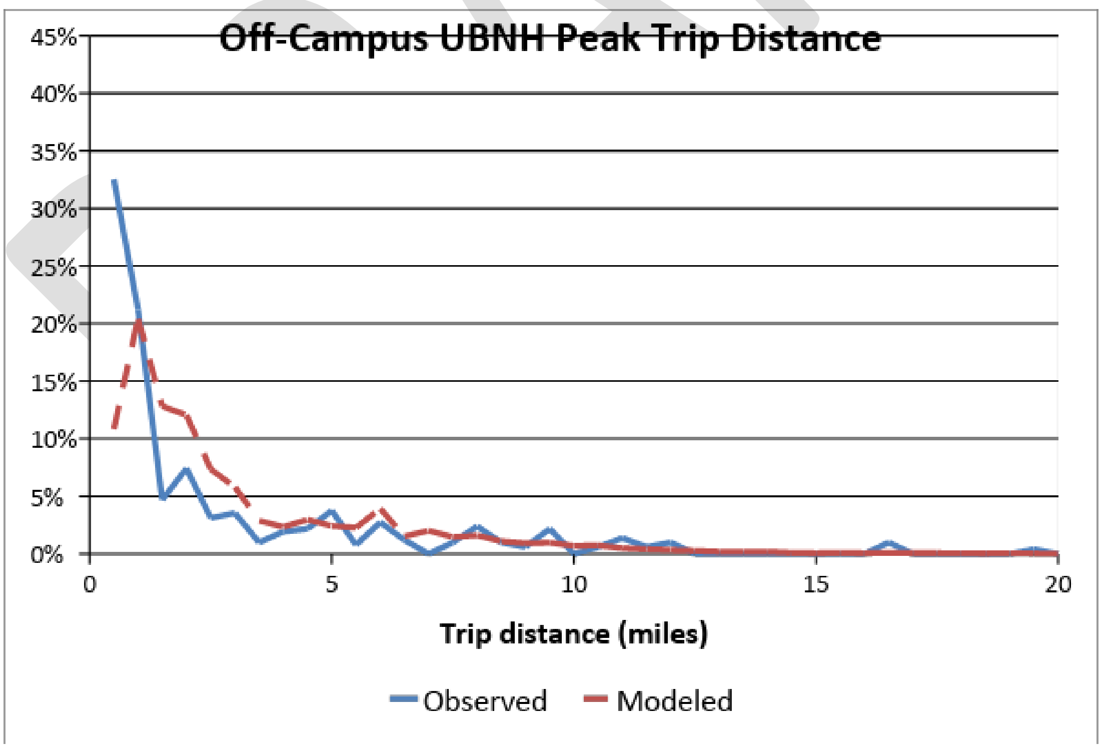


Figure 9-65 Off-campus UBNH trip distance frequency distribution (peak)

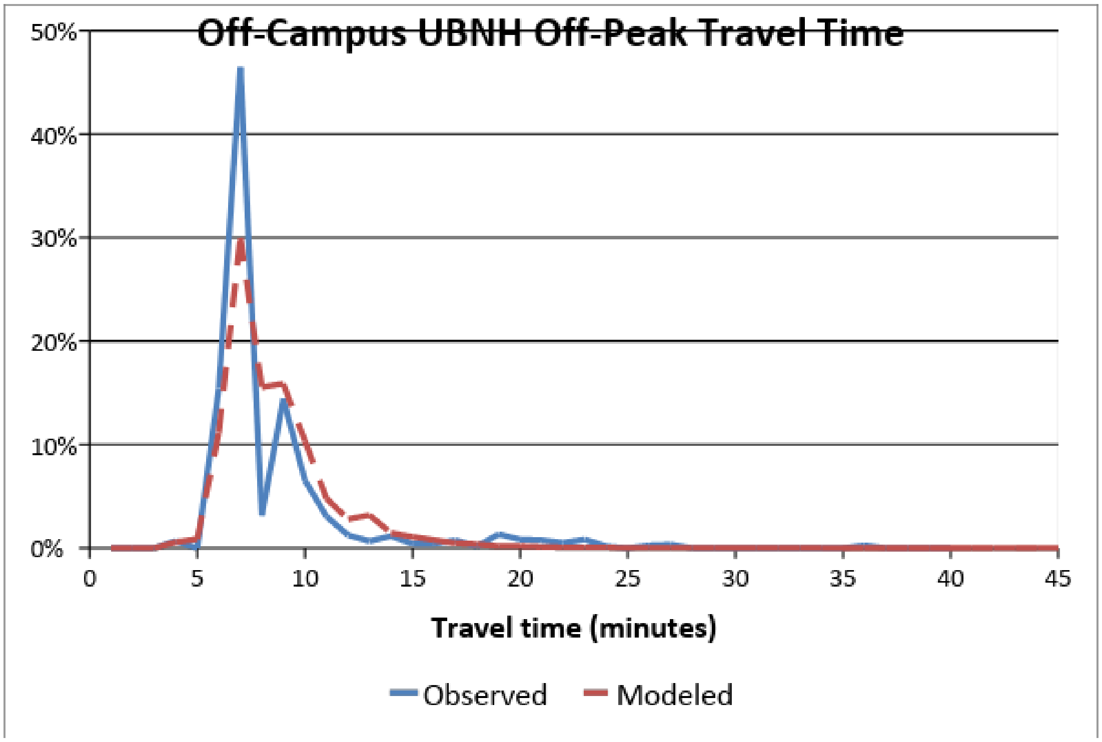


Figure 9-66 Off-campus UBNH trip duration frequency distribution (off-peak)

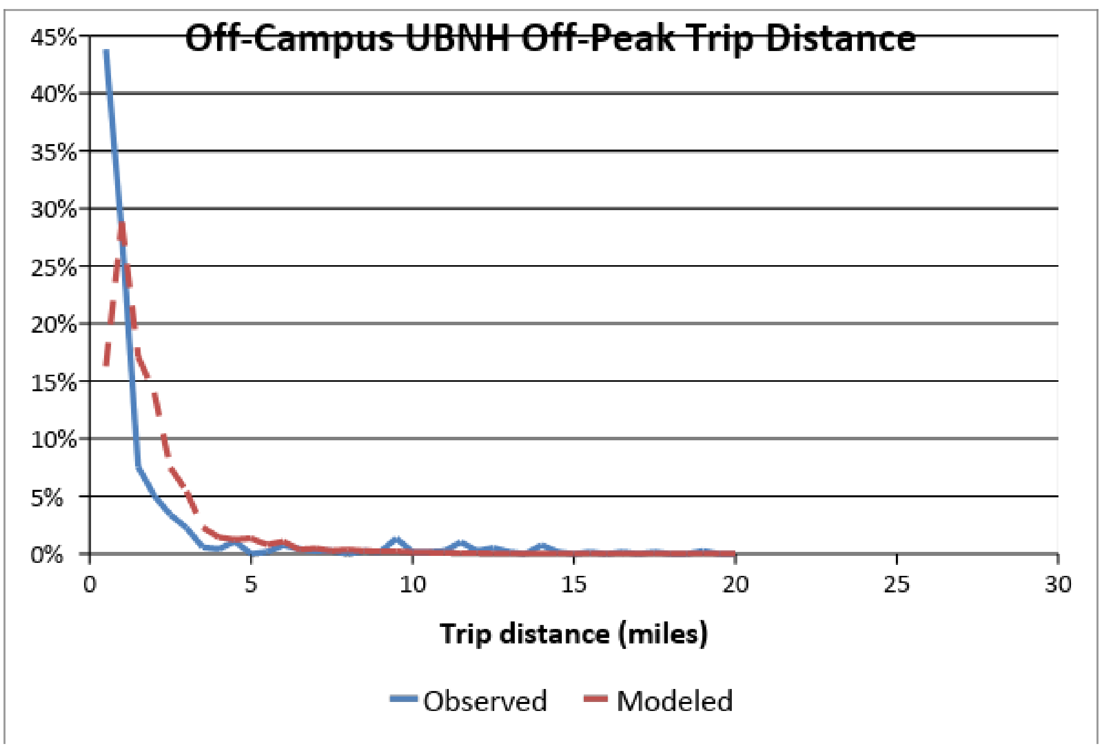


Figure 9-67 Off-campus UBNH trip distance frequency distribution (off-peak)

Table 9-126 Summary of coincidence ratios for off-campus UBNH trips

	Travel Time	Trip Distance
Off-Campus UBNH Peak	0.584	0.534
Off-Campus UBNH Off-Peak	0.590	0.508

9.2.3.4.6 On-Campus NHNU Trips

On-campus NHNU trips are Non Home Non University trips made by on-campus students. Neither the production ends nor the attraction ends are home locations or on-campus locations. A linear regression model was developed to calculate on-campus NHNU trip productions by TAZ, using the results of the 2001 NCSU Student Survey. This model is shown in Table 9-127, and is identical to the model developed for on-campus NHNU trip attractions. For more details, refer to Sections 9.2.2.2.1 and 9.2.2.2.5.

Table 9-127 Regression model for on-campus NHNU productions

Formula	StudOn_NHNU_P = 2.5636 * Retail/OP_TT_sqr + 544.3458 * Retail/OP_TT_4
t-value for "Retail/OP_TT_sqr"	3.65
t-value for "Retail/OP_TT_4"	6.45
R^2	0.84
Note	Based on 49 districts (excluding the NCSU district).

In Table 9-127, "StudOn_NHNU_P" is the number of on-campus NHNU trip productions in a given TAZ. "Retail/OP_TT_sqr" is the same TAZ's retail employment divided by the square of the off-peak travel time from that TAZ to the designated central TAZ of a university (TAZ 1490 in the case of NCSU). "Retail/OP_TT_4" is the TAZ's retail employment divided by the fourth power of the off-peak travel time from the TAZ in question to the designated central TAZ of a university.

There were only 71 on-campus NHNU trip records in the 2001 NCSU Student Survey. Because the number of trip records is so low, only one model of daily on-campus NHNU trips was developed, instead of separate peak and off-peak models. The model calibration was conducted by following these steps:

1. Calculate daily productions of on-campus NHNU trips for each TAZ, using the equation shown in Table 9-127;
2. Apply the on-campus NHNU destination choice model to distribute daily on-campus NHNU trips from production TAZs to attraction TAZs;
3. Compare the modeled average trip duration and distance with observed values from the 2001 NCSU Student Survey;
4. Add a new variable, highway distance, to the destination choice model, and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 5%).

The calibration results are shown in Table 9-128. The destination choice model after calibration is shown in Equation 9-32. To ensure that all on-campus NHNU trips are attracted to off-campus TAZs, the variables $Retail_j$, $NonRet_j$, and $TotPop_j$ in this equation were set to zero for on-campus TAZs during the model calibration and application steps.

$$U_{ij} = -0.165 \times Dist_{ij} - 0.226 \times OP\_MCT_{ij} + 0.00165 \times OP\_MCT_{ij}^2 + ln(Retail_j + e^{-3.86} \times NonRet_j + e^{-3.07} \times TotPop_j) \quad (9\text{-}32)$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
$Dist_{ij}$ = highway distance from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$OP\_MCT_{ij}^2$ = square of the off-peak motorized composite time from TAZ i to TAZ j;
$Retail_j$ = retail employment in TAZ j;
$NonRet_j$ = non-retail employment in TAZ j; and
$TotPop_j$ = total population in TAZ j, including household population, student group quarters population, and other non-institutional group quarters population.

Table 9-128 Calibration results of the destination choice model for on-campus NHNU trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Daily	Observed	9.896		4.213	
	Before calibration	48.731	392.4%	38.000	802.0%
	After calibration	9.836	-0.6%	4.238	0.6%

This is a daily destination choice model for on-campus NHNU trips, with no distinction between peak and off-peak periods. Off-peak, rather than peak, motorized composite time was selected as an impedance term, because more than half (62%) of on-campus NHNU trips occurred in off-peak periods in the 2001 NCSU Student Survey. On-campus NHNU trips are the only university-student trips whose destination-choice model uses a non-linear impedance term: the square of off-peak motorized composite time (OP_MCT_{ij}). This term was included because doing so dramatically improved the fit between the modeled and observed trip-length frequency distribution curves. Before model calibration, the average travel time and trip distance were much higher than observed values, as shown in Table 9-128 (“before calibration”). During calibration, it was found that travel time and trip distance are very sensitive to the coefficient of $Dist_{ij}$. Therefore, caution should be taken when applying this model.

Figure 9-68 and Figure 9-69 show frequency distributions for the observed and modeled travel times and distances of on-campus NHNU trips. The coincidence ratios are shown in Table 9-129.

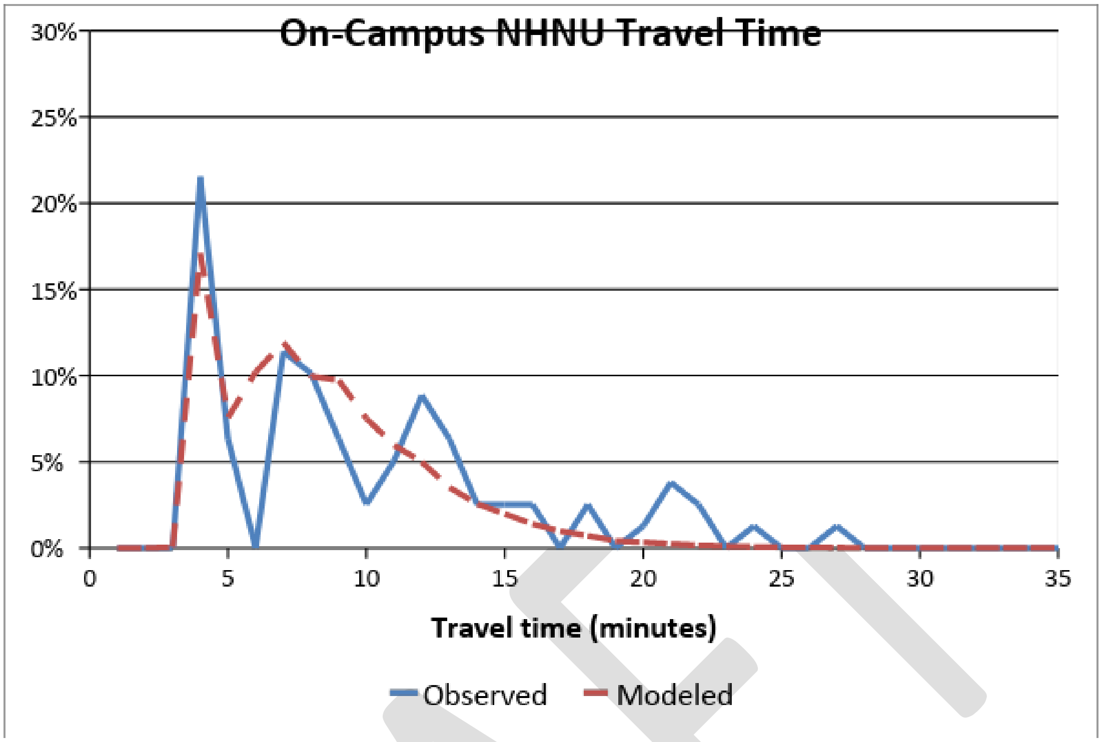


Figure 9-68 On-campus NHNU trip duration frequency distribution

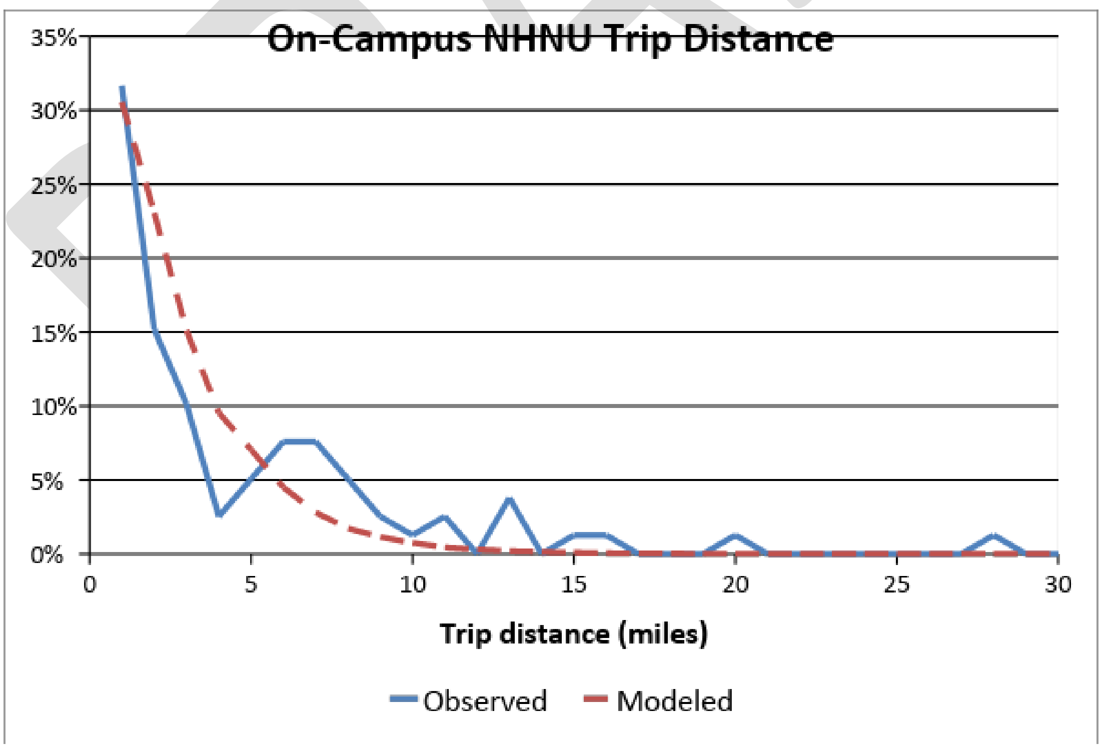


Figure 9-69 On-campus NHNU trip distance frequency distribution

Table 9-129 Summary of coincidence ratios for on-campus NHNU trips

	Travel Time	Trip Distance
On-Campus NHNU	0.596	0.603

9.2.3.4.7 Off-Campus NHNU Trips

Off-campus NHNU trips are Non Home Non University trips made by off-campus students. Neither the production ends nor the attraction ends are home locations or on-campus locations. A linear regression model was developed to calculate off-campus NHNU trip productions by TAZ, using the results of the 2001 NCSU Student Survey. This model is shown in Table 9-130, and is identical to the model developed for on-campus NHNU trip attractions. For more details, refer to Sections 9.2.2.2.1 and 9.2.2.2.9.

Table 9-130 Regression model for off-campus NHNU productions

Formula	StudOff_NHNU_P = 0.0457 * POP/OP_TT + 3.2152 * Retail/Dist_sqr
t-value for “POP/OP_TT”	3.74
t-value for “Retail/Dist_sqr”	20.63
R^2	0.94
Note	Based on 49 districts (excluding the NCSU district).

In Table 9-130, “StudOff_NHNU_P” is the number of off-campus NHNU trip productions in a given TAZ. “POP/OP_TT” is the same TAZ’s household population divided by the off-peak travel time from that TAZ to the designated central TAZ of a university (TAZ 1490 in the case of NCSU). “Retail/Dist_sqr” is the TAZ’s retail employment divided by the square of the highway distance from the TAZ in question to the designated central TAZ of a university.

There were only 198 off-campus NHNU trip records in the 2001 NCSU Student Survey. Because the number of trip records is so low, only one model of daily off-campus NHNU trips was developed, instead of separate peak and off-peak models. The model calibration was conducted by following these steps:

1. Calculate daily productions of off-campus NHNU trips for each TAZ, using the equation shown in Table 9-130;
2. Apply the off-campus NHNU destination choice model to distribute daily off-campus NHNU trips from production TAZs to attraction TAZs;
3. Compare the modeled average trip duration and distance with observed values from the 2001 NCSU Student Survey;
4. Add a new variable, highway distance, to the destination choice model, and adjust its coefficient (starting from an arbitrary value) so that the modeled average trip duration and distance match observed values (within 5%).

The calibration results are shown in Table 9-131. The destination choice model after calibration is shown in Equation 9-33. To ensure that all off-campus NHNU trips are attracted to off-campus TAZs, the variables $Retail_j$, $NonRet_j$, and $TotPop_j$ in this equation were set to zero for on-campus TAZs during the model calibration and application steps.

$$U_{ij} = -0.03 \times Dist_{ij} - 0.131 \times OP\_MCT_{ij} + ln(Retail_j + \ e^{-2.27} \times NonRet_j + e^{-2.82} \times TotPop_j) \tag{9-33}$$

where

U_{ij} = utility of travel from TAZ i to TAZ j;
$Dist_{ij}$ = highway distance from TAZ i to TAZ j;
OP_MCT_{ij} = off-peak motorized composite time from TAZ i to TAZ j;
$Retail_j$ = retail employment in TAZ j;
$NonRet_j$ = non-retail employment in TAZ j; and
$TotPop_j$ = total population in TAZ j, including household population, student group quarters population, and other non-institutional group quarters population.

Table 9-131 Calibration results of the destination choice model for off-campus NHNU trips

		Average travel time (minutes)	Deviation from observed value	Average trip distance (miles)	Deviation from observed value
Daily	Observed	10.622		4.390	
	Before calibration	11.225	5.7%	4.616	5.1%
	After calibration	10.772	1.4%	4.254	-3.1%

This is a daily destination choice model for off-campus NHNU trips, with no distinction between peak and off-peak periods. Off-peak motorized composite time, rather than peak-period or all-day motorized composite time, was selected as an impedance term, because more than half (59%) of off-campus NHNU trips occurred in off-peak periods in the 2001 NCSU Student Survey.

Figure 9-70 and Figure 9-71 show frequency distributions for the observed and modeled travel times and distances of off-campus NHNU trips. The coincidence ratios are shown in Table 9-132.

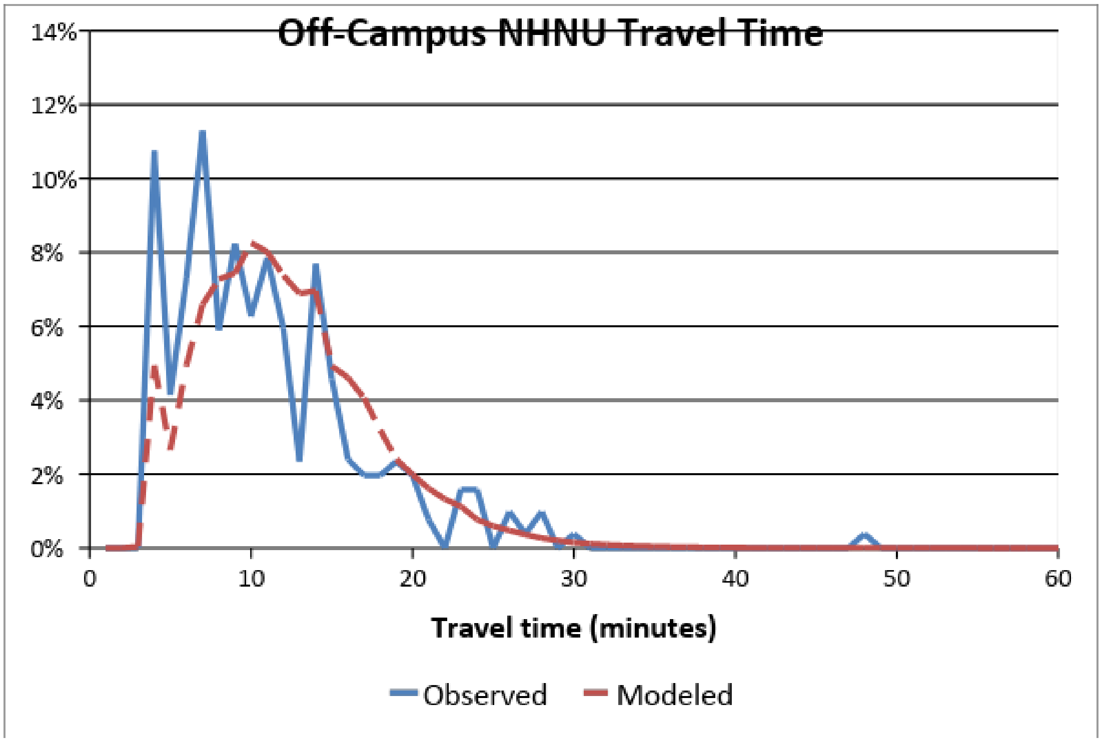


Figure 9-70 Off-campus NHNU trip duration frequency distribution

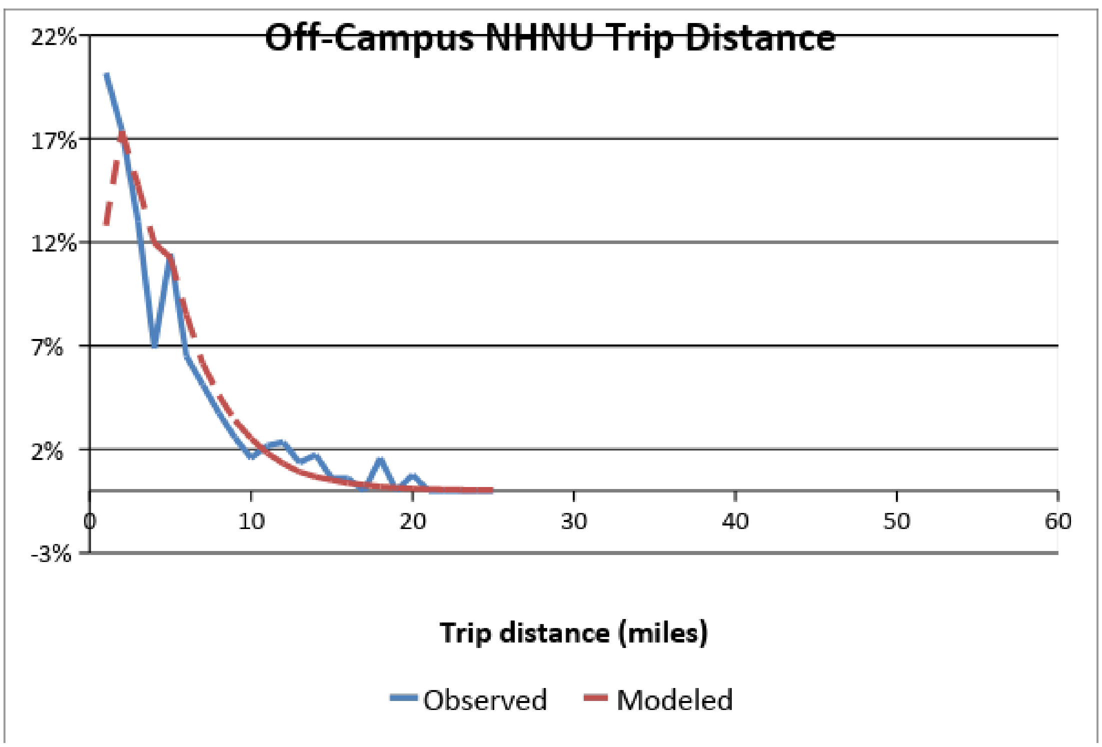


Figure 9-71 Off-campus NHNU trip distance frequency distribution

Table 9-132 Summary of coincidence ratios for off-campus NHNU trips

	Travel Time	Trip Distance
Off-Campus NHNU	0.681	0.766

9.2.3.5 Application of Destination Choice Models

The destination choice models presented in the preceding section, 9.2.3.4, were developed and calibrated using the results of the 2001 NCSU Student Survey. These models were then applied to students attending universities other than NCSU in the model area: UNC, Duke, and NCCU. The results of applying these models to students attending all four major universities are presented in this section.

Table 9-133 shows the application results of the residence choice model for off-campus HBU trips, including total numbers of trips, average travel times, and average trip distances for off-campus students attending all four major universities.

Table 9-133 Application results of the residence choice model for off-campus HBU trips

	Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	34,840	13.248	4.972
UNC	34,680	13.173	3.912
Duke	14,879	13.658	4.585
NCCU	11,797	13.458	5.071

The average travel time and trip distance shown for NCSU students in Table 9-133 are slightly different from the corresponding "after calibration" values shown in Table 9-113. This is because Table 9-113 shows the results of inputting 2001 values for $Stud\_GQ_j$ (on-campus students living in group quarters in TAZ j) and BAS_j (university building floor area for service in TAZ j), whereas Table 9-133 shows the results of inputting 2010 values for these variables.

Table 9-134 through Table 9-140 show application results for the other seven trip-purpose/student-type combinations. No unreasonable average travel times or trip distances were found in these results.

Table 9-134 Application results of the destination choice model for on-campus HBU trips

		Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	Peak	19,537	7.528	0.767
	Off-Peak	22,014	7.384	0.805
UNC	Peak	19,677	8.740	0.808
	Off-Peak	22,171	8.765	0.859
Duke	Peak	11,595	8.801	0.863
	Off-Peak	13,065	8.841	0.976

NCCU	Peak	4,317	6.876	0.392
	Off-Peak	4,864	6.871	0.399

Table 9-135 Application results of the destination choice model for on-campus HBO trips

		Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	Peak	2,907	12.001	4.156
	Off-Peak	4,727	11.120	4.253
UNC	Peak	2,928	12.021	3.376
	Off-Peak	4,761	11.511	3.521
Duke	Peak	1,725	12.375	3.898
	Off-Peak	2,805	11.811	3.999
NCCU	Peak	642	14.343	5.632
	Off-Peak	1,044	13.501	5.771

Table 9-136 Application results of the destination choice model for off-campus HBO trips

		Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	Peak	14,638	15.792	7.245
	Off-Peak	14,761	11.233	4.925
UNC	Peak	15,073	15.916	7.288
	Off-Peak	15,200	10.658	4.260
Duke	Peak	7,090	15.320	7.442
	Off-Peak	7,150	10.740	4.663
NCCU	Peak	4,947	15.649	7.625
	Off-Peak	4,989	10.926	4.838

Table 9-137 Application results of the destination choice model for on-campus UBNH trips

		Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	Peak	6,688	7.764	0.999
	Off-Peak	16,021	7.184	0.805
UNC	Peak	6,735	8.348	0.760
	Off-Peak	16,135	7.950	0.606
Duke	Peak	3,969	8.452	0.803
	Off-Peak	9,508	7.912	0.617
NCCU	Peak	1,478	7.535	0.944
	Off-Peak	3,540	6.768	0.503

Table 9-138 Application results of the destination choice model for off-campus UBNH trips

		Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	Peak	10,030	10.683	2.969
	Off-Peak	23,731	8.134	1.673
UNC	Peak	10,009	10.566	2.281
	Off-Peak	23,680	9.180	1.613
Duke	Peak	4,325	10.695	2.415
	Off-Peak	10,231	8.966	1.388
NCCU	Peak	3,396	13.216	4.672
	Off-Peak	8,034	10.286	3.250

Table 9-139 Application results of the destination choice model for on-campus NHNU trips

	Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	2,029	9.836	4.238
UNC	2,044	9.500	3.929
Duke	1,204	9.819	4.558
NCCU	448	9.587	4.270

Table 9-140 Application results of the destination choice model for off-campus NHNU trips

	Total Trips	Average Travel Time (Minutes)	Average Trip Distance (Miles)
NCSU	10,576	10.772	4.254
UNC	11,369	10.287	3.415
Duke	5,922	10.457	4.411
NCCU	3,566	10.617	4.583

9.2.4 Non-Motorized Travel

9.2.4.1 Introduction

The estimation of the university student non-motorized trip split model was based on the 2001 NCSU Student Survey. It was intended that university student non-motorized trip split models would be estimated for each combination of trip purpose (four possibilities), stratum (two possibilities), and time period (two possibilities). However, due to the limited number of trip records in the survey, some models had to be combined, so that only nine non-motorized trip split models were estimated. Because almost all non-motorized trips are less than ten miles, ten miles is used as a threshold for using non-motorized modes in the model estimation.

University student non-motorized trip split models were estimated using the software Biogeme. Each trip has two alternatives, using a motorized mode or using a non-motorized mode. Because only relative utility matters in the model, the utility of choosing a motorized mode was fixed at zero and only the utility of choosing a non-motorized mode was estimated. In all university-student non-motorized trip split models, non-motorized distance was selected as an impedance term. For trips with on-campus production ends (HBU and HBO trips by on-campus students and UBNH trips by both on-campus and off-campus students), only variables describing potential attraction ends were included in the model specifications, since all production ends are on campus and therefore very similar. For trips with off-campus production ends (NHNU trips by on-campus students and HBU, HBO, and NHNU trips by off-campus students), variables describing both production and attraction ends were included in the model specifications.

9.2.4.2 Data Preparation

To estimate coefficients for the non-motorized trip split models, estimation files were generated, based on the 2001 NCSU Student Survey. These files included, for each observed trip, impedance between the production TAZ and the attraction TAZ and TAZ-attribute variables describing the two trip ends.

9.2.4.2.1 Numbers of Trip Records

The non-motorized trip split models in the TRMv5 were estimated for each combination of trip purpose, stratum, and time period. It was intended that the university student non-motorized trip split models in the TRMv6 would follow the same approach. Since university students in the TRMv6 have four possible trip purposes (HBU, HBO, UBNH, and NHNU), two strata (on-campus and off-campus) and two time periods (peak and off-peak), sixteen non-motorized trip split models were intended to be estimated. However, due to the limited number of trip records in the 2001 NCSU Student Survey, some models had to be combined. Table 9-141 shows numbers of trip records from the 2001 NCSU Student Survey.

Table 9-141 Numbers of trip records from the 2001 NCSU Student Survey

		Non-Motorized Trip Records			All-Mode Trip Records		
		Peak	Off-Peak	Daily	Peak	Off-Peak	Daily
On-Campus	HBU	774	873	1,647	868	978	1,846
	HBO	21	45	66	123	200	323
	UBNH	248	639	887	291	697	988
	NHNU	1	10	11	30	49	79
	Subtotal	1,044	1,567	2,611	1,312	1,924	3,236
Off-Campus	HBU	40	34	74	397	277	674
	HBO	7	10	17	287	278	565
	UBNH	96	326	422	199	452	651
	NHNU	8	10	18	84	119	203
	Subtotal	151	380	531	967	1,126	2,093
Total		1,195	1,947	3,142	2,279	3,050	5,329

In the end, nine non-motorized trip split models were estimated, as will be described in Section 9.2.4.3. The basic rule applied was that the number of trip records used to estimate a model should be greater than 300. The only exception was the model for UBNH peak-period trips by on-campus students (291 trip records). It was estimated as a separate model on the grounds that it had a large number of non-motorized trip records (248).

9.2.4.2.2 Variables in the Estimation Files

Only internal to internal (I-I) trips were considered in the estimation files, including intrazonal trips and trips by all modes. The dictionary for the estimation files is shown in Table 9-142.

Table 9-142 Dictionary for non-motorized trip split model estimation files

Column	Variable	Description
1	Trip_ID	Trip ID in the 2001 NCSU Student Survey
2	Weight	2010 trip weight
3	Mode	Mode of the trip (1=motorized; 2=non-motorized)
4	P_TAZ	Production TAZ ID
5	A_TAZ	Attraction TAZ ID
6	ON_OFF_Stud	Residence status (1=on-campus; 2=off-campus)
7	If_PK	Peak (PK) trip (=1) or off-peak (OP) trip (=0)
8	NM_Dist	Non-motorized shortest distance (in miles) from P_TAZ to A_TAZ
9	NM_Time	Non-motorized travel time (in minutes) from P_TAZ to A_TAZ
10	Comp_Time	Composite motorized travel time (in minutes), with auto highway driving cost and transit fare included (converted via a value-of-time factor), from P_TAZ to A_TAZ
11	ATYPE_P	Area type of P_TAZ (1=CBD; 2=urban; 3=suburban; 4=rural)
12	AVEBLOCK_P_P	P_TAZ average block size measured by perimeter (miles)
13	AVEBLOCK_A_P	P_TAZ average block size measured by area (square miles)
14	Campus_NCSU_P	Whether P_TAZ is on the NCSU campus (0=no; 1=yes)
15	ShortWalk_P	Whether P_TAZ is within a 0.25-mile-buffer of the Wolfline bus routes (0=no; 1=yes)
16	TotPopDen_P	Total population (includes household population, student group quarters population, and other non-institutional group quarters population) density (people per square mile) in P_TAZ
17	TotEmpDen_P	Total employment density (employees per square mile) in P_TAZ
18	LandMix_P	Land use mix at P_TAZ
19	NM_PathDen_P	Non-motorized path density (miles per square mile) in P_TAZ
20	RetEmp_P	Retail employment density (employees per square mile) in P_TAZ
21	SidewalkD_P	Sidewalk density (miles per square mile) in P_TAZ
22	GreenwayD_P	Greenway density (miles per square mile) in P_TAZ
23	BAS2001D_P	Density of building floor area for service in 2001 (million square feet per square mile) in P_TAZ

24	BAS2010D_P	Density of building floor area for service in 2010 (million square feet per square mile) in P_TAZ
25-38		Similar to columns 11-24, for A_TAZ

Many of the variables in Table 9-142 were also used in the university student destination choice models, such as “If_PK,” “NM_Dist,” and “Comp_Time.” Refer to Section 9.2.3.1.1 for the definitions of these variables.

The variable “NM_Time” is calculated from “NM_Dist” and the average non-motorized travel speed, which is calculated for each trip purpose and each stratum as a weighted average of walk, bicycle, and skateboard speeds, which are assumed to be 3 mph, 10 mph, and 5 mph, respectively. The walk, bicycle and skateboard mode shares of all non-motorized trips in the 2001 NCSU Student Survey are shown in Table 9-143.

Table 9-143 Walk, bicycle, and skateboard shares of non-motorized trips in the 2001 NCSU Student Survey

	Trip Purpose	Walk Share	Bicycle Share	Skateboard Share	Average Travel Speed (mph)
On-Campus	HBU	98.48%	1.15%	0.36%	3.09
	HBO	100.00%	0.00%	0.00%	3.00
	UBNH	99.32%	0.45%	0.23%	3.04
	NHNU	100.00%	0.00%	0.00%	3.00
	Total	98.81%	0.88%	0.31%	3.07
Off-Campus	HBU	83.57%	16.43%	0.00%	4.15
	HBO	95.50%	4.50%	0.00%	3.32
	UBNH	99.30%	0.70%	0.00%	3.05
	NHNU	100.00%	0.00%	0.00%	3.00
	Total	97.05%	2.95%	0.00%	3.21

The variable LandMix measures land use mix, also abbreviated as “LUM,” and was calculated in the same way in the TRMv6 as it was in the TRMv5:

$$LUM_i = \frac{2*(Population_i+Employment_i)-abs(Population_i-Employment_i)}{Area_i} \quad (9\text{-}34)$$

where

LUM_i = land use mix in TAZ i;
$Population_i$ = total population in TAZ i, including household population, student group quarters population, and other non-institutional group quarters population;
$Employment_i$ = total employment in TAZ i, including industry, office, service_ratelow, service_ratehigh, and retail; and
$Area_i$ = area of TAZ i in acres.

9.2.4.2.3 Threshold for Using Non-Motorized Mode

In the TRMv5, 15 miles was used as the threshold for using non-motorized modes; any trip longer than 15 miles was assumed to only be able to be made by motorized modes. This assumption avoided distortion of the model estimation by long non-motorized trips, and the household travel survey showed that very few non-motorized trips were longer than 15 miles. To follow the same practice in the TRMv6, the 2001 NCSU Student Survey was analyzed to show how the non-motorized mode share drops as trip distance increases. Table 9-144 and Table 9-145 present numbers of non-motorized trip records by distance for on-campus and off-campus students.

Table 9-144 Non-motorized trip records by distance for on-campus students

Trip Length Bracket (miles)	Trip Purpose				Total
	HBU	HBO	UBNH	NHNU	
≤ 2	1,639	55	868	11	2,573
(2, 5]	2	6	14	0	22
(5, 10]	0	5	3	0	8
(10, 15]	0	0	0	0	0
> 15	0	0	0	0	0
Total	1,641	66	885	11	2,603

Table 9-145 Non-motorized trip records by distance for off-campus students

Trip Length Bracket (miles)	Trip Purpose				Total
	HBU	HBO	UBNH	NHNU	
≤ 2	60	15	417	13	505
(2, 5]	7	1	4	2	14
(5, 10]	6	1	1	2	10
(10, 15]	1	0	0	0	1
> 15	0	0	0	1	1
Total	74	17	422	18	531

Table 9-144 and Table 9-145 show that most non-motorized trips were two miles or shorter, with only two trips longer than ten miles (one HBU trip and one NHNU trip, both by off-campus students). Weighted non-motorized trip length distributions by distance are shown in Table 9-146 and Table 9-147.

Table 9-146 Weighted non-motorized trip length distribution by distance for on-campus students

Trip Length Bracket (miles)	Trip Purpose				Total
	HBU	HBO	UBNH	NHNU	

≤ 2	99.88%	83.33%	98.08%	100.00%	98.84%
(2, 5]	0.12%	9.09%	1.58%	0.00%	0.85%
(5, 10]	0.00%	7.58%	0.34%	0.00%	0.31%
(10, 15]	0.00%	0.00%	0.00%	0.00%	0.00%
> 15	0.00%	0.00%	0.00%	0.00%	0.00%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

Table 9-147 Weighted non-motorized trip length distribution by distance for off-campus students

Trip Length Bracket (miles)	Trip Purpose				Total
	HBU	HBO	UBNH	NHNU	
≤ 2	80.47%	88.39%	98.86%	70.99%	95.10%
(2, 5]	9.21%	7.11%	0.88%	11.11%	2.55%
(5, 10]	8.77%	4.50%	0.27%	13.58%	2.00%
(10, 15]	1.55%	0.00%	0.00%	0.00%	0.21%
> 15	0.00%	0.00%	0.00%	4.32%	0.14%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

Table 9-146 and Table 9-147 show that non-motorized trips longer than ten miles only account for 0.35% (= 0.21% + 0.14%) of non-motorized trips made by off-campus students. Based on the results shown in Table 9-144 through Table 9-147, it was decided to use 10 miles as the threshold for university students to be able to use non-motorized modes.

9.2.4.3 Model Estimation

University student non-motorized trip split models were estimated using Biogeme software. Each trip has two alternatives, using a motorized mode, or using a non-motorized mode. Because only relative utility matters in the model, the utility of choosing a motorized mode was fixed at zero, and only the utility of choosing a non-motorized mode was estimated. The results of that estimation are presented in this section.

In all university student non-motorized trip split models, non-motorized distance (NM_Dist) was selected as an impedance term. Non-motorized time (NM_Time) was not selected because it is simply calculated as NM_Dist divided by average non-motorized travel speed, which is fixed for each combination of trip purpose and stratum (as shown in Table 9-143). Therefore, NM_Time and NM_Dist have a linear relationship, meaning that they would each provide the same explanatory power in the model estimation. Composite motorized travel time (Comp_Time) was not selected because it is a weighted composite of automobile and public transit travel time, which could differ significantly between the university student population and the general population, because public transit mode shares are usually higher among university students. NM_Time and Comp_time were tested as possible explanatory variables for some model estimations. However, the adjusted R^2 values associated with models that use those two variables were similar to those associated with models that use NM_Dist as an impedance term. Functions of NM_Dist, such as the square of NM_Dist and NM_Dist to the power of 1.5, were also tested, but the resulting models either were not statistically significant or the coefficients did not have correct signs.

9.2.4.3.1 On-Campus HBU Trips

On-campus HBU trips are Home Based University trips made by on-campus students. The production ends are on-campus residence halls, and the attraction ends are also on-campus locations, such as classrooms and libraries. As shown in Table 9-141, there were enough trip records in the survey that peak-period and off-peak-period trips could be modeled separately for on-campus HBU trips.

Most of the variables in Table 9-142 were tested either separately or grouped together in the model estimation. After testing, the following utility function was selected for both peak and off-peak on-campus HBU trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bBASD\_A * BASD_j \quad (9\text{-}35)$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bBASD\_A$ = coefficient for density of building floor area for service at attraction TAZ, and
$BASD_j$ = density of building floor area for service at attraction TAZ j.

A high density of building floor area for service (BASD) indicates that many classrooms, libraries, gyms, and dining halls are located in close proximity to each other; as a result, students are more likely to walk or bike to their destinations. The BASD values used for this model estimation are for 2001, rather than 2010. 2001 was the year of the NCSU Student Survey, and NCSU constructed many new buildings (including classrooms and residence halls) between 2001 and 2010. 2001 travel behaviors are best be explained using 2001 BASD values.

Some variables describing the production ends of on-campus HBU trips (i.e., on-campus residence halls) were tested for explanatory power, but either the resulting models were not statistically significant or the coefficients did not have correct signs.

The estimation results for peak-period trips are shown in Table 9-148 and those for off-peak trips are in Table 9-149.

Table 9-148 On-campus student HBU non-motorized trip split model (peak)

Utility Coefficients	Value	t-stat
Constant	4.89	12.36
Non-Motorized Distance	-4.59	-10.18
Density of Building Area for Service, Attraction End	0.0896	5.10
Rho-square: 0.629		
Adjusted rho-square: 0.624		
Number of records: 868		

Table 9-149 On-campus student HBU non-motorized trip split model (off-peak)

Utility Coefficients	Value	t-stat
Constant	3.70	11.23
Non-Motorized Distance	-3.65	-9.94
Density of Building Area for Service, Attraction End	0.121	6.96
R^2: 0.626		
Adjusted R^2: 0.622		
Number of records: 978		

In both Table 9-148 and Table 9-149, all coefficients are significant and have correct signs. The coefficient for non-motorized distance is negative, which means that longer trips are less likely to be made by non-motorized modes. The coefficient for the density of building floor area for service at the attraction end is positive, indicating that higher densities encourage non-motorized trip-making. The adjusted R^2 values are 0.624 for the peak-period model and 0.622 for the off-peak-period model.

9.2.4.3.2 On-Campus HBO Trips

On-campus HBO trips are Home Based Other trips made by on-campus students. The production ends are on-campus residence halls, and the attraction ends are off-campus locations. Because there were not enough trip records to create separate estimations for the peak and off-peak periods, trip records from both of those periods were pooled together for the estimation of on-campus HBU trips.

The following utility function was selected for on-campus HBO trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bNM\_PathDen\_A * NM\_PathDen_j \qquad (9\text{-}36)$$

where

U_{ij}^{NM} = utility to choose non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bNM\_PathDen\_A$ = coefficient for non-motorized path density at attraction TAZ, and
$NM\_PathDen_j$ = non-motorized path density at attraction TAZ j.

The estimation results are shown in Table 9-150. The coefficient for the non-motorized path density is positive, as expected. The adjusted rho-square value is 0.354.

Table 9-150 On-campus student HBO non-motorized trip split model (both peak and off-peak)

Utility Coefficients	Value	t-stat
Constant	-1.39	-3.51
Non-Motorized Distance	-0.35	-3.12
Non-Motorized Path Density, Attraction End	0.0446	4.06
R^2: 0.368		
Adjusted R^2: 0.354		
Number of records: 306		

9.2.4.3.3 On-Campus UBNH Trips

On-campus UBNH trips are University Based Non Home trips made by on-campus students. The production ends are on-campus locations, and the attraction ends may be on-campus or off-campus locations. It is intuitive that if an attraction end is on-campus, it is more likely to be made by a non-motorized mode. As explained in Section 9.2.4.2, peak and off-peak on-campus UBNH trips were modeled separately, because there were judged to be enough non-motorized trip records during both time periods to do so.

The following utility function was selected for on-campus UBNH peak-period trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bCampus\_A * Campus_j \qquad (9\text{-}37)$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bCampus\_A$ = coefficient for on-campus dummy variable, and
$Campus_j$ = on-campus dummy variable (whether attraction TAZ j is on campus).

The estimation results are shown in Table 9-151. The coefficient for the on-campus dummy variable is positive, as expected. The adjusted R^2 value is 0.584.

Table 9-151 On-campus student UBNH non-motorized trip split model (peak)

Utility Coefficients	Value	t-stat
Constant	1.00	1.92
Non-Motorized Distance	-0.696	-2.59
On-Campus Dummy Variable, Attraction End	2.12	4.29
R^2: 0.599		
Adjusted R^2: 0.584		
Number of records: 291		

The following utility function was selected for on-campus UBNH off-peak trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bNM\_PathDen\_A * NM\_PathDen_j + bBASD\_A * BASD_j \tag{9-38}$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bNM\_PathDen\_A$ = coefficient for non-motorized path density at attraction TAZ,
$NM\_PathDen_j$ = non-motorized path density at attraction TAZ j,
$bBASD\_A$ = coefficient for density of building floor area for service at attraction TAZ, and
$BASD_j$ = density of building floor area for service at attraction TAZ j.

The estimation results are shown in Table 9-152. The coefficients for non-motorized path density and the density of building floor area for service are both positive, as expected. The adjusted R^2 value is 0.711.

Table 9-152 On-campus student UBNH non-motorized trip split model (off-peak)

Utility Coefficients	Value	t-stat
Constant	1.34	3.19
Non-Motorized Distance	-0.62	-4.17
Non-Motorized Path Density, Attraction End	0.0422	2.77
Density of Building Area for Service, Attraction End	0.149	4.92
R^2: 0.719		
Adjusted R^2: 0.711		
Number of records: 697		

9.2.4.3.4 NHNU Trips by both On-Campus and Off-Campus Students

NHNU trips are Non Home Non University trips. Both the production and attraction ends are off-campus locations. As shown in Table 9-141, only 79 NHNU trip records (including both motorized and non-motorized trips) were recorded for on-campus students in the 2001 NCSU Student Survey, and only 203 were recorded for off-campus students. Among those trip records, 11 were non-motorized trips by on-campus students and 18 were non-motorized trips by off-campus students. Because there were so few trip records, on-campus and off-campus NHNU trips (both peak and off-peak) were pooled together for a single estimation model. An on-campus/off-campus dummy variable was tested during the model estimation process, but it was found to be insignificant as an explanatory variable. Ultimately, the following utility function was selected for NHNU trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bLandMix\_P * LandMix_i + bAVEBLOCK\_A\_A * AVEBLOCK\_A_j \tag{9-39}$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bLandMix\_P$ = coefficient for land use mix at production TAZ,
$LandMix_i$ = land use mix at production TAZ i,
$bAVEBLOCK\_A\_A$ = coefficient for average block size by area at attraction TAZ, and
$AVEBLOCK\_A_j$ = average block size by area at attraction TAZ j.

The estimation results are shown in Table 9-153. The coefficient for land use mix is positive, indicating that mixed land uses are conducive to non-motorized trips. The coefficient for average block size by area is negative, meaning that larger block sizes lead to fewer non-motorized trips. Both of these coefficients are as expected. The adjusted R^2 value is 0.691.

Table 9-153 NHNU non-motorized trip split model for both on- and off-campus students (both peak and off-peak)

Utility Coefficients	Value	t-stat
Constant	0.0847	0.09
Non-Motorized Distance	-0.341	-2.18
Land Use Mix, Production End	0.0302	2.47
Average Block Size by Area, Attraction End	-17.9	-2.71
R^2: 0.712		
Adjusted R^2: 0.691		
Number of records: 277		

In contrast to the models for on-campus HBU, HBO and UBNH trips, the model for on-campus NHNU trips includes a variable describing the production TAZ (Land Use Mix, Production End). Although variables describing production TAZs were tested for the on-campus HBU, HBO and UBNH models, either their explanatory power was not statistically significant or the coefficients did not have correct signs. This is possibly because the production TAZs for those trip categories are all necessarily on-campus, meaning that the production TAZs have similar attributes and lack significant variations that could be used to explain the observed travel behavior. However, the production TAZs of NHNU trips are all off-campus, which is likely why the explanatory power of a variable describing production TAZs was found to be significant.

9.2.4.3.5 Off-Campus HBU Trips

Off-campus HBU trips are Home Based University trips made by off-campus students. As the name suggests, the production ends are off-campus students' home locations, and the attraction ends are on-campus locations. Because there were not enough trip records to model them separately, peak and off-peak trips were pooled together for this model estimation.

The following utility function was selected for off-campus HBU trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bAVEBLOCK\_A\_P * AVEBLOCK\_A_i + bAVEBLOCK\_A\_A * AVEBLOCK\_A_j \quad (9\text{-}40)$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bAVEBLOCK\_A\_P$ = coefficient for average block size by area at production TAZ,
$AVEBLOCK\_A_i$ = average block size by area at production TAZ i,
$bAVEBLOCK\_A\_A$ = coefficient for average block size by area at attraction TAZ, and
$AVEBLOCK\_A_j$ = average block size by area at attraction TAZ j.

The estimation results are shown in Table 9-154. The coefficients for average block size by area, at both the production and attraction ends, are negative, as expected. The adjusted R^2 value is 0.592.

Table 9-154 Off-campus student HBU non-motorized trip split model (both peak and off-peak)

Utility Coefficients	Value	t-stat
Constant	2.59	3.82
Non-Motorized Distance	-0.717	-5.23
Block Size by Area, Production End	-13.1	-2.79
Block Size by Area, Attraction End	-8.1	-2.73
R^2: 0.601		
Adjusted R^2: 0.592		
Number of records: 636		

9.2.4.3.6 Off-Campus HBO Trips

Off-campus HBO trips are Home Based Other trips made by off-campus students. Both the production ends and the attraction ends are off-campus locations. Because there were not enough trip records to treat the peak and off-peak periods separately, data from both periods were pooled together for this model estimation.

The following utility function was selected for off-campus HBO trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bAVEBLOCK\_A\_P * AVEBLOCK\_A_i + bNM\_PathDen\_A * NM\_PathDen_j \quad (9\text{-}41)$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bAVEBLOCK\_A\_P$ = coefficient for average block size by area at production TAZ,
$AVEBLOCK\_A_i$ = average block size by area at production TAZ i,
$bNM\_PathDen\_A$ = coefficient for non-motorized path density at attraction TAZ, and
$NM\_PathDen_j$ = non-motorized path density at attraction TAZ j.

The estimation results are shown in Table 9-155. The signs of the coefficients are consistent with expectations. The adjusted R^2 value is 0.869.

Table 9-155 Off-campus student HBO non-motorized trip split model (both peak and off-peak)

Utility Coefficients	Value	t-stat
Constant	-0.445	-0.39
Non-Motorized Distance	-0.869	-3.18
Average Block Size by Area, Production End	-12.5	-1.85
Non-Motorized Path Density, Attraction End	0.0549	2.62
R^2: 0.88		
Adjusted R^2: 0.869		
Number of records: 532		

9.2.4.3.7 ***Off-Campus UBNH Trips***

Off-campus UBNH trips are University Based Non Home trips made by off-campus students. The production ends are on-campus locations, and the attraction ends may be on-campus or off-campus locations. Because there were not enough trip records to treat the peak and off-peak periods separately, data from both periods were pooled together for this model estimation.

The following utility function was selected for off-campus UBNH trips:

$$U_{ij}^{NM} = C + bNM\_Dist * NM\_Dist_{ij} + bBASD\_A * BASD_j \qquad (9\text{-}42)$$

where

U_{ij}^{NM} = utility of choosing non-motorized mode for a trip from production TAZ i to attraction TAZ j,
C = constant term,
bNM_Dist = coefficient for non-motorized distance,
NM_Dist_{ij} = non-motorized distance from production TAZ i to attraction TAZ j,
$bBASD\_A$ = coefficient for density of building floor area for service at attraction TAZ, and
$BASD_j$ = density of building floor area for service at attraction TAZ j.

The estimation results are shown in Table 9-156. The coefficient for the density of building floor area for service is positive, as expected. The adjusted R^2 value is 0.592.

Table 9-156 Off-campus student UBNH non-motorized trip split model (both peak and off-peak)

Utility Coefficients	Value	t-stat
Constant	2.54	8.3
Non-Motorized Distance	-2.14	-9.14
Density of Building Area for Service, Attraction End	0.0864	4.65
R^2: 0.599		
Adjusted R^2: 0.592		
Number of records: 638		

9.2.4.4 Model Calibration

Nine university student non-motorized trip split models were estimated, as discussed above. Those nine models are for:

1) MHBU peak-period trips by on-campus students (on-campus HBU peak trips)
2) MHBU off-peak trips by on-campus students (on-campus HBU off-peak trips)
3) MHBO trips by on-campus students (on-campus HBO trips)
4) MUBNH peak-period trips by on-campus students (on-campus UBNH peak trips)
5) MUBNH off-peak trips by on-campus students (on-campus UBNH off-peak trips)
6) MNHNU trips by either on-campus or off-campus students (NHNU trips)
7) MHBU trips by off-campus students (off-campus HBU trips)
8) MHBO trips by off-campus students (off-campus HBO trips)
9) MUBNH trips by off-campus students (off-campus UBNH trips)

The calibration results for these nine models are presented in this section. The calibration was conducted by following these steps:

1) Write the GISDK code to implement the non-motorized trip split models;
2) For each of the nine university-student non-motorized trip split models, take the corresponding trip distribution matrices outputted from the calibrated destination-choice models and split them into motorized trip matrices and non-motorized trip matrices;
3) Calculate the modeled non-motorized trip shares;
4) Adjust the constant terms in the university-student non-motorized trip split models and repeat Steps 2 and 3 until the modeled non-motorized trip shares are within 0.5% of observed values.

The calibration results are shown in Table 9-157 through Table 9-165.

Table 9-157 Calibration results of the non-motorized trip split model for on-campus HBU peak trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		89.17%	
Before calibration	4.89	78.65%	-10.52%
After calibration	6.19	89.12%	-0.05%

Table 9-158 Calibration results of the non-motorized trip split model for on-campus HBU off-peak trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		89.26%	
Before calibration	3.70	75.53%	-13.74%
After calibration	5.25	89.21%	-0.05%

Table 9-159 Calibration results of the non-motorized trip split model for on-campus HBO trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		20.43%	
Before calibration	-1.39	17.36%	-3.07%
After calibration	-1.17	20.14%	-0.29%

Table 9-160 Calibration results of the non-motorized trip split model for on-campus UBNH peak trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		85.22%	
Before calibration	1.00	82.59%	-2.63%
After calibration	1.25	85.13%	-0.09%

Table 9-161 Calibration results of the non-motorized trip split model for on-campus UBNH off-peak trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		91.68%	
Before calibration	1.34	84.07%	-7.61%
After calibration	2.09	91.36%	-0.32%

Table 9-162 Calibration results of the non-motorized trip split model for NHNU trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		9.62%	
Before calibration	0.0847	10.38%	0.76%
After calibration	0.00	9.81%	0.18%

Table 9-163 Calibration results of the non-motorized trip split model for off-campus HBU trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		11.02%	
Before calibration	2.59	9.20%	-1.82%
After calibration	2.79	10.61%	-0.41%

Table 9-164 Calibration results of the non-motorized trip split model for off-campus HBO trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		2.94%	
Before calibration	-0.445	2.36%	-0.58%
After calibration	-0.155	2.94%	0.00%

Table 9-165 Calibration results of the non-motorized trip split model for off-campus UBNH trips

	Constant	Non-motorized trip share	Deviation from observed non-motorized trip share
Observed		66.48%	
Before calibration	2.54	44.53%	-21.95%
After calibration	4.44	66.88%	-0.60%

9.2.4.5 Model Application

The university-student non-motorized trip split models presented above were developed and calibrated using the results of the 2001 NCSU Student Survey. These models were then applied to the other major universities in the TRM region, UNC, Duke and NCCU, using 2010 socioeconomic data.

Table 9-166 and Figure 9-72 show shares of non-motorized trips by trip-purpose/student-type/time-of-day-specific model for students attending the four major universities in the TRM region.

Table 9-166 Shares of non-motorized trips for students attending the four major universities

ID	Model	Observed	Modeled			
		NCSU	NCSU	UNC	Duke	NCCU
1	On-Campus HBU Peak	89%	89%	85%	80%	98%
2	On-Campus HBU Off-Peak	89%	89%	84%	80%	97%
3	On-Campus HBO	20%	20%	42%	20%	13%
4	On-Campus UBNH Peak	85%	85%	84%	89%	76%
5	On-Campus UBNH Off-Peak	92%	91%	99%	96%	93%
6	NHNU (both On- and Off-Campus)	10%	10%	19%	8%	7%
7	Off-Campus HBU	11%	11%	16%	8%	15%

8	Off-Campus HBO	3%	3%	12%	4%	3%
9	Off-Campus UBNH	66%	66%	66%	75%	33%

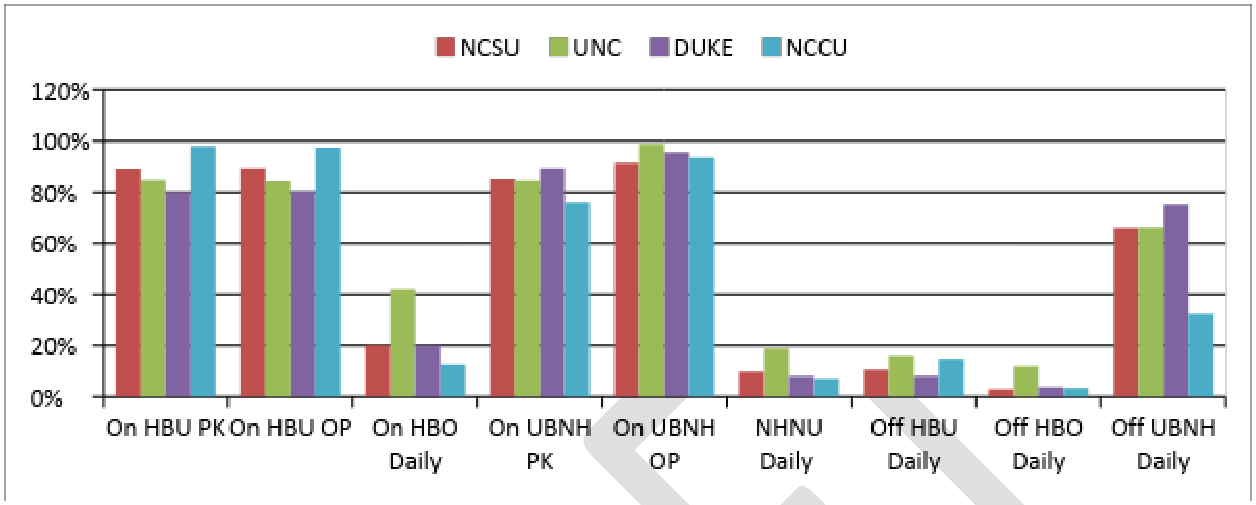


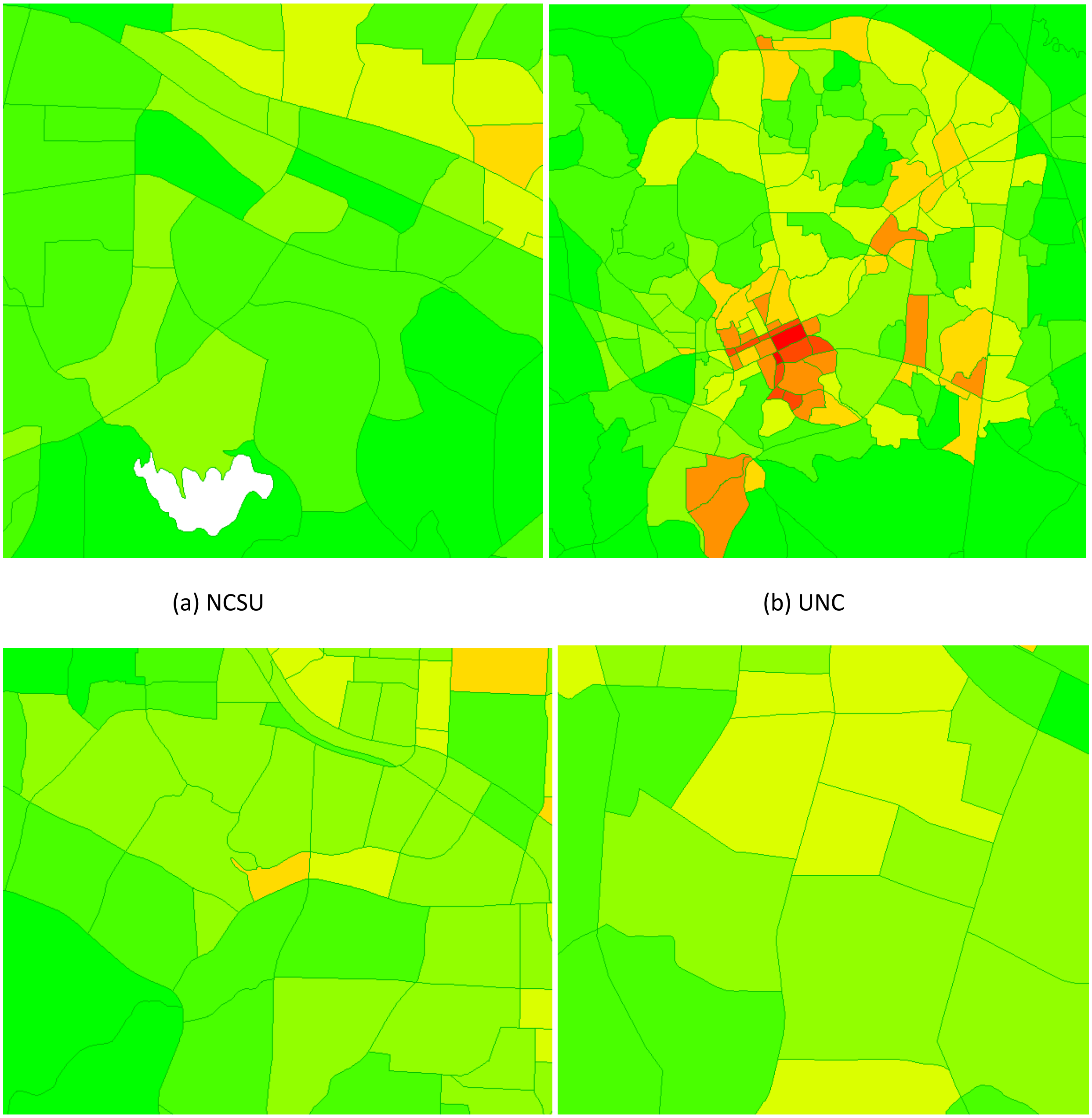
Figure 9-72 Modeled shares of non-motorized trips for students attending the four major universities

Table 9-166 and Figure 9-72 show that NCCU has higher non-motorized shares for on-campus HBU trips (both peak and off-peak) than the other three universities, likely because it has a smaller campus than the others, meaning that on-campus HBU trips are shorter and therefore more often made by non-motorized modes. NCCU also has a much lower non-motorized share for off-campus UBNH trips than the other three universities, because trips of that type are generally longer for NCCU students than for students attending the other universities (as shown in Table 9-138).

Table 9-166 and Figure 9-72 show that UNC has higher non-motorized shares for some categories of trips, including on-campus and off-campus HBO trips. The major reason for this is that the models include the non-motorized path density ($NM\_PathDen$) as a variable, and UNC generally has a much higher non-motorized path density than the other three universities, as shown in Figure 9-73. In that figure, non-motorized path length densities at all four universities are color coded in the same way: red means higher density, green means lower density and the remaining colors refer to intermediate densities.

Without survey data for students attending universities other than NCSU, it is difficult to judge whether or not the non-motorized trip shares in Table 9-166 are accurate. A validation of the non-motorized trip share for UNC off-campus HBU trips is presented in the next section, using data from the 2011 UNC Campus Commuting Survey. Data is not available to validate non-motorized-share results for other categories or trips or for other universities.

To get a better sense of the modeled non-motorized trip shares, Table 9-167 through Table 9-170 aggregate the results shown in Table 9-166 and present modeled numbers of motorized and non-motorized trips by stratum (on-campus students versus off-campus students). The results seem reasonable. In future versions of the TRM, if more observed data are available, the performance of the current models may be evaluated and, if necessary, further efforts may be made to yield more accurate results.



(a) NCSU (b) UNC

(c) Duke (d) NCCU

Figure 9-73 Comparison of non-motorized path length densities at four major universities

Table 9-167 Shares of non-motorized trips by stratum for NCSU students

	Motorized Trips	Non-Motorized Trips	Motorized Share of Trips	Non-Motorized Share of Trips
On-Campus Students	14,694	59,228	20%	80%
Off-Campus Students	80,752	27,823	74%	26%
Total	95,447	87,050	52%	48%

Table 9-168 Shares of non-motorized trips by stratum for UNC students

	Motorized Trips	Non-Motorized Trips	Motorized Share of Trips	Non-Motorized Share of Trips
On-Campus Students	13,894	60,556	19%	81%
Off-Campus Students	76,269	33,742	69%	31%
Total	90,163	94,297	49%	51%

Table 9-169 Shares of non-motorized trips by stratum for Duke students

	Motorized Trips	Non-Motorized Trips	Motorized Share of Trips	Non-Motorized Share of Trips
On-Campus Students	10,448	33,425	24%	76%
Off-Campus Students	36,443	13,154	73%	27%
Total	46,890	46,579	50%	50%

Table 9-170 Shares of non-motorized trips by stratum for NCCU students

	Motorized Trips	Non-Motorized Trips	Motorized Share of Trips	Non-Motorized Share of Trips
On-Campus Students	2,675	13,658	16%	84%
Off-Campus Students	30,688	6,041	84%	16%
Total	33,362	19,699	63%	37%

9.2.4.6 Model Validation

The 2011 UNC Campus Commuting Survey[16] was used to validate the modeled non-motorized trip share for UNC Off-campus HBU trips. The purpose of the UNC Campus Commuting Survey was to survey both students and employees at UNC about the various travel modes they used to commute to campus, as well as the origins and destinations of those commute trips. For the purposes of the 2011 survey, "the student population consisted of all undergraduate, graduate, and professional students who lived off-campus during spring 2011," which means that the UNC Campus Commuting

[16] Martin / Alexiou / Bryson, P.C., UNC-Chapel Hill, *2011 UNC Campus Commuting Survey,* Project Report, November 2011.

Survey can only be used to validate results for UNC off-campus HBU trips. From the student population, "a random sample of 5,000 was drawn. A total of 484 responses were received for a response rate of 9.7%. The margin of error for the student survey is +/-4.4% at a confidence level of 95%."

Table 9-171 is based on Table 4.6 from the report for the 2011 UNC Campus Commuting Survey. In the original survey questionnaire, students were asked "how do you typically travel to campus each day?" and had to specify which mode or modes they usually used on each day of the week (Monday through Sunday). The survey report provided numbers of students indicating each combination of mode and "number of days used," as shown in Table 9-171. For example, 48 students said that they usually drove alone to the UNC campus once a week.

Table 9-171 Approximate mode shares from the 2011 UNC Campus Commuting Survey

Mode	Number of Days Used					Approximate Total Trips	Mode Share
	1	2	3	4	5+		
Drive Alone (Not Park & Ride)	48	118	19	17	44	1,258	21.0%
Park & Ride	3	15	12	10	56	778	13.0%
Carpool	3	9	2	0	9	144	2.4%
Vanpool	0	1	2	0	2	36	0.6%
Bus	11	24	23	22	186	2,292	38.2%
Motorcycle/Moped	0	0	1	2	4	62	1.0%
Walk	9	14	6	6	44	598	10.0%
Bicycle	2	10	8	2	40	508	8.5%
Dropped Off by Friend/ Spouse	13	11	6	0	7	176	2.9%
Telework from Home	8	7	1	1	5	108	1.8%
Other	0	2	0	1	2	36	0.6%
Total						5,996	100.0%

It is difficult to obtain accurate numbers of trips for each travel mode in Table 9-171, due to the way in which the question was asked. As an approximation, it is assumed that all off-campus students use the same mode to travel to campus as to return home from campus, and that they do not go to campus on weekends (therefore "5+ days" means 5 days). Under these assumption, since 48 students said they usually drove alone to the UNC campus once a week, as shown in Table 9-171, they are taken to have made a total of 96 drive-alone trips in a week (48 trips to campus and 48 trips from campus). Similarly, 118 students drove alone to the UNC campus two days a week, so they are taken to have made 472 drive-alone trips in a week (=118 * 2 * 2). The math works out similarly for students using a given mode three days a week, four days a week, or five or more days a week (treated here as five days a week). The column for "Approximate Total Trips" in Table 9-171 is the sum of the off-campus HBU trips that the 484 student respondents made in a week by each mode. The column for "Mode Share" in Table 9-171 was calculated from the values for "Approximate Total Trips." The commuting survey dataset was not weighted, for which reason "Approximate Total Trips" and "Mode Share" in Table 9-171 are not weighted either.

As shown in Table 9-171, the observed non-motorized share for off-campus HBU trips is 18.5% (10.0% for the walk mode and 8.5% for the bicycle mode). Meanwhile, the modeled value in the TRM is 16%, as shown in Table 9-166.

It should be noted that the non-motorized trip split models were developed and calibrated using the results of a survey conducted at NCSU in 2001 and is being applied to represent non-motorized shares for UNC students in 2010. The spatial and temporal differences between the dataset used during model development and the context to which the models are applied make model creation, application, and validation very challenging, due to potential differences in student travel behaviors.

9.2.5 Mode Choice

This section documents the TRMv6 university student model's motorized mode choice step. The structure of the university student motorized mode choice model and the methods of estimating and calibrating it are the same as those for the general-population mode choice model, as described in Chapter 8. Therefore, this section focuses on things that are different between the university-student and general-population models, primarily the Alternative Specific Constants (ASCs) that were generated during calibration of the university student mode choice model. Also, the university student mode choice model substitutes the two residence statuses of on-campus students and off-campus students for the five socioeconomic strata used for the general-population model, uses the four designated university-student-specific trip purposes (HBU, HBO, UBNH, and NHNU) instead of the ones used for the general population, and has as its input the results of the university-student non-motorized trip split model instead of the general-population non-motorized trip split model. Because the two mode choice models use different sets of trip purposes, they also employ different rules regarding which combinations of trip purpose and mode of travel are allowed. Furthermore, whereas the general population mode choice model was calibrated to targets derived from the 2006 Household Travel Survey and the non-university-student portion of the responses to the 2006 Transit On-Board (TOB) Survey, the university student mode choice model was calibrated to targets derived from the 2001 NCSU Student Survey and the university-student portion of the responses to the 2006 TOB Survey.

9.2.5.1 Data Sources and Processing

This subsection discusses the data sources and data preparation used for mode-choice calibration target development in the university student model.

9.2.5.1.1 2001 North Carolina State University Student Survey

During the development of the TRMv6, data from the 2001 NCSU Student Survey were expanded to match 2010 numbers of on- and off-campus students. The 2010 total number of motorized person trips, including automobile and transit trips but excluding school bus trips, was calculated by applying expansion factors to the motorized trip records in the survey results. This information was used to derive percent mode shares of automobile person trips by vehicle occupancy, which were used to develop the automobile portion of the 2013 mode choice model calibration targets.

9.2.5.1.2 2006 Transit On-Board (TOB) Survey

Re-Expansion to 2013 Average Weekday Daily Ridership

The results of the 2006 Transit On-Board Survey were re-expanded to match 2013, rather than 2010, average weekday ridership. Therefore, target 2013 numbers of trips by any transit mode (or sub-mode) were calculated by applying different expansion/weighting factors than those used for automobile person trips by vehicle occupancy or for calibrating any other part of the university student model. The implied assumption is that automobile percent mode shares by vehicle occupancy did not change during 2010-2013.

Separation of Trips by University Students from Those by General Population

In the 2006 TOB survey, transit trips made by students of the four major universities, including those living on- or off-campus, were distinguished from those by the general population, so that such trips could be modeled using the university student model.

Table 9-172 summarizes 2013 inter-TAZ transit person trips by the general population and by university students. Only 2,742 records of transit trips by the university students were used to develop the public-transit portion of the TRMv6 2013 university student model motorized mode share targets.

Table 9-172 2013 transit person trips: university students vs. general population

Population Subset	Sample Size	Percent of Total	2013 Transit Trips (Expanded)	Percent of Total
General Population	3,278	54%	40,870	48%
University Students	2,742	46%	43,824	52%
Total	**6,020**	**100%**	**84,694**	**100%**

Source: 2006 TOB survey processed results
Note: Inter-TAZ trips only

9.2.5.2 Mode Choice Target Development

This subsection describes the development of 2013 mode choice calibration targets for the TRMv6 university student model. The development of these targets followed a similar process to that used for the general population, which is therefore not repeated here.

9.2.5.2.1 Target Adjustments

The university student mode choice model represents inter-TAZ motorized trips, including automobile and transit trips, while excluding school bus trips and non-motorized trips. Transit-trip targets include only local and express bus trips, as public transit rail service did not exist in the base year of 2013. It was judged that, even though the quantity of transit-related data in the results of the 2001 NCSU Student Survey was insufficient for developing targets, its reported figures for automobile person trips by trip purpose, time of day, and university student residence status and for percent shares of automobile trips by vehicle occupancy were reliable and accurate for NCSU students. It was also judged that the 2006 TOB survey provided an adequate quantity of university-student transit trip records, as well as reliable, accurate, and detailed information on access modes, boarding/alighting locations, and whether each route referred to in a survey response was a local or express route, all separated out by trip purpose, time of day, and student residence status. Therefore, motorized mode choice targets were developed using combined information from the 2001 NCSU Student Survey and the 2006 TOB survey.

It was decided to only use the 2001 NCSU Survey to inform targets for automobile travel behavior, including that of students attending the other three major universities besides NCSU (Duke, NCCU, and UNC), on account that no university-student automobile trip-making data was available for those other three universities. Although it was acknowledged that automobile travel behavior may vary between students of the four universities, it was assumed that the 2001 NCSU Student Survey provided university-student automobile travel behavior information that may be applied to students attending the other universities, unless and until data relating to students attending the other three universities becomes available.

The input trip tables for the university student motorized mode choice model are from the output trip tables of the non-motorized trip split model.

Total Automobile Person Trips

Due to the strict requirements of the mode choice Alternative Specific Constant (ASC) self-calibration module developed by Parsons Brinckerhoff, numbers of trips were used as calibration targets, rather than percent shares of trips by each mode. Theoretically, automobile person trip targets could be taken directly from the results of the 2001 NCSU Student Survey, if it is assumed that the data on public transit trips are accurate.

The modeled total number of motorized person trips and the number of observed 2013 transit trips were both used to derive an “adjusted” total automobile person trip target. This “adjusted” target was the difference between total motorized inter-TAZ person trips (TRMv6 2013 non-motorized trip split model output) and 2013 transit person trips (from the 2006 TOB survey).

Table 9-173 summarizes the resulting university student motorized mode choice model calibration targets for inter-TAZ automobile person trips by vehicle occupancy. Due to time constraints, data from the 2001 NCSU Student Survey were not re-expanded to match 2013 figures. Instead, 2010 observed percent mode shares by vehicle occupancy were used, assuming that 2013 percent mode shares were the same as in 2010 (i.e., no changes during that three year span).

Table 9-173 2013 university student mode choice model adjusted inter-TAZ automobile person trip targets

Trip Purpose Time of Day Residence Status	TRMv6 2013 Modeled Total Motorized Person Trips	2013 Observed Transit Trips	TRMv6 2013 Adjusted Total Auto Person Trip Target	2010 Observed % Mode Shares by Vehicle Occupancy			TRMv6 2013 Auto Person Trip Targets by Vehicle Occupancy		
				% Drive 1-Person	% Drive 2-Person	% Drive 3+-Person	Drive 1-Person	Drive 2-Person	Drive 3+-Person
HBU_PK									
On-campus	8,465	1,975	**6,490**	50%	25%	25%	3,245	1,623	1,623
Off-campus	49,295	12,472	**36,823**	89%	9%	2%	32,595	3,336	893
All	57,760	14,447	**43,313**	86%	10%	4%	**35,840**	**4,958**	**2,515**
HBU_OP									
On-campus	9,292	4,209	**5,083**	66%	23%	11%	3,361	1,148	574
Off-campus	35,058	10,568	**24,490**	88%	11%	1%	21,527	2,710	253
All	44,350	14,776	**29,573**	86%	12%	2%	**24,888**	**3,858**	**827**
HBO_PK									
On-campus	6,319	187	**6,132**	57%	34%	9%	3,495	2,110	527
Off-campus	39,885	932	**38 ,954**	78%	18%	4%	30,554	6,872	1,528
All	46,204	1,119	**45,086**	76%	20%	5%	**34,049**	**8,982**	**2,055**
HBO_OP									
On-campus	10,289	257	**10,032**	39%	38%	23%	3,931	3,796	2,305
Off-campus	38,571	952	**37,619**	73%	22%	5%	27,548	8,237	1,835

All	48,861	1,209	**47,651**	67%	25%	8%	**31,480**	**12,033**	**4,139**
UBNH_PK									
On-campus	2,950	943	**2,007**	54%	25%	21%	1,075	502	430
Off-campus	12,975	3,521	**9,454**	85%	11%	5%	7,994	1,016	444
All	15,926	4,465	**11,461**	81%	12%	7%	**9,070**	**1,517**	**874**
UBNH_OP									
On-campus	2,139	1,857	**283**	23%	45%	33%	64	127	92
Off-campus	20,999	5,525	**15,475**	77%	19%	5%	11,874	2,882	719
All	23,139	7,381	**15,758**	70%	22%	8%	**11,937**	**3,010**	**811**
NHNU_Daily									
On-campus	4,487	58	**4,430**	43%	29%	28%	1,908	1,295	1,227
Off-campus	26,677	370	**26,308**	67%	28%	6%	17,580	7,242	1,486
All	31,165	427	**30,738**	63%	28%	9%	**19,488**	**8,537**	**2,712**

Sources and notes:

1) All trips are inter-TAZ person trips
2) 2013 observed transit person trips: 2006 TOB survey (expanded to 2013 transit ridership)
3) TRMv6 2013 adjusted total auto person trip targets = TRMv6 2013 motorized person trips - 2013 observed transit trips (from 2006 TOB survey)
4) 2010 observed percent mode shares by automobile occupancy: 2001 NCSU Student Survey (expanded to 2010 enrollment)
5) TRMv6 2013 adjusted automobile person trips by vehicle occupancy targets = TRMv6 2013 adjusted total automobile person trip target * 2010 observed percent mode shares by automobile vehicle occupancy

Transit Access Mode

The university student mode choice model only allows certain transit access modes for each trip purpose/time of day combination, based on what is typical in the region, regardless of what access modes appear in the observed raw data for each trip purpose and time of day. For example, the results of the 2006 TOB survey may include an NHNU trip on a local bus with Park & Ride access, but because such behavior is rare in the Triangle region, that particular combination of trip purpose, transit mode, and access mode is not modeled. For any given trip purpose/time of day/access mode combination, if the number of observed trips was particularly low, including that combination would not have resulted in a reliable and well-calibrated model.

In order to keep the exclusion of those rare combinations from creating targets for total trips using Park & Ride access to local bus routes that deviate from observed data, the TRMSB allocated the necessary balance of trips to the trip purpose of U_HBO (variable name used in the university student model to distinguish from HBO trips by the general population), separated out by time period. This was done even though the TRMv6 seems to overestimate local-bus riders who access the mode via Park & Ride facilities for U_HBO trips.

Table 9-174 summarizes the transit access modes that the model either allows or prohibits for each trip purpose/time of day combination. Only NHNU trips are not allowed to be by express bus. Only HBU trips to certain UNC TAZs are allowed to be auto-intercept trips (wherein most of a trip's distance is traveled by automobile, but the traveler switches to a bus for the leg of the trip that starts/ends at UNC, due to the scarcity/expense of parking spaces on or near the UNC campus). Only HBU trips and peak-period HBO trips may employ the Park & Ride access mode to express bus service, and only HBU trips may employ the Kiss & Ride access mode to express bus service.

Any observed trip record with a bus type/access mode combination that the university student mode choice model does not represent was adjusted (i.e., transferred) to match one of the combinations that are represented, while maintaining the same time-of-day categorization.

Table 9-174 University student mode choice model transit access mode adjustments

Access Mode	Allowed Trip Purposes/Times of Day	Adjustments	Notes ["Observed" refers to number of observed records for the corresponding access mode/trip purpose/time of day]
Auto-Intercept	HBU	UBNH peak or off-peak changed to HBU peak or off-peak trips, respectively	1) Auto-intercept trips are only to designated UNC TAZs 2) U_HBO and NHNU: observed = 0
Local - Walk	All	None	None
Local - Park & Ride	HBU, U_HBO, UBNH	NHNU trips changed to UBNH peak-period trips (NHNU trips were not divided into peak and off-peak)	HBU peak-period trips by on-campus students: observed = 0
Local - Kiss & Ride	HBU-PK/OP UBNH-OP	1) UBNH peak-period trips changed to HBU peak-period trips 2) U_HBO peak-period Kiss & Ride trips changed to Park & Ride	1) 1U_HBO off-peak: observed = 0 2) 2NHNU: observed = 0
Express - Walk	HBU-PK/OP U_HBO-PK UBNH-PK/OP	U_HBO off-peak trips changed to peak-period	NHNU: observed = 0
Express - Park & Ride	HBU-PK/OP U_HBO-PK	1) UBNH peak-period trips changed to HBU peak-period trips 2) UBNH off-peak trips changed to HBU off-peak trips 3) U_HBO off-peak trips changed to U_HBO peak-period trips	NHNU: observed = 0
Express - Kiss & Ride	HBU	UBNH peak-period trips changed to HBU peak-period trips	HBU off-peak, U_HBO, UBNH off-peak, NHNU: observed = 0

Target Development - Step-by-Step Approach

The university student mode-choice calibration target development approach was similar to the one used for the general population. The primary difference is that automobile percent mode shares by vehicle occupancy were derived from the 2001 NCSU Student Survey, rather than the 2006 Household Travel Survey.

The general target-development procedure was as follows for each inter-TAZ trip purpose/time of day/student residence status combination (all trips are inter-TAZ, as only inter-TAZ trips are assigned in the TRM):

1) From the results of the 2001 NCSU Student Survey (expanded to match 2010 numbers of students), calculate
    - 2010 total automobile person trips in vehicle with one person, two people, or three or more people
    - 2010 percent mode shares of overall automobile person trips for vehicles with one person, two people, or three or more people

2) From 2006 TOB survey (expanded to 2013 ridership), calculate
    - 2013 total transit trips by combination of transit mode (local vs. express bus) and access mode

3) From university student non-motorized trip split model output, obtain
   - 2013 total motorized person trips

4) Calculate total automobile person trips and automobile person trips by vehicle occupancy:
   Adjusted 2013 total automobile person trips
   = Total 2013 modeled motorized person trips – 2013 total transit trips (2006 TOB survey)

   Adjusted 2013 person trips in automobiles with one person, two people, or three or more people
   = Adjusted 2013 total automobile person trips
   * respective 2010 percent mode share for 1-person, 2-person, or 3+-person automobiles

5) Apply allowed combinations of transit access mode, trip purpose, and time of day (Table 9-174)

6) Combine automobile and public transit components in the necessary format and layout for the mode choice ASC self-calibration module and save the target file in .csv format

9.2.5.2.2 Mode Choice Targets

Table 9-175 shows mode choice calibration targets by trip purpose (HBU, HBO, UBNH, or NHNU), time of day (peak or off-peak), and student residence status (on- or off-campus). Non-motorized trips are not included in this submodel and trips by rail transit are excluded from this list of targets because public-transit rail service did not exist in 2013. Although it is not shown in Table 9-175, non-motorized trips and rail-transit trips are assigned calibration targets of zero in the actual file. There were low numbers of observed trips for some of the modeled public transit modes, which made calibration difficult.

Table 9-175 2013 university student model mode choice calibration targets

Trip Purpose Time of Day Res. Status	Auto 1-P	Auto 2-P	Auto 3+-P	Transit Auto Int.	Transit Local Walk	Transit Local P&R	Transit Local K&R	Transit Local Total	Transit Express Walk	Transit Express P&R	Transit Express K&R	Transit Express Total	Total Motorized Person Trips
HBU_PK													
On-campus	3,242	1,623	1,623	13	1,783	0	3	1,786	179	0	0	179	8,465
Off-campus	32,482	3,336	893	669	7,331	2,799	87	10,216	794	756	149	1,699	49,295
All	**35,724**	**4,958**	**2,515**	**682**	**9,114**	**2,799**	**90**	**12,002**	**974**	**756**	**149**	**1,878**	**57,760**
HBU_OP													
On-campus	3,353	1,148	574	5	4,161	36	0	4,198	3	10		13	9,292
Off-campus	21,447	2,710	253	232	7,564	2,306	78	9,948	207	260		467	35,058
All	**24,801**	**3,858**	**827**	**237**	**11,726**	**2,342**	**78**	**14,146**	**210**	**270**		**480**	**44,350**
HBO_PK													
On-campus	3,495	2,110	527		159	26		185	2	0		2	6,319
Off-campus	30,494	6,872	1,528		602	110		712	156	123		279	39,885
All	**33,989**	**8,982**	**2,055**		**761**	**136**		**897**	**158**	**123**		**281**	**46,204**
HBO_OP													
On-campus	3,931	3,796	2,305		238	19		257					10,289
Off-campus	27,608	8,237	1,835		667	226		892					38,571
All	**31,539**	**12,033**	**4,139**		**905**	**244**		**1,150**					**48,861**

UBNH_PK													
On-campus	1,078	502	430		899	4		902	38			38	2,950
Off-campus	8,040	1,016	444		2,950	431		3,382	94			94	12,975
All	**9,118**	**1,517**	**874**		**3,849**	**435**		**4,284**	**132**			**132**	**15,926**
UBNH_OP													
On-campus	71	127	92		1,820	14	0	1,834	15			15	2,139
Off-campus	11,919	2,882	719		5,015	289	107	5,411	68			68	20,999
All	**11,990**	**3,010**	**811**		**6,835**	**303**	**107**	**7,245**	**83**			**83**	**23,139**
NHNU_Daily													
On-campus	1,908	1,295	1,227		58			58					4,487
Off-campus	17,661	7,242	1,486		289			289					26,677
All	**19,569**	**8,537**	**2,712**		**346**			**346**					**31,165**

Notes:

1) All trips are inter-TAZ person trips.
2) The values in this table may be slightly different from those in Table 9-173, due to rounding and/or necessary manual adjustments.
3) Total motorized person trips exclude school bus trips.
4) A null cell means that the indicated mode is not modeled for the corresponding trip purpose/time of day/residence status combination.
5) **Red numbers**: observed trips ≤ 10.

9.2.5.3 University Student Model Mode Choice Alternative Specific Constant Calibration

This subsection documents the final calibration of ASCs for the university student motorized mode choice model.

Table 9-176 summarizes the ASCs used in the TRMv6 motorized mode choice model for each trip purpose/time of day combination. It is assumed that mode choice behavior differs by student residence status (on- versus off-campus) for each trip purpose/time of day combination, meaning that each student residence status has its own set of ASCs, which does not include KExp (controls the percent of all transit trips that are made using express routes), wherein one ASC is used for students with either residence status. Whether a set of ASCs for a mode (or sub-mode) needed to be calibrated or not was decided on the basis of whether the mode (or sub-mode) is modeled (i.e., allowed) by the TRMv6 university student mode choice model (Table 9-174).

Table 9-176 University student model required ASCs by trip purpose/time of day combination

ASC (n)	Description	Purpose - Time of Day: Modeled ASC Used Calibration Needed	Purpose - Time of Day: Not Modeled ASC Not Used No Calibration Needed
KTrn (n)	% transit of all motorized person trips for each residence status (n)	All	None
KSr (n)	% shared-vehicle (2+ people per vehicle) person trips of all automobile person trips for each residence status (n)	All	None
K3P (n)	% with 3+ people per vehicle of all shared-vehicle (2+ people per vehicle) person trips for each residence status (n)	All	None
KAtr (n)	% auto-intercept trips of all transit person trips for each residence status (n)	HBU-Peak/Off-Peak	U_HBO-Peak/Off-Peak UBNH-Peak/Off-Peak NHNU-Daily

KDrv (n)	% drive access to transit of all transit person trips for each residence status (n)	HBU-Peak/Off-Peak U_HBO-Peak/Off-Peak UBNH-Peak/Off-Peak	NHNU-Daily
KPnR (n)	% park-and-ride access to transit of all drive-access-to-transit person trips for each residence status (n)	HBU-Peak/Off-Peak U_HBO-Peak UBNH-Peak/Off-Peak	U_HBO-Off-Peak NHNU-Daily
KExp (n)	% transit trips using express bus route of total transit person trips for all residence statuses (n)	HBU-Peak/Off-Peak U_HBO-Peak UBNH-Peak/Off-Peak	U_HBO-Off-Peak NHNU-Daily

Note: (n) indicates residence status: n=1 means on-campus; n=2 means off-campus

The mode choice model is a nested logit model. The TRMSB calibrated the major mode nests first, then calibrated the lower-nested mode categories. For example, calibration to match percent-transit targets was done before calibration to match targets for the percent of transit person trips that consist of using park-and-ride access to a local bus route.

9.2.5.3.1 ASC Calibration Results

Table 9-177 through Table 9-180 summarize the TRMv6 2013 university student mode choice model ASC calibration results for the HBU, HBO, UBNH, and NHNU trip purposes, respectively. Inter-TAZ motorized person trip targets, observed percent mode shares, calibrated ASCs, and resulting estimated percent mode shares are presented.

Although the targets inputted to the calibration module were numbers of trips by mode, what the module actually compared were modeled (after each iteration) and observed/target percent mode shares.

Calibration convergence criteria were not the same for every mode, with the differences depending mostly on relative trip volumes by each mode. A large person-trip target is the result of possessing a large number of data points for which use of the mode in question was observed, which increases the likelihood that the target is a close representation of reality. Therefore, it was decided that modes with larger person-trip targets would be held to tighter calibration convergence criteria (e.g., percent mode share differs from observed by less than 0.1%). For those modes with extremely low person-trip targets, it is very challenging to calibrate. However, for such modes as those, even a 100% difference between modeled values and target values would have negligible impact on the rest of the model (e.g., a convergence criterion of getting the modeled mode share within 10% of the target value could be deemed acceptable). Being 1% off from a target of 12,000 trips (public transit mode) is equal to a difference of 120 trips, whereas being 50% off from a target of 13 trips (auto-intercept mode) is equal to a difference of only seven trips.

Table 9-177 University student model mode choice ASCs: HBU

	Peak Period				Off-Peak Period			
KTrn: Transit Constant								
Student Residence Status	**Transit Person Trip Target**	**% Transit Target**	**% Estimated**	**ASC** (KTrn)	**Transit Person Trip Target**	**% Transit Target**	**% Estimated**	**ASC** (KTrn)
KTRN(1)	1,965	23.21%	23.21%	-1.67824	4,211	45.32%	45.32%	-0.72504
KTRN(2)	11,915	24.17%	24.17%	-1.28061	10,415	29.71%	29.71%	-0.74896
KSr: Auto Shared-Ride Constant								
Student Residence Status	**Share-Drive Person Trip Target**	**% Share-Drive Target**	**% Estimated**	**ASC** (KSr)	**Share-Drive Person Trip Target**	**% Share-Drive Target**	**% Estimated**	**ASC** (KSr)

KSR(1)	3,242	49.93%	49.93%	-0.17711	1,722	33.90%	33.90%	-0.44999
KSR(2)	4,229	11.31%	11.31%	-1.07883	2,964	12.02%	12.02%	-1.01226

K3P: 3+-Person Auto Constant

Student Residence Status	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)
K3P(1)	1,621	50.00%	50.00%	-0.00597	574	33.33%	33.33%	-0.20949
K3P(2)	893	21.12%	21.12%	-0.33034	253	8.54%	8.54%	-0.59550

KAtr: Auto-Intercept Constant

Student Residence Status	Auto-Intercept Person Trip Target	% Auto-Intercept Target	% Estimated	ASC (KAtr)	Auto-Intercept Person Trip Target	% Auto-Intercept Target	% Estimated	ASC (KAtr)
KATR(1)	13	0.20%	0.20%	-2.34839	5	0.10%	0.10%	-2.83190
KATR(2)	669	1.79%	1.79%	-2.01692	232	0.94%	0.94%	-2.33632

KDrv: Transit Drive-Access Constant

Student Residence Status	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)
KDRV(1)	3	0.15%	0.15%	-2.07256	47	1.09%	1.09%	-3.65785
KDRV(2)	3,790	31.81%	31.81%	-2.00686	2,644	25.39%	25.39%	-2.67859

KPnR: Transit Park-and-Ride Constant

Student Residence Status	Transit Park-&-Ride Person Trip Target	% Park-&-Ride Target	% Estimated	ASC (KPnR)	Transit Park-&-Ride Person Trip Target	% Park-&-Ride Target	% Estimated	ASC (KPnR)
KPNR(1)	0	0.00%	0.10%	-3.00000	47	100.00%	99.75%	3.00000
KPNR(2)	3,555	93.77%	93.77%	1.47180	2,566	97.05%	97.05%	1.86797

KExp: Express Bus Constant

Student Residence Status	Transit Express Bus Person Trip Target	% Express Bus Target	% Estimated	ASC (KExp)	Transit Express Bus Person Trip Target	% Express Bus Target	% Estimated	ASC (KExp)
KEXP	1,878	13.53%	13.53%	0.46125	480	3.28%	3.28%	0.49980

Notes:

1) **Orange**: target < 30 trips
2) KTrn (Transit): % of total motorized person trips
3) KSr (Automobile - shared ride (≥ 2 persons)): % of total automobile person trips
4) K3P (Automobile - 3+-person): % of total automobile shared-ride person trips
5) KAtr (Auto-intercept): % of total automobile shared-ride person trips
6) KDrv (Drive access): % of total transit trips
7) KPnR (Park & Ride): % of total drive-access transit trips
8) KExp (Express bus): % of total transit trips
9) Any travel (sub-)mode/trip purpose/time of day combination for which an ASC is not presented in the table is prohibited from being modeled
10) Residence status: 1 = on-campus students and 2 = off-campus students

Table 9-178 University student model mode choice ASCs: HBO

	Peak Period				Off-Peak Period			
KTrn: Transit Constant								
Student Residence Status	Transit Person Trip Target	% Transit Target	% Estimated	ASC (KTrn)	Transit Person Trip Target	% Transit Target	% Estimated	ASC (KTrn)
KTRN(1)	187	2.96%	2.96%	3.33700	257	2.50%	2.50%	-3.16650

KTRN(2)	991	2.48%	2.48%	2.84623	892	2.32%	2.31%	-2.89959

KSr: Auto Shared-Ride Constant

Student Residence Status	Share-Drive Person Trip Target	% Share-Drive Target	% Estimated	ASC (KSr)	Share-Drive Person Trip Target	% Share-Drive Target	% Estimated	ASC (KSr)
KSR(1)	2,637	43.00%	43.00%	0.19768	6,101	60.82%	60.82%	0.10035
KSR(2)	4,199	21.60%	21.60%	0.69388	10,071	26.73%	26.73%	-0.54989

K3P: 3+-Person Auto Constant

Student Residence Status	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)
K3P(1)	527	19.98%	19.98%	0.35116	2,305	37.78%	37.78%	-0.12626
K3P(2)	1,527	18.19%	18.19%	0.37951	1,835	18.22%	18.22%	-0.38293

KDrv: Transit Drive-Access Constant

Student Residence Status	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)
KDRV(1)	26	13.90%	13.90%	2.46366	19	7.39%	7.39%	-0.82093
KDRV(2)	233	23.51%	23.51%	3.20100	226	25.31%	25.31%	-0.92117

KPnR: Transit Park-and-Ride Constant

Student Residence Status	Transit Park-&-Ride Person Trip Target	% Park-&-Ride Target	% Estimated	ASC (KPnR)
KPNR(1)	26	100.00%	99.53%	2.30000
KPNR(2)	233	100.00%	99.79%	2.52500

KExp: Express Bus Constant

Student Residence Status	Transit Express Bus Person Trip Target	% Express Bus Target	% Estimated	ASC (KExp)
KEXP	281	23.85%	23.86%	0.73346

Notes: See Table 9-177

Table 9-179 University student model mode choice ASCs: UBNH

	Peak Period				Off-Peak Period			
KTrn: Transit Constant								
Student Residence Status	Transit Person Trip Target	% Transit Target	% Estimated	ASC (KTrn)	Transit Person Trip Target	% Transit Target	% Estimated	ASC (KTrn)
KTRN(1)	940	4.18%	31.89%	-0.78069	1,849	86.44%	85.46%	15.00000
KTRN(2)	155	0.70%	26.78%	-0.30777	5,480	26.09%	26.09%	-0.63248
KSr: Auto Shared-Ride Constant								
Student Residence Status	Share-Drive Person Trip Target	% Share-Drive Target	% Estimated	ASC (KSr)	Share-Drive Person Trip Target	% Share-Drive Target	% Estimated	ASC (KSr)
KSR(1)	932	46.37%	46.37%	-0.27949	219	75.52%	94.50%	-20.00000
KSR(2)	1,459	15.37%	15.37%	-0.94367	3,601	23.20%	23.20%	-0.65347
K3P: 3+-Person Auto Constant								

Student Residence Status	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)	Auto - 3+-P Person Trip Target	% Auto - 3+-P Target	% Estimated	ASC (K3P)
K3P(1)	430	46.14%	46.14%	-0.12646	92	42.01%	90.00%	-15.00000
K3P(2)	444	30.41%	30.41%	-0.20747	719	19.97%	19.97%	-0.34866

KDrv: Transit Drive-Access Constant

Student Residence Status	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)	Transit Drive-Access Person Trip Target	% Drive-Access Target	% Estimated	ASC (KDrv)
KDRV(1)	4	0.43%	0.43%	-2.96906	14	0.76%	0.72%	-13.93456
KDRV(2)	431	12.40%	12.40%	-2.39678	396	7.23%	7.23%	-1.30091

KPnR: Transit Park-and-Ride Constant

Student Residence Status	Transit Park-&-Ride Person Trip Target	% Park&Ride Target	% Estimated	ASC (KPnR)	Transit Park-&-Ride Person Trip Target	% Park-&-Ride Target	% Estimated	ASC (KPnR)
KPNR(1)	4	100.00%	98.27%	2.00000	14	100.00%	99.28%	5.00000
KPNR(2)	431	100.00%	99.45%	2.36000	289	72.98%	72.98%	1.04981

KExp: Express Bus Constant

Student Residence Status	Transit Express Bus Person Trip Target	% Express Bus Target	% Estimated	ASC (KExp)	Transit Exp Bus Person Trip Target	% Express Bus Target	% Estimated	ASC (KExp)
KEXP	132	2.99%	2.99%	-0.23784	83	1.13%	1.13%	0.63223

Notes: See Table 9-177

Table 9-180 University student model mode choice ASCs: NHNU

		Daily		
KTrn: Transit Constant				
Student Residence Status	**Transit Person Trip Target**	**% Transit Target**	**% Estimated**	**ASC** (KTrn)
KTRN(1)	58	1.29%	1.29%	-3.63989
KTRN(2)	289	1.08%	1.08%	-4.29332
KSr: Auto Shared-Ride Constant				
Student Residence Status	**Share-Drive Person Trip Target**	**% Share-Drive Target**	**% Estimated**	**ASC** (KSr)
KSR(1)	2,522	56.93%	56.93%	-0.11568
KSR(2)	8,728	33.07%	33.07%	-0.38459
K3P: 3+-Person Auto Constant				
Student Residence Status	**Auto - 3+-P Person Trip Target**	**% Auto - 3+-P Target**	**% Estimated**	**ASC** (K3P)
K3P(1)	1,227	48.65%	48.65%	-0.16487
K3P(2)	1,486	17.03%	17.03%	-0.41048

Notes: See Table 9-177

9.2.5.3.2 Future-Year University Student Model Rail-Transit-Related ASCs

For future-year models, additional rail-transit-related ASCs by trip purpose/time of day combination are asserted (Table 9-181).

Table 9-181 University student mode choice model future-year rail-transit-related ASCs

	HBU Peak & Off-Peak	UHBO Peak & Off-Peak	UBNH Peak & Off-Peak	NHNU _Daily
KRal: Rail Constant				
KRal(1)	0.15	0.06	0.12	0.12
KRal(2)	0.15	0.06	0.12	0.12
KRalW: Rail Walk-Access Constant				
KRalW	0.75	0.75	0.75	0.75
CRIVTW: Coefficient for Rail In-Vehicle-Time Weight (Discount)				
CRIVTW	0.85	0.85	0.85	0.85

Notes:

1) KRal (Rail constant): Percent rail trips of total transit trips (among local and express buses and rail)
2) KRailW (Rail walk-access constant): Percent walk access of all rail-transit trips (vs. drive access, which includes Park & Ride and Kiss & Ride)
3) CRIVTW (In-vehicle travel time weight discount): Accounts for passenger perception that in-vehicle time on rail transit is less onerous than on a bus
4) Residence status: 1 = on-campus students and 2 = off-campus students

9.3 Land Use Model

Do we need anything here about the investigations? Or not?

9.4 External Travel Models

Put the work to integrate the CV and external auto models with the NCSTM here

9.5 Links to MOVES Air Quality Models

Put the work to develop a MOVES post processor here

9.6 Sub-Area and Corridor Analysis Procedures

Placeholder for work yet to be done

10 Trip Assignment, Calibration and Validation

10.1 Introduction

10.2 PA to OD and Time of Day

Remember to include addition of mid-day time of day

10.3 Highway Assignment

10.3.1 Feedback Loop

10.3.2 Highway Calibration

10.3.2.1 Types of Adjustments and Corrections Made

10.3.2.2 Model Performance Compared to Targets

10.4 Transit Assignment

10.4.1 Transit Calibration

10.5 Model Chain Calibration

10.6 Sensitivity Testing Analysis

10.6.1 Introduction

10.6.2 Growth Trends

10.6.3 High Density Land Use Test

10.6.4 Highway Lane/Capacity Reduction Test

10.6.5 Transit Headway Tests

10.6.6 High Speed Rail Test

10.6.7 High Parking Cost Test

10.6.8 Non-Motorized Path Length/Density Test

10.6.9 Average Block Size Test