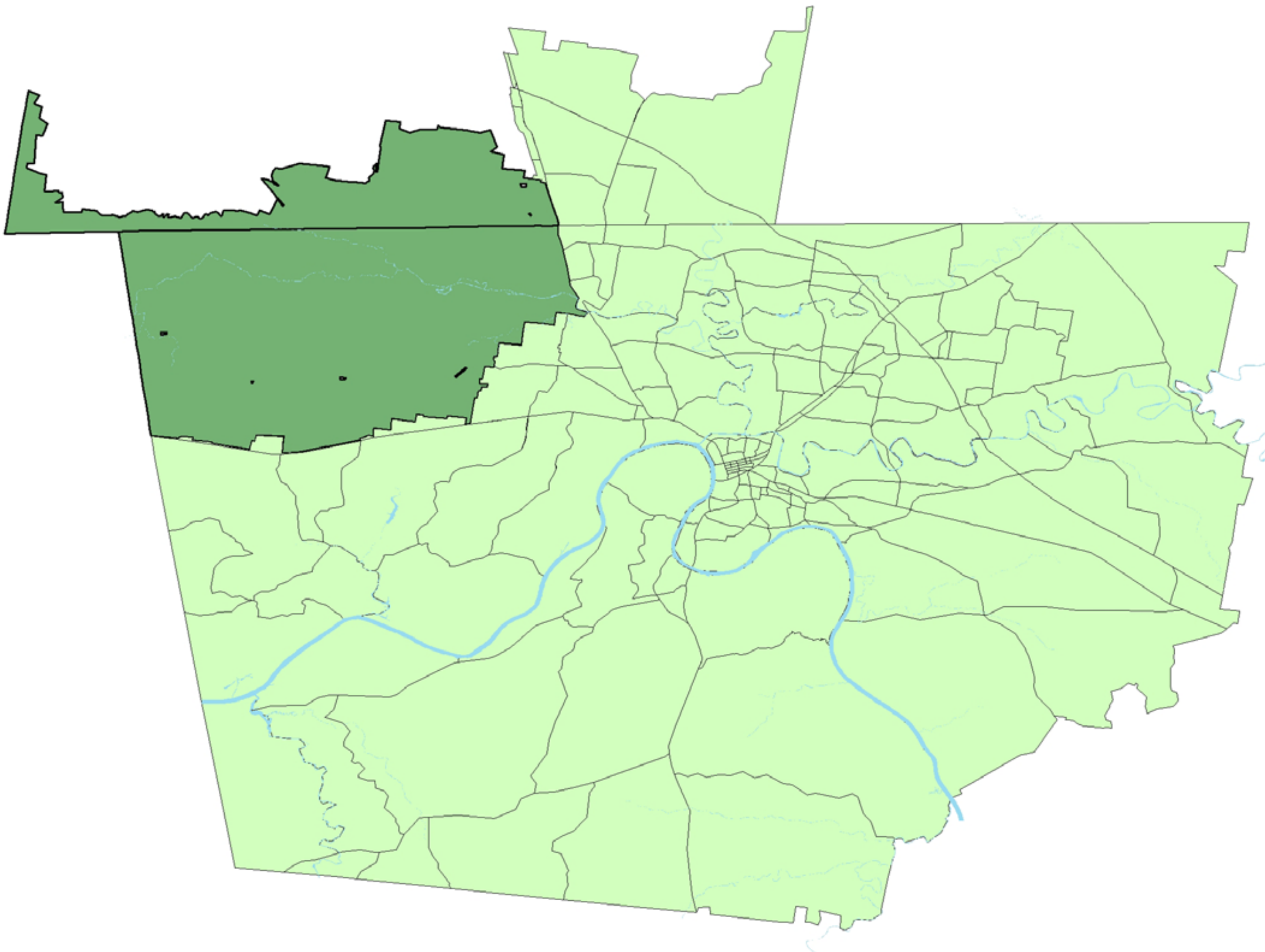
Clarksville/Montgomery County

Travel Demand Model



Model Development Report

July 2009

Clarksville / Montgomery County
Travel Demand Model
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Alliance Transportation Group, Inc.

and

RPM Transportation Consultants, LLC

This report documents the development and calibration of a small urban travel demand model for the City of Clarksville and surrounding Montgomery County.

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Introduction

This report documents the methodology used and the steps taken in development of the City of Clarksville / Montgomery County Travel Demand Model, which is referred to herein as the Clarksville Travel Demand Model or Clarksville model. The study area for this model includes entire Montgomery County, Tennessee including the City of Clarksville, Tennessee, and a small portion of Christian County, Kentucky. The model base year is 2008 and the model horizon years include 2016, 2025, and 2035.

The report describes the input data such as travel network geography and attributes, demographic estimates and forecasts, and characteristics of travel behavior for the study area that were obtained or developed and approved by Clarksville Area Metropolitan Planning Organization (MPO) for use in the model. This report also describes the statistical analysis of the input data used in model application as well as statistical analysis of the resulting output of each model component.

This statistical analysis includes a description of the methodology used at each step of model estimation, calibration and validation. A complete set of calibration and validation data is provided for each model component. At each step in the process, care was taken to insure that the Clarksville Travel Demand Model maintained a high level of predictive value. To this end, the Clarksville model contains no arbitrary K-factors or other isolated adjustment factors. All changes and adjustments to model parameters were performed in a comprehensive and systemic manner and were applied uniformly and consistently across the entire model.

The resulting model provides a realistic and reliable predictor of magnitude and pattern of future travel in and around the City of Clarksville and Montgomery County and should serve as a useful and informative tool for performing travel forecasts and analysis of proposed transportation projects.

At each stage of model development, the data being applied were presented to Clarksville Area MPO, the State, and to local stakeholders, including county and city professional planning and engineering professionals, for review and refinement. This stakeholder input process was particularly helpful in developing the traffic analysis zone geography and demographic forecasts.

Highway Network And Traffic Analysis Zones

The two basic building blocks of a travel demand model are the transportation system networks and the traffic analysis zones (TAZs). The networks represent the transportation system, including different categories of roads (such as freeways, arterials, collectors, ramps, etc.). The TAZs are geographical areas that link land uses with the transportation system. The data describing socioeconomic and demographic characteristics of the TAZs are tied to the transportation system using zonal centroids and their associated centroid connectors. The network and zonal densities (granularity) of these two elements should be relatively consistent in order to produce realistic loading of traffic onto the transportation system.

Highway Network

The Clarksville Travel Demand Model Highway Network geographic layer contains roadway links and attributes for 2008. It is expected that the networks for the Clarksville Travel Demand Model will be continuously modified to add detail for specific projects and analysis needs. To make the editing of the networks as easy as possible, the model uses the state-of-the-practice technique of having a master line layer from which networks for various years and modes can be extracted. The companion document *Clarksville / Montgomery County Travel Demand Model Users Manual* (Users Manual) provides detail on how to work with multi-year networks.

Base Year Highway Network Creation

The GIS map data provided by Clarksville Area MPO, supplemented by Census 2000 TIGER line files were used to create a 2008 base year network of roadway links depicting the attributes of the transportation system. This road network was further refined with the TAZ structure development in an iterative process that also incorporated Census 2000 information and aerial photography.

The Consultant Team obtained information on roadway improvement projects from Clarksville Area MPO. The projects that have been completed prior to year 2008 are incorporated in the base year network.

Functional Classification

The functional class of roadways is an attribute that defines roadways in terms of their operational and performance characteristics. This attribute allows roadways to be combined into analysis groups or facility types based upon the similarities of their characteristics.

The GIS map data provided by Clarksville Area MPO contains functional classification information for the road network. As shown in Table 1, the Consultant Team coded FHWA functional classes onto the roadway network based on the functional and location information of links from the original GIS data. This process also included coding related attributes such as numbers of lanes; presence of left turn lanes at major intersections; and posted speed information as determined from aerial photography.

TABLE 1: FUNCTIONAL CLASSIFICATION

FHWA Functional Classification		**Description**	**Functional Class Number for Model**	**Original Functional Classification**
Rural	01	Interstate	1	Freeway/Rural
	02	Other Principal Arterial	2	Principal Art/Rural
	06	Minor Arterial	6	Minor Art/Rural
	07	Major Collector	7	Collector/Rural
	08	Minor Collector	8	
	09	Local	9	
Urban	11	Interstate	11	
	12	Freeway/Expressway	12	
	14	Other Principal Arterial	14	Principal Art & Expressway/Urban&CBD
	16	Minor Arterial	16	Minor Art/Urban&CBD
	17	Collector	17	Collector/Urban&CBD
	19	Local	19	
	NA	Ramp	20	Fwy to Net Ramp
	NA	Centroid Connector	0	Centroid Conn

Capacity

Link capacity was calculated based on the methodology provided by the Highway Performance Monitoring System Field Manual, which conforms to the Highway Capacity Manual 2000 (HCM 2000). The methodology was based on service flow rates for level of service E for the peak direction, see details in the Appendix to this report.

Network Attributes

Network attributes define how the transportation system interacts with its various components given a specific demand, and are used during the execution of the travel demand model. The required network attributes for each year are presented in Table 2.

TABLE 2: REQUIRED NETWORK ATTRIBUTES

Field	Layer	Description
FUNCCLASS_ID	Network	Functional class ID
AvgADT	Network	AADT based on group summation of links with like names
LaneConfig	Network	Contains a code used to determine the lane group configuration (L1LS0T3RS1R1). Code is # dedicated left, # shared left, # through, # shared right, # dedicated right
LanesAB	Network	Directional # of lanes
LanesBA	Network	Directional # of lanes
PostedSpeed	Network	Posted speed limit of road
Div	Network	Flag denoting divided or undivided road 1 = divided, 0 = undivided
Shoulder	Network	Flag denoting shoulders 1 = shoulder, 0 = no shoulder
ShoulderWidth	Network	Width in feet of the shoulder
Type	Node	Flag denoting signalized or stop sign intersection 1 = signalized, 2 = stop sign
Terrain	Network	Flag denoting the topology of land
Parking	Network	Parking value to use for number of parking movements
Alpha*	Network	BPR function parameter
Beta*	Network	BPR function parameter
AB_Speed*	Network	Directional speed
BA_Speed*	Network	Directional speed
AB_Time*	Network	Directional Time
BA_Time*	Network	Directional Time
AB_CAPACITY*	Network	Directional capacity
BA_CAPACITY*	Network	Directional capacity
AB_CapacityPeak*	Network	Directional peak capacity
BA_CapacityPeak*	Network	Directional peak capacity
IntCap*	Network	Intersection capacity
IntCapPeak*	Network	Intersection peak capacity
IntTime*	Network	Intersection time
AB_ASSNCAP*	Network	Capacity for traffic assignment

BA_ASSNCAP*	Network	Capacity for traffic assignment
AB_EVALCAP*	Network	Evaluation Capacity
BA_EVALCAP*	Network	Evaluation Capacity
*These fields will be populated by the network update macro		

Traffic Analysis Zones

The Clarksville MPO model area includes the entire Montgomery County and the contiguous urbanized portion of Oak Grove and Christian County, near the Stateline. The County and this portion of the MPO planning area were sub-divided into 175 TAZs, 10 of which are located Kentucky. Figure 1 depicts the TAZ structure of the Clarksville MPO model.

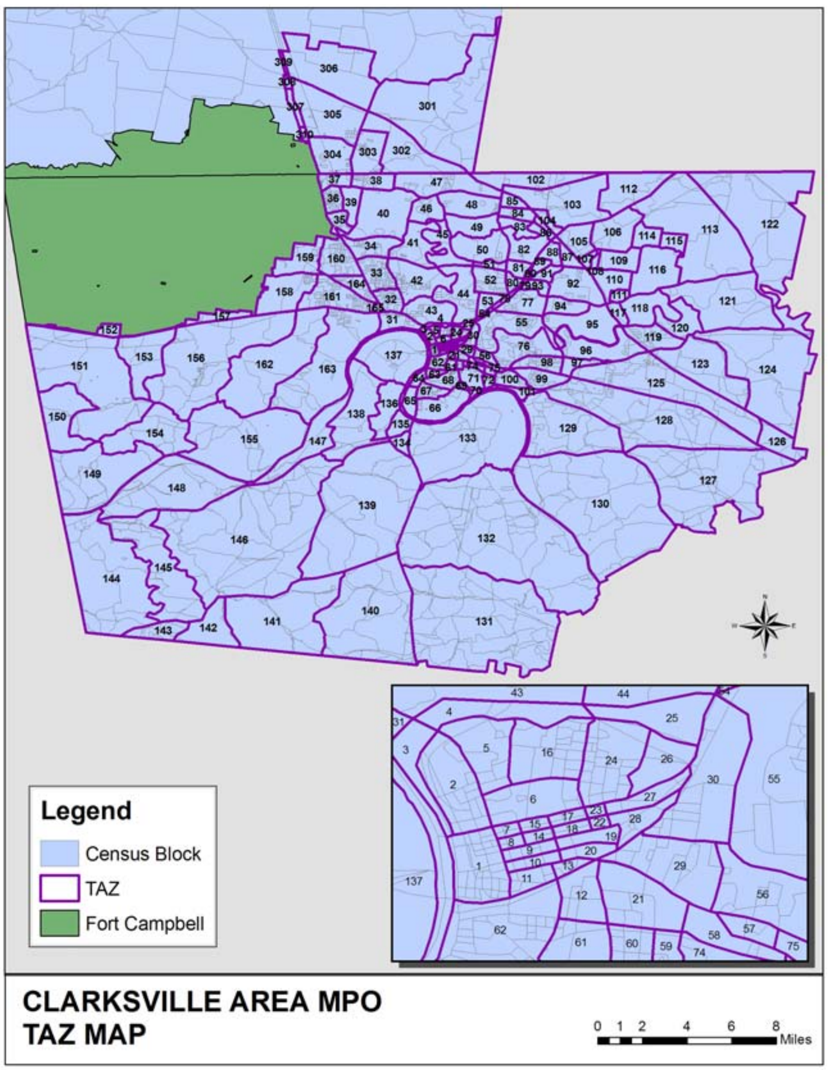

FIGURE 1: CLARKSVILLE MPO MODEL TAZ MAP

ATTRIBUTES

The TAZ attributes include socioeconomic and demographic data such as population, households, household size and employment, most of which are derived from external sources such as the US Census. Additional discussion of these items is contained within this report. These data items must be forecast for each scenario and analysis year to which the travel model is applied. Other attributes, such as Area Type are calculated from these data. The Area Types in the model were defined based on the density of population and employment by TAZ. The methodology is easily applied to any forecast year.

AREA TYPES

Area Types are used to provide an estimate of land use intensity, activity characteristics and other values that are not inherently provided in the definitions of the transportation system infrastructure. Area Types are used to help the model discriminate among facilities. The Area Type designation of a roadway can be combined with functional class to define capacity, speed and other operating characteristics of similarly defined roadways (e.g. a major arterial in a central business district vs. a major arterial in a suburban area.) Area Types are also sometimes used to help interpret other activities such as access to transit or the potential for a traveler to walk rather than drive to a destination. Once the boundaries of the Area Types have been defined the speed survey data along with other technical references can be used to help define capacity and speed lookup tables for the various roadways by functional class.

The process of defining Area Types for the model area was based on the activity densities of each zone. Activity density is a function of the amount of population and employment in the zone as well as the size of the zone. Table 3 presents the four Area Types used in the Clarksville Travel Demand Model.

TABLE 3: AREA TYPES

Area Types	Area Type Number
CBD	1
Urban	2
Suburban	3
Rural	4

These Area Types can generally be defined as follows:

1. **Central Business District (CBD)** refers to the principle urban activity center of the core community. The CBD designation is somewhat subjective since these areas are usually defined by local custom rather than based on a consistent set of criteria. However, in most cases the local definition is adequate to discriminate trip generation and traffic operation characteristics.
2. **Urban** refers to areas that are urban in character, but are less dense and have more balance between commercial and residential uses.
3. **Suburban** refers to areas that are primarily residential in nature and there is typically clearly defined separation between residential and other uses.
4. **Rural** refers to areas that are characterized by agricultural uses or very large lot residential. Typically access to retail and service activities require trips to another Area Type.

The process of allocating these Area Types to the zones involves two steps:

Step 1. Perform a preliminary estimation of the boundaries of each type based on a set of qualitative criteria.

Step 2. Once this preliminary estimation has been completed, calculate activity densities for each TAZ. The following formula is used to calculate an activity density factor.

$$Density\ Factor = Population\ Density + \beta \cdot Employment\ Density$$

$$\beta = \frac{Total\ Study\ Area\ Population}{Total\ Study\ Area\ Employment}$$

$$Population\ Density = \frac{Total\ Population}{Acres}$$

$$Employment\ Density = \frac{Total\ Employment}{Acres}$$

Table 4 shows the density ranges used for the Clarksville model.

TABLE 4: AREA TYPE RANGES

Area Types	Area Type Number	Density Ranges
CBD	1	20.01-500
Urban	2	3.51-20
Suburban	3	.501-3.50
Rural	4	0-.50

DEMOGRAPHICS

POPULATION AND HOUSEHOLD DEMOGRAPHICS

Population and households at the Census block level were aggregated to the TAZ for population, households, and average household size based on 2000 US Census. Parcel level geo-coded residential building permit data for the years 2000-2008 were provided from the planning agencies of Clarksville-Montgomery County, Oak Grove, and Hopkinsville-Christian County. Permit data were assigned to the respective 2000 Census block and the average household size for that block was used to establish a 2008 base year population and household number which was then assigned to the TAZ. This process was control totaled to the 2008 population and household estimates from *Woods & Poole Economics, Inc*. Table 5 and Table 6 summarize some demographic statistics for Montgomery and Christian Counties, and for the Clarksville MPO model.

TABLE 5: POPULATION DATA - 2000 AND 2008

County	2000 Population Census	2008 Population Woods & Poole
Montgomery County	134,768	157,955
Christian County	72,265	81,475
Clarksville MPO Model	136,240	161,320

TABLE 6: HOUSEHOLD DATA - 2000 AND 2008

County	2000 Household Census	2008 Households*
Montgomery County	48,329	55,414
Christian County	25,004	28,413
Clarksville MPO Model	50,047	58,846

* Calculated using 2000 Census average household size

EMPLOYMENT

Employment data was obtained from the MPO which included geo-coded *InfoUSA* data by NACIS code as well as KY State Employment data. These datasets were compared and balanced to *Woods & Poole Economics, Inc*. 2008 employment estimates for Montgomery and Christian Counties. Employment data was aggregated to the TAZ for three employment categories: retail, service, and basic. Table 7 and Table 8 summarize the employment data.

TABLE 7: MODEL EMPLOYMENT CLASSIFICATIONS

Employment Classification	Includes	NACIS Codes
Retail Employment	Retail	44
Service Employment	Services (professional, technical, health, educational, recreational, etc.), FIRE, Government, Federal	52,53,54,55, 61,62,71,72,81,92
Basic Employment	Agricultural, forestry, fishing, mining, utilities, construction, manufacturing, wholesale, warehousing and transportation	11,21,22,23,31,42,4 8,51,56

TABLE 8: MODEL EMPLOYMENT BY CLASSIFICATION - 2008

Employment Classification	2008
Retail Employment	7,585
Service Employment	27,465
Basic Employment	15,164
Total Employment*	50,214

* Total excludes military jobs

SCHOOL ENROLLMENT

School enrollment figures were obtained from the Clarksville-Montgomery County School System and are shown in Table 9 (http://www.cmcss.net/documents/pdf/enrollment.pdf). Enrollment is for year 2008. School enrollment was not forecast because in the long term, school enrollment at existing school sites is likely to remain relatively constant over time due to physical infrastructure limitations. New school enrollment due to population growth is more likely to occur at new, currently unidentified school locations.

TABLE 9: MONTGOMERY COUNTY (TN) SCHOOL ENROLLMENT 2008

School Name	Enrollment
Barkers Mill Ele.	820
Barksdale Ele.	665
Burt Ele.	247
Byrns Darden Ele.	580
Clarksville Hi.	1391
Cumberland Heights Ele.	725
East Montgomery Ele.	793
Glenellen Ele.	881
Hazelwood Ele.	822
Kenwood Ele&Mid&Hi	2982
Liberty Ele.	825
Minglewood Ele & New Providence Mid	1852
Montgomery Central Ele&Mid&Hi	2142
Moore Magnet Ele.	562
Norman Smith Ele.	526
Northeast Ele&Mid&Hi	3519
Northwest Hi.	1316
Richview Mid.	1049
Ringgold Ele.	752
Rossview Mid&Hi	2613
Sango Ele.	1120
St. Bethlehem Ele.	696
West Creek Ele&Mid	1743
Woodlawn Ele.	713

MODEL DEVELOPMENT

TRIP GENERATION

Trip generation is the first step in the travel demand model process. The result of the trip generation model is a set of trip productions, and trip attractions for each TAZ. These productions and attractions are used to populate a seed matrix that is passed to the TransCAD trip distribution step to create trip tables for assignment.

The following trip purposes are included in trip generation:

- Home Based Work (HBW)
- Home Based Other (HBO)
- Non Home Based (NHB)
- Commercial Vehicle (CMVEH)
- Freight Vehicle (FRT)

HOUSEHOLD STRATIFICATION MODEL

The trip production models apply a cross-classification method to generate trips, which classify households by household size and vehicle availability. Consequently, it is necessary to develop household submodels, which estimate households by each independent social-economic variable for each transportation analysis zone. Household stratification curves were derived from Census Transportation PP Part 1 data. The data used in developing the vehicle availability submodel are from Public Use Microdata Survey (PUMS) household files. The models were estimated using STATA 10.

Table 10 presents the household stratification model estimation results which are depicted in Figure 2 thru Figure 5.

Household Stratification Model Specification:

$$Percent\ of\ HH\ (n) = \beta_0 + \beta_1 \cdot AverageHHSIZE + \beta_2 \cdot AverageHHSIZE^2$$

TABLE 10: HOUSEHOLD STRATIFICATION MODEL ESTIMATION RESULTS

Proportions	Model	β_0	t	β_1	t	β_2	t	R^2
HHSIZE=1	Quadratic	1.4948	11.96	-0.6997	-7.64	0.0871	5.21	0.69
HHSIZE=3	Quadratic	-0.2992	-2.96	0.3339	4.50	-0.0556	-4.11	0.22
HHSIZE=4	Linear	-0.3572	-14.82	0.2319	24.94			0.89

The proportion of 2-person household was calculated by one minus the sum of all the other proportions so as to ensure the whole proportions add up to 1. Table 11 shows a comparison of the predicted household stratification versus the CTPP.

TABLE 11: HOUSEHOLD STRATIFICATION- CTPP VS. PREDICTED (BASED ON CENSUS 2000)

	CTPP	Predicted
HH1	26.7%	28.5%
HH2	30.8%	29.0%
HH3	18.5%	18.1%
HH4+	24.0%	24.4%

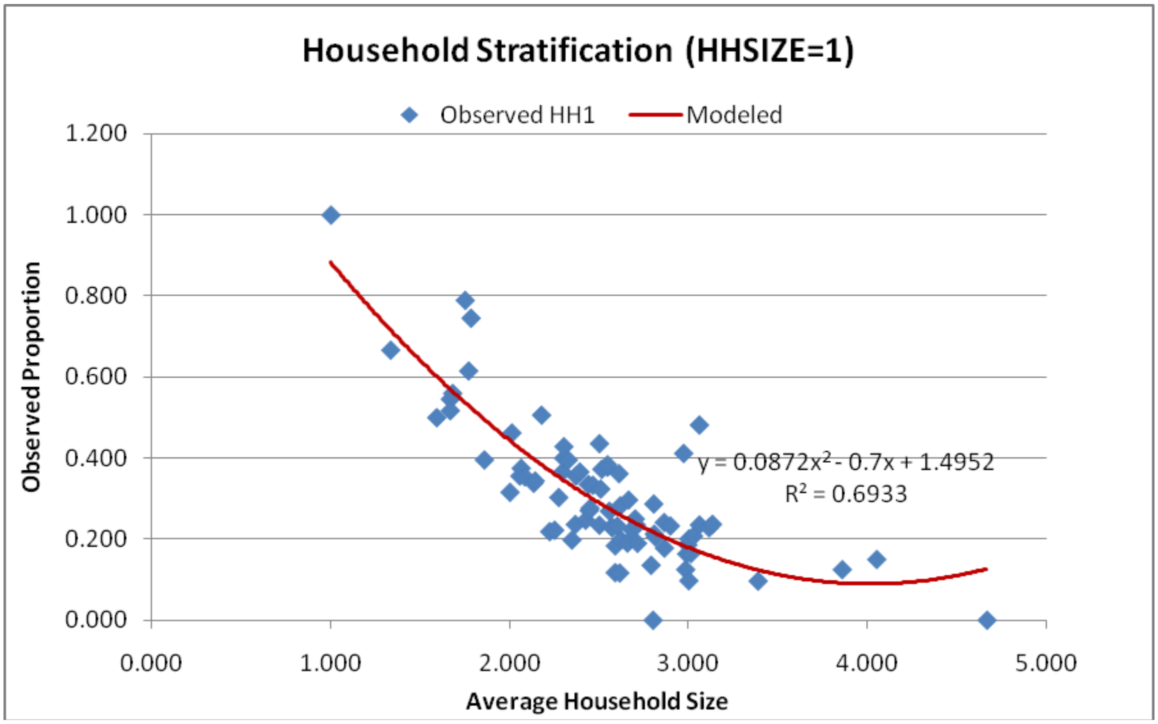

FIGURE 2: HOUSEHOLD STRATIFICATION (HHSIZE=1)

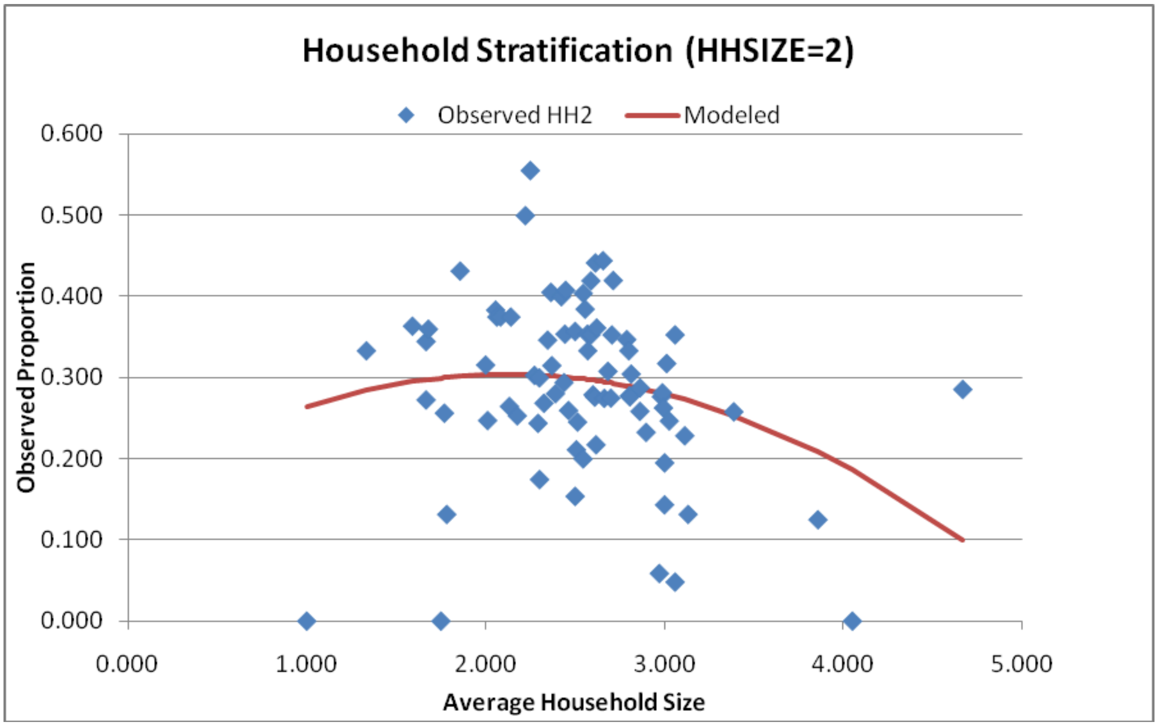

FIGURE 3: HOUSEHOLD STRATIFICATION (HHSIZE=2)

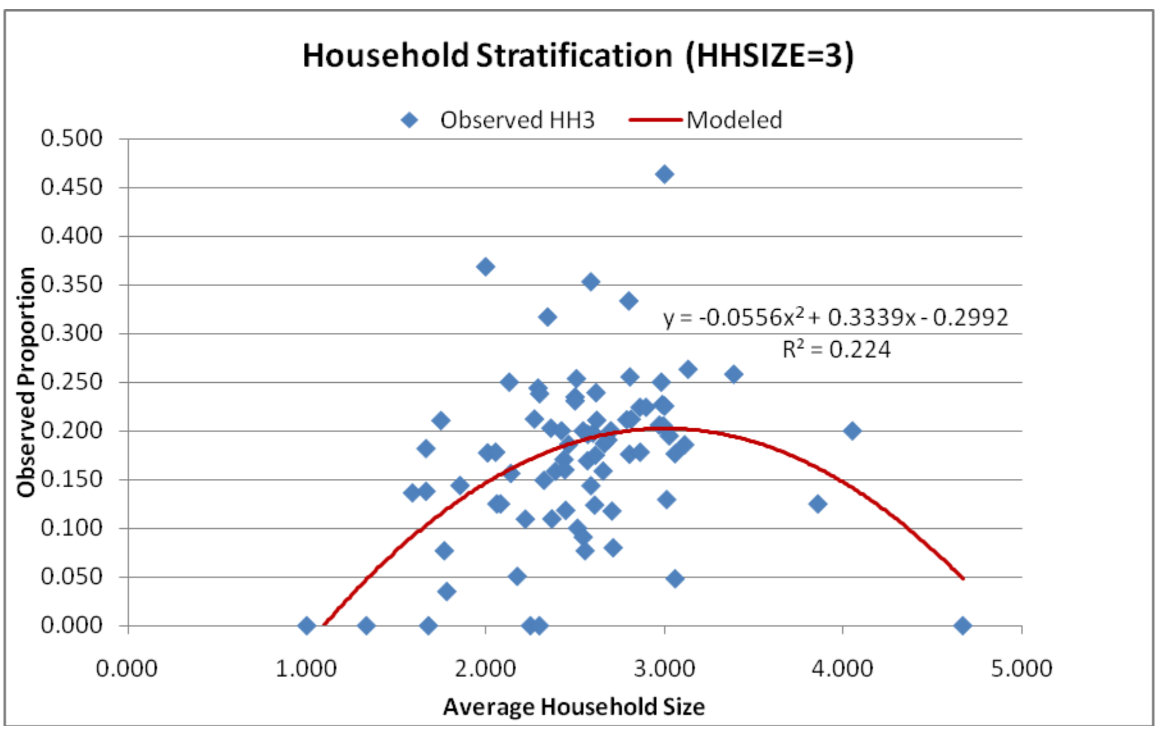

FIGURE 4: HOUSEHOLD STRATIFICATION (HHSIZE=3)

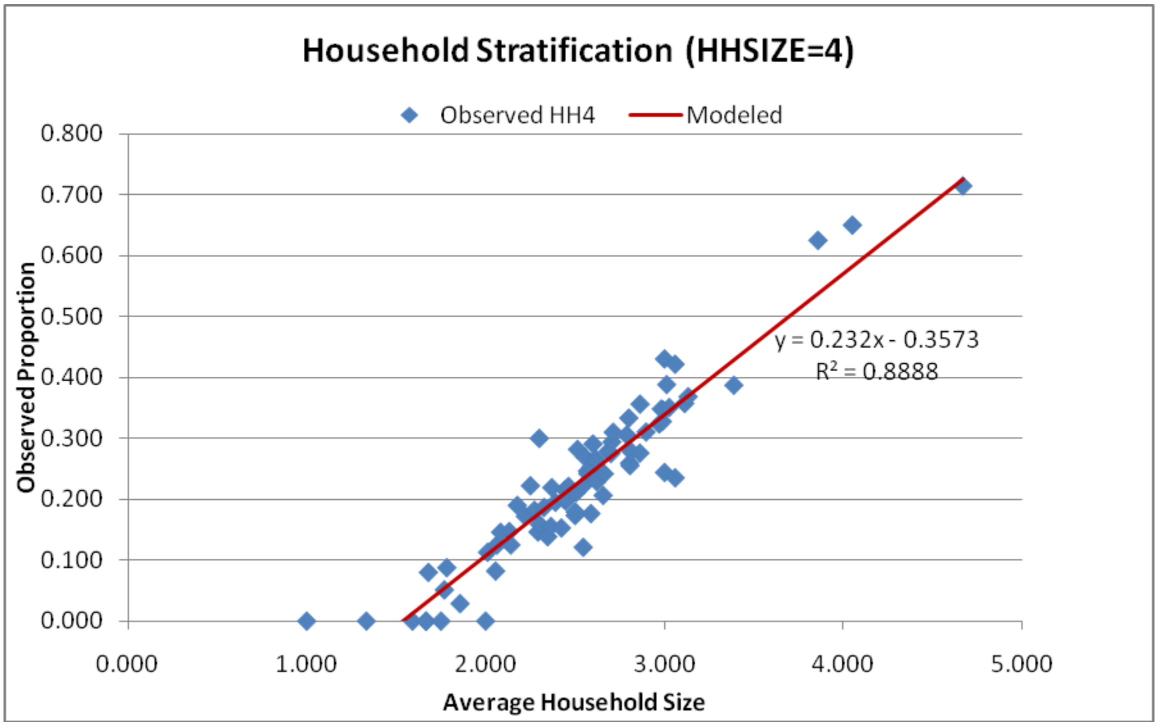

FIGURE 5: HOUSEHOLD STRATIFICATION (HHSIZE=4)

VEHICLE AVAILABILITY MODEL

Vehicle availability has a fundamental impact on household travel patterns. Therefore, this variable was chosen as the primary market segmentation parameter for the trip production model. The decision of having zero, one or more vehicles are often made in a sequential manner (0 or 1, 1 or 2, 2 or 3, etc.); therefore, there is an order inherent in those choices, which justify an ordered logit model against a multinomial logit (MNL) formulation. The model was estimated based on disaggregate data (individual household data) and was applied to the aggregate zonal level.

Vehicle Availability Model Specification:

$$z_i = \beta X_i + u$$

$$\Pr(veh_i = j) = \Pr(k_{j-1} < z_i < k_j)$$

$$= \frac{1}{1+\exp(-k_j + \beta X_i)} - \frac{1}{1+\exp(-k_{j-1} + \beta X_i)}$$

Where,

i = Observation index, each observation will be a TAZ

j Alternative index, $j = 0, 1, 2, 3, 4$ if there are 0, 1, 2, 3 or 4 or more workers in household

k	Thresholds to be estimated ($k_1,\ldots,k_4$), $k_0=-\infty$, $k_5=+\infty$
β	Estimated parameters
X	Household characteristics, including household size ($hhsize$) and annual income ($\log inc$); $hhsize = 4$ if there are 4 or more persons in household; $\log inc_i$ is the natural log value of household i's annual income in dollars

Table 12 and Table 13 reflect the results of the vehicle availability model estimations.

TABLE 12: VEHICLE AVAILABILITY MODEL ESTIMATION RESULTS

	Coefficient	Robust Std. Err.	z	P>|z|	[95%	Conf. Interval]
hhsize	0.458	0.0778	5.89	0	0.3056	0.6105
loginc	1.1464	0.0901	12.72	0	0.9698	1.323
k_1	10.0823	0.8721			8.373	11.7917
k_2	12.6053	0.9195			10.8032	14.4074
k_3	14.7586	0.9595			12.8779	16.6392
k_4	16.5367	0.978			14.6199	18.4535
Log pseudo-likelihood	-1287.7307					
Pseudo R-square	0.1554					
Prob > chi2	0					

TABLE 13: OBSERVED VEHICLE AVAILABILITY SEGMENTATION

Segmentation	Observed	Predicted
0-vehicle households	10.60%	11.80%
1-vehicle households	36.10%	35.90%
2-vehicle households	34.60%	34.40%
3-vehicle households	13.60%	13.40%
4+ vehicle households	5.20%	4.50%

MEDIAN HOUSEHOLD INCOME

Median household income was derived for each TAZ based on 2000 US Census tract level data, adjusted to 2008 dollars using a wage rate increase of 1.31. Median household data was then aggregated to the TAZ based on location of the TAZ and Census tract.

PERSON TRIP RATES

The cross-classification trip rates were derived using 2001 National Household Travel Survey (NHTS) data for similar areas. This process used available NHTS evaluation tools to identify transferability parameters for the study area that allowed the development of trip rate values based upon the household characteristics and travel patterns for Montgomery County and Christian County.

The NHTS data were used to statistically compare a range of independent variables to determine the optimal predictive combination for use in the cross-classification tables. For use in the Clarksville Travel Demand Model the selected combination was household size vs. auto availability. The derived trip rates are shown in Table 14.

TABLE 14: DAILY PERSON TRIPS PER HOUSEHOLD

Purpose	HH size	Vehicle Ownership (Number of Vehicles)				
		0	**1**	**2**	**3**	**4 +**
HBW	1	0.57	0.65	0.80	0.95	1.11
	2	1.04	1.08	1.12	1.14	1.16
	3	1.39	1.47	1.49	1.51	1.53
	4 +	1.79	1.83	1.86	1.88	1.95
HBO	1	2.10	2.39	2.95	3.53	4.13
	2	4.13	4.29	4.46	4.55	4.64
	3	6.02	6.29	6.40	6.46	6.54
	4 +	8.47	8.83	8.87	8.94	9.32
NHB	1	1.00	1.14	1.47	1.79	2.08
	2	2.14	2.25	2.37	2.49	2.58
	3	3.47	3.57	3.70	3.80	3.89
	4 +	5.58	5.78	5.88	5.98	6.26

Trip attractions were calculated using National Cooperative Highway Research Program 365 regression models. The standard attraction rates for urban areas of similar size and character were used to develop regression equation variables and coefficients for use in the Clarksville Travel Demand Model. The model parameters are listed in Table 15.

TABLE 15: ATTRACTION RATES[1]

Employment Type	HBW	HBO	NHB
Retail	1.45	9.00	4.10
Service	1.45	1.70	1.20
Basic	1.45	0.50	0.50
HH	0.00	0.90	0.50

Truck Trip Rates

Truck Trip rates were derived based on the Quick Response Freight Manual, which are shown in Table 16. These rates are based upon the magnitude and distribution of standard TAZ attribute data such as population and employment densities.

TABLE 16: TRUCK TRIP GENERATION RATES (MONTGOMERY COUNTY, TN)[2]

Employment Type	CMV Trip Generation Rate	FRT Trip Generation Rate
Retail	0.21	0.15
Service	0.13	0.022
Basic	0.8	1.5
HH	0.01	0.004

Special Generators

Special generators are activity centers that exhibit travel characteristics that are out of scale with normal patterns in the study area. Typically this means that the special generator attracts

[1] Source: NCHRP 365: Travel Estimation Techniques for Urban Planning
[2] Source: Quick Response Freight Manual, September 1996

more trips than can be predicted using the normalized trip attraction rates from the study area data.

There are several reasons for this phenomenon. The special generator may be:

- A site for special events or periodic activity such as a stadium or convention facility;
- A site that operates 24/7 with multiple shifts of employees such as hospitals and military bases;
- A site of a unique character in comparison to other activity centers, such as a regional airport; or
- A site with a special population of trip makers such as the students at a university or college.

The use of special generators in the model set should be exercised judiciously and to the minimum degree possible. This conservative approach is used because special generators require additional data, additional steps, and call for a level of subjectivity that has the potential to bias model performance.

Just because a facility is large, or attracts a large number of trips, does not mean it is, by definition, a special generator. A regional retail mall for example, should typically be accounted for in the primary modeling. If such a facility's trip rates are inadequately replicated in the model, it is more likely a function of poorly documented employment levels (the primary attraction variable) than an indication of a need for special treatment.

Except under very unusual circumstances, special generators do not include areas that are primarily the home-based production end of the trip such as residential areas. These areas are normally embraced within the limits of the travel surveys and the variations among types are typically accounted for during calibration of the model. Home-based trip attractions and trip productions and attractions for non-home-based travel play a larger role in special generator markets.

Based on these general guidelines, a set of presumptions regarding candidate special generators were adopted for use in conducting the analysis. The presumptions were not conclusive, but represented a relative "burden of proof" in making special generator determinations.

Presumptive special generators – the following categories were treated as presumptive special generators unless the survey results and resulting analysis specifically determined that they should be removed.

- Airports
- Military Bases
- Large Hospitals
- Universities and Colleges

Presumptive normal generators - The following categories were treated as normal generators unless significant evidence to the contrary surfaced in the survey or the analysis.

- Residential Areas
- Retail Malls or Outlets
- The Central Business District

CLARKSVILLE, TENNESSEE SPECIAL GENERATORS

The special generator locations selected for inclusion in the Clarksville Travel Demand Model are listed below.

- Austin Peay University
- Gateway Medical Center
- Draughons Junior College

For each location identified as a special generator, its name is included on the TAZ layer in the "SPECIAL_GENERATOR" attribute.

For each special generator, an estimate of the person trips is necessary. The Institute of Transportation Engineers (ITE) Trip Generation Manual 8th edition and the information provided by the facilities were used to calculate vehicle trips. Person trips were then calculated by applying auto occupancy factors to the vehicle trips. Person trips were added to the production and attraction trip table for each special generator TAZ. Table 17 presents the special generator trip rates from the ITE Manual. Table 18 presents the special generator vehicle trips used in the model that were developed based on the rates listed in Table 17 and the information provided by those local facilities.

TABLE 17: SPECIAL GENERATOR VEHICLE TRIP RATES[3]

Generator Type	Variable	Vehicle Trip Rate
Junior/Community College	Student	1.2
Junior/Community College	Employee	15.55

[3] Source: ITE Trip Generation Manual, 8th Edition

University/College	Student	2.38
University/College	Employee	9.13
Hospital	Bed	11.81
Hospital	Employee	5.2
Nursing home	Bed	2.37
Nursing home	Employee	6.55
Military base	Employee	1.78

TABLE 18: SPECIAL GENERATOR VEHICLE TRIPS (2008) – CLARKSVILLE, MONTGOMERY COUNTY

Facility	Trip rate	Variable Label	Variable	Vehicle Trips
Austin Peay University	2.38	Student	7964	18954
Gateway Medical Center	5.2	Employment	1100	5720
Draughons Junior College	1.2	Student	550	660

Special generator vehicle trips were first converted to person trips using auto occupancy factors. Those person trips were split by trip purpose according to the proportions calculated based on the special generator's employment characteristics.

External-External and External-Internal Trips

External stations for the Clarksville Travel Demand Model, 35 in total as illustrated in Figure 6, were established at each point where a roadway identified in the network crossed the Montgomery County Line.

The EE trip tables were forecasted using a Fratar, or iterative proportional fit process, using a doubly constrained growth factor methodology. EI and IE trips were taken into account at the trip balancing step. The base year EE trip tables at each external station served as input to this process. The EI and IE vehicle trips by station location are shown in Table 19. The EE vehicle trips by station are shown in Table 20.

TABLE 19: EXTERNAL-INTERNAL AND INTERNAL-EXTERNAL VEHICLE TRIPS

Station ID	Road Name	Passenger Car	Truck	Total
500	Screaming Eagle Blvd, Gate 4	18498	572	19070
501	Forrest Rd, Gate 5	1176	36	1212
502	Morgan Rd, Gate 6	6492	201	6692
503	Glider Rd, Gate 7	1824	939	2763
504	KY 117	3492	108	3600
505	I-24	3548	1520	5068
506	US 41A	7700	238	7938
507	KY 115	2068	132	2200
600	SR 48	1862	58	1920
601	SR 249	591	12	603
602	SR 238	386	38	425
603	SR 13, US 79	6091	389	6480
604	SR 11, US 41	109	1	111
605	SR 11, US 41	237	2	240
606	SR 76	639	41	680
607	Stroudsville Rd, Harmony Church Rd	199	17	217
608	I-24	16324	6996	23320
609	SR 112, US 41A	4178	129	4307
610	Old Clarksville Pk	437	4	442
611	SR 12	3502	108	3610
612	Southside Rd, Chapel Hill Rd	374	8	381
613	Ryes Chapel Rd, Cunningham Rd	90	6	95
614	SR 48	2744	271	3015
615	SR 235	741	39	780
616	Chambers Rd	120	10	130
617	Thorne Hollow Rd	160	14	173
618	Ellis Mill Rd	62	7	69
619	SR 13	588	18	607
620	SR 149	4406	490	4896
621	SR 233	679	14	693
622	SR 76, US 79	5442	168	5610
623	101sr Airborne Rd, Gate 10	4091	170	4261
624	Lee Rd, Gate 1	6985	216	7201
625	1st St, Gate 2	672	21	693

626	Air Assault St, Gate 3	5171	160	5331

TABLE 20: EXTERNAL-EXTERNAL VEHICLE TRIPS

Station ID	Road Name	Passenger Car	Truck	Total
500	Screaming Eagle Blvd, Gate 4	3412	218	3630
501	Forrest Rd, Gate 5	171	17	188
502	Morgan Rd, Gate 6	1008	100	1108
503	Glider Rd, Gate 7	288	149	437
504	KY 117	519	51	570
505	I-24	9122	3910	13032
506	US 41A	10085	877	10962
507	KY 115	0	0	0
600	SR 48	0	0	0
601	SR 249	95	2	97
602	SR 238	59	6	65
603	SR 13, US 79	677	43	720
604	SR 11, US 41	1710	190	1899
605	SR 11, US 41	1710	190	1900
606	SR 76	113	7	120
607	Stroudsville Rd, Harmony Church Rd	31	3	33
608	I-24	15303	5377	20680
609	SR 112, US 41A	672	21	693
610	Old Clarksville Pk	68	1	68
611	SR 12	179	11	190
612	Southside Rd, Chapel Hill Rd	57	1	59
613	Ryes Chapel Rd, Cunningham Rd	14	1	15
614	SR 48	305	30	335
615	SR 235	114	6	120
616	Chambers Rd	18	2	20
617	Thorne Hollow Rd	24	2	27
618	Ellis Mill Rd	11	0	11
619	SR 13	91	3	93
620	SR 149	490	54	544
621	SR 233	99	7	107
622	SR 76, US 79	960	30	990

623	101sr Airborne Rd, Gate 10	699	0	699
624	Lee Rd, Gate 1	1127	72	1199
625	1st St, Gate 2	100	6	107
626	Air Assault St, Gate 3	843	26	869

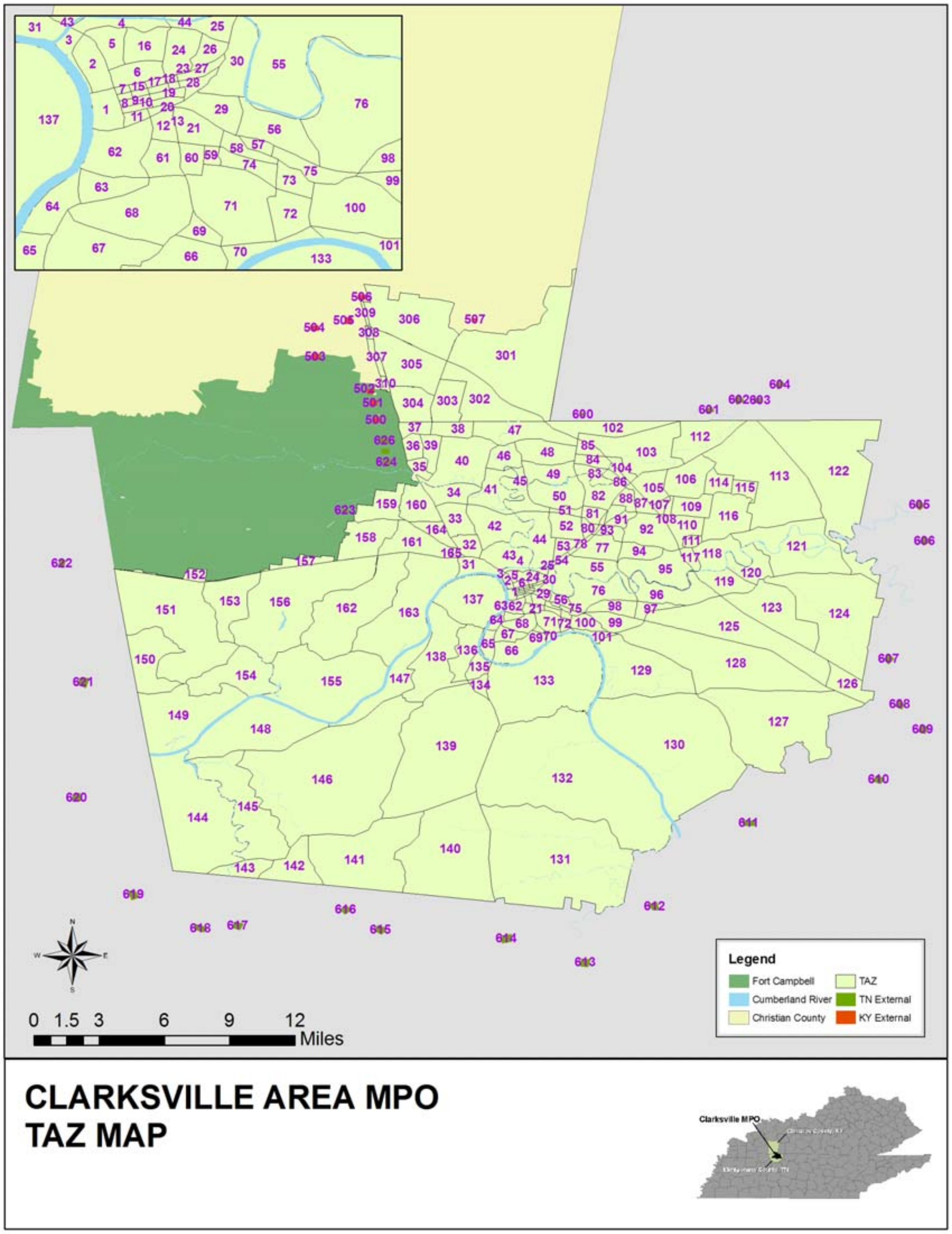

FIGURE 6: EXTERNAL STATIONS

TRIP DISTRIBUTION

Trip Distribution is the second step in the traditional travel demand modeling process. The trip distribution process takes the production and attraction trip ends produced during trip generation, and connects them in origin-destination pairs based on the trip length frequency curves for each trip purpose. The trip length frequency curves are applied through the use of a gravity model. In essence, while the trip generation models estimate “how many trips,” the trip distribution models estimate “where do they go.”

The Clarksville Model uses a traditional gravity model. A traditional gravity model distributes trips according to characteristics of land use and the transportation system in the study area. This Newtonian analogy states that the number of trips traveling between any zone pair is a function of the magnitude of the total productions and attractions in the two zones and the travel impedance between the zones. The highway network attributes describe the transportation system characteristics used to measure travel impedance (e.g. distance, travel time, etc.). The model can be mathematically stated as:

$$T_{ij} = P_i \times \frac{A_j \times F_{ij}}{\sum_k A_k \times F_{ik}}$$

Where:
T_{ij} = forecast flow produced by zone i and attracted to zone j
P_i = the forecast number of trips produced by zone i
A_j = the forecast number of trips attracted to zone j
F_{ik} = Impedance between zone i and zone k (F-Factors)

Although this method is borrowed from Newton’s Law of Gravity, which states that force is inversely proportional to the distance between two bodies, the effect of distance is not as strong a determinant of travel between zones as travel time. Therefore, travel time is typically used as the measurement of separation between zones for the purposes of applying the gravity model, with trip lengths measured in minutes.

TRIP LENGTH FREQUENCY DISTRIBUTION

The trip length frequency distribution was derived from NHTS 2001 data. To get a statistically significant estimate of trip length from the NHTS, it is necessary to perform the analysis for the aggregate census division in which the Clarksville Travel Demand Model study area is located. Population size and transit services availability were also used as criteria to select the records that are similar to the study area. Considering the size of the study area, only trips no longer than 100 minutes were selected to estimate trip length distribution to avoid the bias induced by longer trips. Gamma distributions were used to match the general shape of typical trip length frequency distributions derived from available survey data. The Gamma trip length frequency distribution curves are used to develop travel impedances called friction factors (F-Factors) for each trip purpose. F-Factors are calibrated by comparing the trip length frequencies in the model to observed data from surveys or other sources.

$$F_{ik} = a \cdot t_{ik}^{-b} \cdot e^{-c \cdot (t_{ik})}$$

Where, F_{ik} is the Impedance between zone i and zone k, t_{ik} is the travel time from zone i to zone k; a, b and c are the Gamma function parameters as listed in Table 21.

TABLE 21: GAMMA FUNCTION PARAMETERS FOR FRICTION FACTORS (MONTGOMERY COUNTY)

Purpose	a	b	c
HBW	0.002346	-4.520231	0.501039
HBO	0.000591	-5.440084	0.568010
NHB	3.09607	0.882068	0.122165

The observed average trip lengths for the Clarksville Model are presented in Table 22. The observed trip length frequency distribution curves by purpose are shown in Figure 7 through Figure 9.

TABLE 22: MONTGOMERY COUNTY AVERAGE TRIP LENGTH BY PURPOSE (IN MINUTES)

Purpose	Observed	Modeled	Coincidence Ratio	Difference
HBW	17.67	18.38	76.2%	4.0%
HBO	16.20	17.89	72.4%	10.4%
NHB	16.32	15.54	73.6%	-4.8%

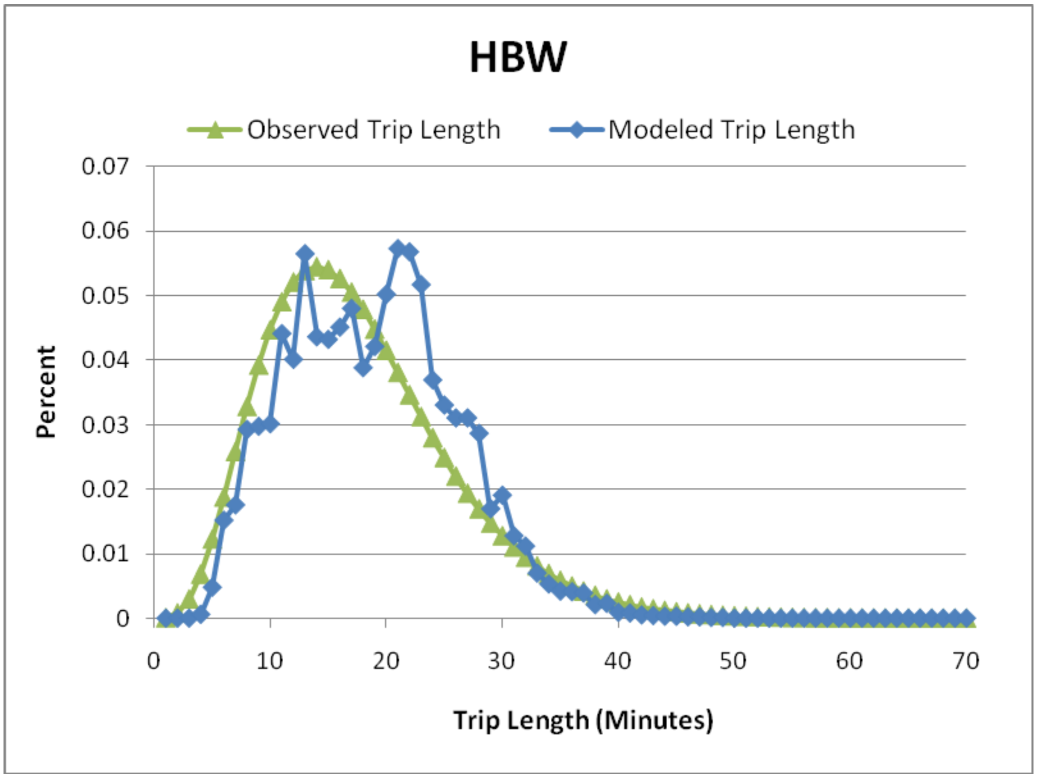

FIGURE 7: OBSERVED VS. MODELED HBW TRIP LENGTH FREQUENCY DISTRIBUTION

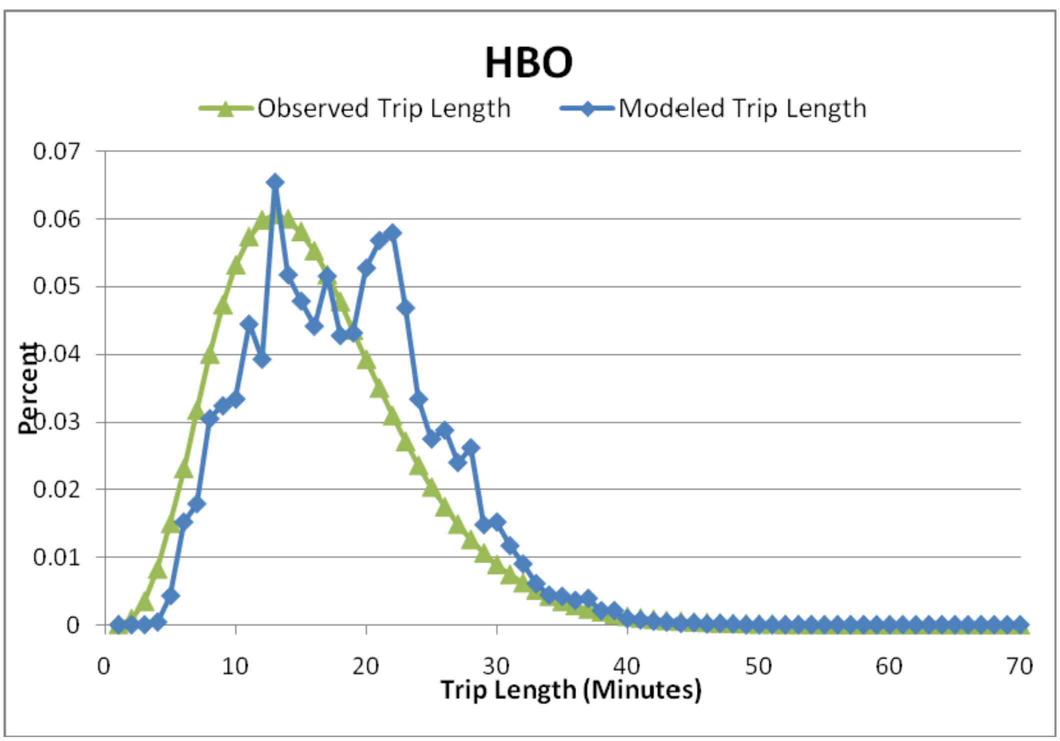

FIGURE 8: OBSERVED VS. MODELED HBO TRIP LENGTH FREQUENCY DISTRIBUTION

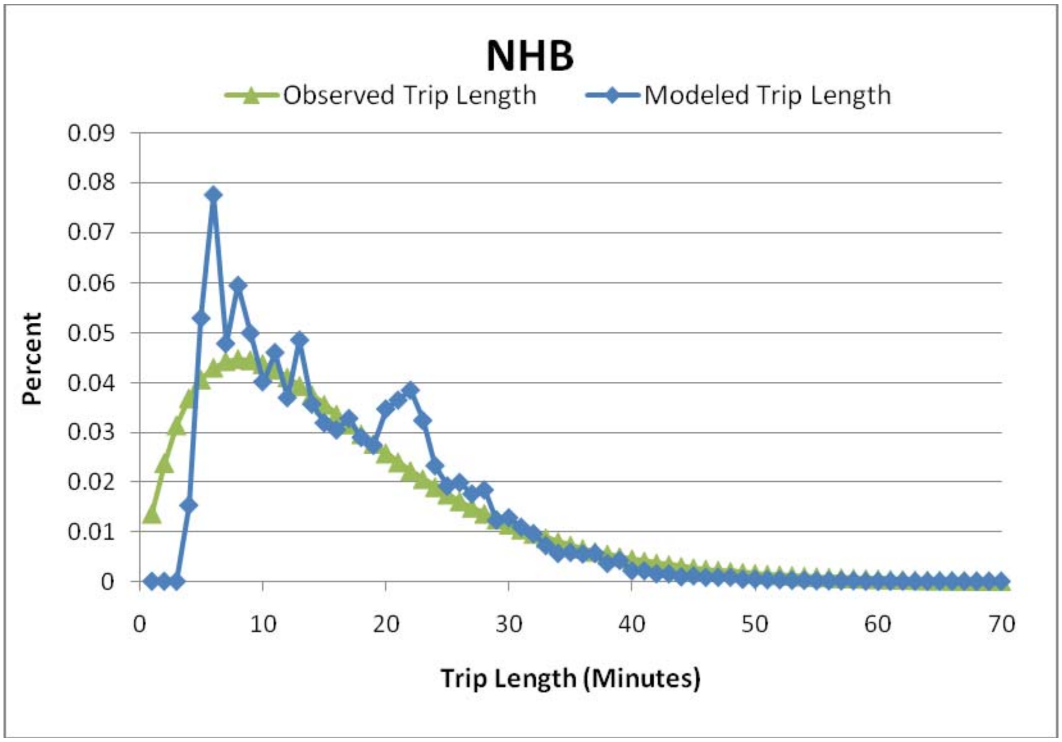

FIGURE 9: OBSERVED VS. MODELED NHB TRIP LENGTH FREQUENCY DISTRIBUTION

AUTO OCCUPANCY

The trip interchanges defined in trip distribution are still defined in terms of person trips between zones. To be assigned to the roadway network these trips must be converted to vehicle trips. Since no mode choice model was included in the model process the following process was used.

To convert the person trip tables output by trip distribution to vehicle trips, an auto occupancy factor was applied. The auto occupancy factors were derived from NHTS 2001 US East South Central Region data as presented in Table 23. It should be noted that the trips for the Commercial Vehicle and Freight Vehicle purposes were derived from traffic count data or other vehicle based sources and were, therefore, produced as vehicle trips that were not factored.

TABLE 23: AUTO OCCUPANCY FACTORS

Purpose	Auto Occupancy Factor
HBW	1.14
HBO	1.65
NHB	1.57
CMVEH	1.00
FRT	1.00

The use of auto occupancy factors instead of a full mode choice model is common practice where transit ridership represents a small portion of the overall number of trip in the region and major capital transit projects are not to be analyzed with the model.

TRAFFIC ASSIGNMENT

Traffic assignment is the final step in the traditional modeling process. It estimates the flow of traffic on a network. The assignment methodology selected for the Clarksville Model is a User Equilibrium model. The equilibrium assignment procedure is run using a maximum of 20 iterations and convergence criteria of 0.01. The model interface automatically runs the highway assignment after generation and distribution are complete. The interface can rerun this assignment step to test various alternative highway project combinations using the established future land use and demographic assumptions. Validation statistics based on the assigned volumes are presented in the following section.

VOLUME DELAY FUNCTION (VDF)

A series of Bureau of Public Roads (BPR) volume delay functions were selected for the Clarksville Model assignment process to account for both link delay and intersection delay by facility type. Intersection delay is accounted for by using intersection capacity to calculate volume-to-capacity (V/C) ratios for intersection links and a separate set of parameters. The VDF parameters were developed taking into account the daily capacity used in the model is true 24 hour capacity and the assignment needs to be capacity constrained. Table 24 shows VDF parameters used in the model and Figure 10 shows the corresponding curves.

TABLE 24: VOLUME DELAY FUNCTION PARAMETERS

	Alpha	Beta
Non-intersection Links		
Minor Arterial/Collector	10.32	2
Interstate/Principal Arterial	10.32	4
Intersection Links		
Minor Arterial/Collector Intersection	202.7	3
Principal Arterial Intersection	202.7	4

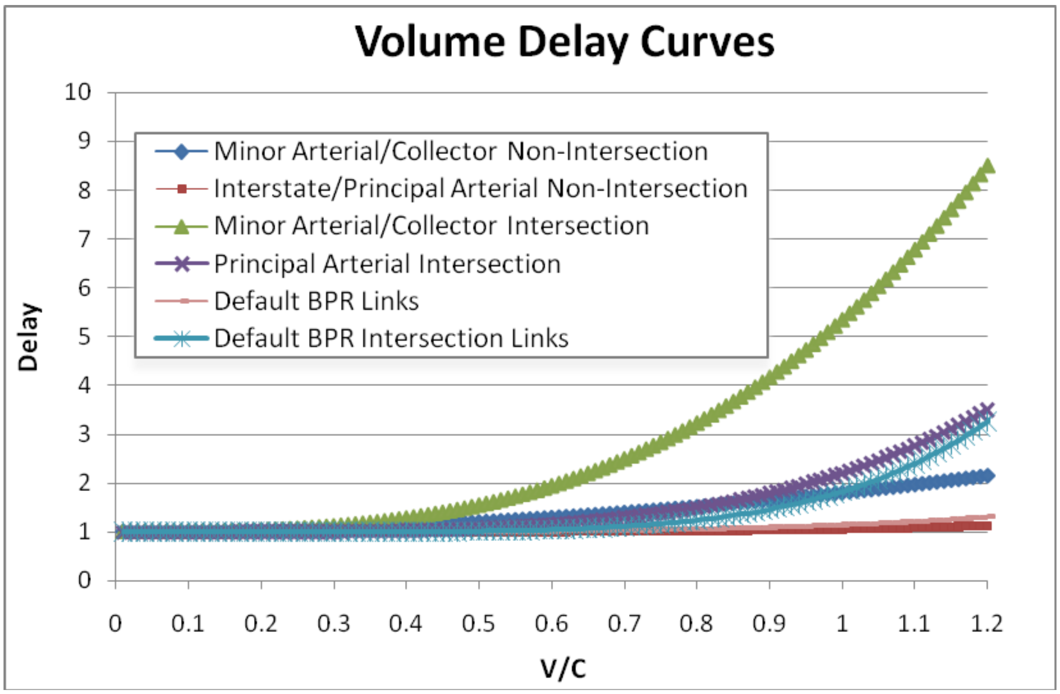

FIGURE 10: VOLUME DELAY CURVES

Model Validation

The ability of travel demand models to forecast future year traffic and other travel behaviors is predicated on their ability to estimate "known" traffic volumes and travel patterns under base year conditions for which extensive data is available. There are two components to the process of matching model results to the observed base year travel data. These components are calibration and validation.

Calibration refers to the process of estimating model variables such as trip rates, friction factors, mean trip length, and trip length frequency distributions. All variables are ideally based on surveyed or observed data. Validation refers to the process of using a calibrated model to estimate travel assignments for the base year and comparing these travel assignments to observed travel data. The typical comparison, when sufficient data is available, is between highway traffic assignments and actual traffic volumes derived from traffic count data. Extensive traffic counts must be available to validate a model. Validation of the model to counted traffic flows is important to the model effort in two areas. First, it shows whether the calibration tools used in the model process and assumptions were reasonable. Second, the validation shows what level of confidence the user can have in the forecast results.

VALIDATION CRITERIA

Although the principle of comparing traffic assignments to traffic count data is intuitively straightforward, subjective review of the travel demand model results and the observed traffic counts is not adequate. The comparative analysis must be carried out in a structured manner using clearly defined benchmarks or measures of success that allow the results of the validation analysis to be tabulated, and quantitatively analyzed in a way that provides the user with a degree of confidence in the statistical foundation and structure of the model.

The model validation procedure for the Clarksville Model is similar to the procedure used by state DOTs and MPOs throughout the country. The locations of year 2008 traffic counts provided by Clarksville Area MPO were coded to the roadway networks. Traffic assignment results for the validation year (2008) were compared to these traffic counts by three indices: **Percent of Count**, **Correlation Coefficient** and **Percent Root Mean Squared Error (RMSE)**, each of which was aggregated and tabulated across a variety of categories. Percent of Count is used to measure the overall difference between modeled and counted flows. Correlation Coefficient estimates the correlation between the actual ground counts and the estimated traffic volumes. Percent Root Mean Squared Error (RMSE) is used to measure the difference between modeled flows and counted volumes on a link-by-link basis, which gives a better picture of the "closeness" between model flows versus counts. The Percent of Count and Percent RMSE calculation are described by the following equations:

$$Percent\ of\ Count = \frac{\sum_{j=1}^{n} Modeled_j}{\sum_{j=1}^{n} Counted_j}$$

$$\%RMSE = \frac{\sqrt{\sum_{j=1}^{n} \frac{(Modeled_j - Counted_j)^2}{n-1}}}{\frac{\sum_{j=1}^{n} Counted_j}{n}} \times 100$$

Where j represents the individual network link with count, n is the total number of links with counts in the network for the specific categories.

When applied to model flows versus counts, RMSE values are usually between 10% and 100%. 10% usually describes flows that are very similar to the counts on a link-by-link basis, while 100% usually describes flows that are very different to the counts.

Additionally, number of count links, center line miles and average count values are also presented to provide a frame for interpreting the results.

The validation results are presented by different categories as listed below and discussed individually in the following sections:

- County-wide
- Facility Type
- Area Type
- Screenlines
- Volume Range

The tests used to validate the Clarksville Model meet the TDOT suggestion: percent difference in value for screenlines and link volumes; percent difference in volume by classification; correlate coefficient by link volumes; and RMSE for link volumes.[4]

County-Wide

The first step in the validation process is to analyze overall traffic flows and vehicle miles of travel (VMT) in the study area. A comparison of traffic counts and VMT vs. the travel demand model assignment results for the transportation system as a whole as well as subcategories is shown in Table 25 thru Table 32.

The proposal goal is to control county-wide percent RMSE within 40%, match modeled county-wide VMT with the HPMS VMT within 5%, and reach county-wide correlation coefficient of more than 0.88.

[4] Wegmann, F & Everett, J, Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee

TABLE 25: COUNTY-WIDE COUNTED VS. MODELED VOLUME

System Wide	Percent of Count Σ	Count Links	Center Line Miles	Average Counted	RMSE	R^2
All Links	99.09	190	183.61	8,588	35.88	0.88

The county-wide correlation coefficient between modeled vs. observed link volume is 0.94. The scatter plot of modeled vs. observed link volume is shown in Figure 11.

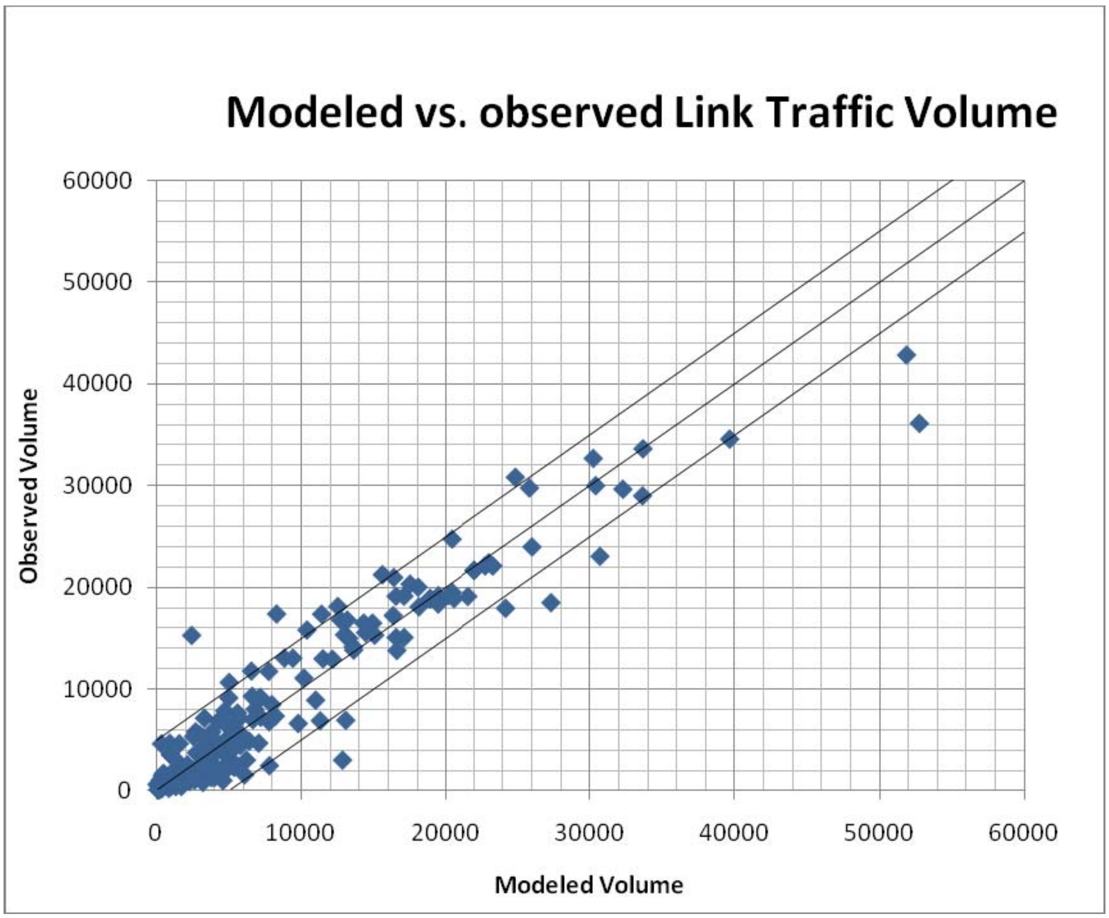

FIGURE 11: SCATTER PLOT OF MODELED VS. OBSERVED LINK TRAFFIC VOLUME

Table 26 compares modeled VMT to HPMS VMT (2007) for Montgomery County. Modeled VMT of total flow and truck flow on different types of link are also presented. It should be noted that the VMT given in Table 26 only include trips inside Montgomery County; trips in Christian County that are also simulated by the model are excluded in Table 27 and Table 28.

TABLE 26: HPMS VMT VS. MODELED VMT

HPMS VMT (2007)	Modeled VMT	% Difference
3,730,824	3,729,650	-0.03%

TABLE 27: COUNTY-WIDE TOTAL FLOW BY FUNCTIONAL CLASS

Total Flow by Functional Class						
Functional Class	**VMT**	**VHT**	**Average AB Speed**	**Average BA Speed**	**Average Speed**	**Energy Consumption**
Centroid Connector (0)	384,080.78	15,708.97	24.87	24.87	24.87	19,204.04
Rural Interstate (1)	694,767.61	10,716.16	64.83	65.08	64.95	34,738.38
Rural Other Principal Arterial (2)	237,241.66	5,331.20	48.67	48.64	48.65	11,862.08
Rural Minor Arterial (6)	267,325.97	6,147.81	47.03	46.98	47.01	13,366.30
Rural Collector (7)	281,707.43	7,647.05	41.13	41.06	41.09	14,085.37
Urban Other Principal Arterial (14)	1,213,568.26	44,563.39	36.89	36.86	36.88	60,678.41
Urban Minor Arterial (16)	388,472.73	14,022.04	27.83	27.25	27.54	19,423.64
Urban Collector (17)	238,944.25	10,230.49	26.77	26.95	26.86	11,947.21
Ramp (20)	23,541.46	2,969.69	5.66	22.91	14.29	1,177.07
Total	3,729,650.15	117,336.81	35.97	37.84	36.90	186,482.51

TABLE 28: COUNTY-WIDE TRUCK FLOW BY FUNCTIONAL CLASS

Truck Flow by Functional Class						
Functional Class	**VMT**	**VHT**	**Average AB Speed**	**Average BA Speed**	**Average Speed**	**Energy Consumption**
Centroid Connector (0)	15,491.88	58,287.06	24.87	24.87	24.87	774.59
Rural Interstate (1)	170,821.21	36,942.73	64.83	65.08	64.95	8,541.06
Rural Other Principal Arterial (2)	18,610.46	31,224.07	48.67	48.64	48.65	930.52
Rural Minor Arterial (6)	20,294.65	39,100.02	47.03	46.98	47.01	1,014.73
Rural Collector (7)	16,513.26	35,771.79	41.13	41.06	41.09	825.66
Urban Other Principal Arterial (14)	99,248.27	337,544.99	36.89	36.86	36.88	4,962.41
Urban Minor Arterial (16)	21,285.33	46,421.88	27.83	27.25	27.54	1,064.27
Urban Collector (17)	11,690.17	36,113.03	26.77	26.95	26.86	584.51
Ramp (20)	3,552.90	15,803.45	5.66	22.91	14.29	177.64
Total	377,508.12	637,209.02	35.97	37.84	36.90	18,875.41

FACILITY TYPE

Another criterion used for model validation was to compare assigned traffic volume to traffic counts aggregated by facility type. The comparison of assigned volumes to counted volumes is considered successful if the value for percent error falls within the ranges suggested by the FHWA, shown in Table 29.

TABLE 29: FHWA FACILITY TYPE VALIDATION TARGETS[5]

Facility Type	FHWA Targets
Freeway	+/- 7%
Principal Arterial	+/-10%
Minor Arterial	+/- 15%
Collector	+/- 25%

Table 30 shows that the model is matching counts by facility type within the FHWA facility type validation targets.

TABLE 30: COUNT VS. MODELED BY FACILITY TYPE

Functional Class		Percent of Count Σ	Count Links	Center Line Miles	Average Counted	RMSE	R^2
1	Rural Interstate	100.0	15	38.04	18,896	7.76	0.61
2	Rural Other Principal Arterial	89.77	10	7.39	11,776	19.92	0.85
6	Rural Minor Arterial	102.85	16	18.12	4,897	35.43	0.84
7	Rural Collector	101.80	58	78.82	1,639	85.26	0.51
14	Urban Principal Arterial	101.07	28	15.63	23,530	22.60	0.56
16	Urban Minor Arterial	88.69	27	9.09	9,410	38.33	0.57
17	Urban Collector	110.36	36	16.52	4,005	90.13	-0.28

5 Wegmann, F & Everett, J, Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee

Area Type

Table 31 lists the Area Types used for the Clarksville Model. The target for this criterion was for the aggregate modeled volume to be within 15% of the aggregate observed volume for each Area Type.

TABLE 31: COUNT VS. MODELED BY AREA TYPE

Area Type	Percent of Count Σ	Count Links	Center Line Miles	Average Counted	RMSE	R^2
1	93.22	15	2.11	6,881	53.01	0.57
2	103.33	36	14.34	11,118	33.50	0.87
3	98.82	50	41.64	13,677	31.84	0.81
4	97.05	89	125.52	4,993	29.67	0.95

Screenlines

A screenline is a linear boundary transecting a set of roadway facilities at points where traffic counts are available on the individual facilities. Screenlines allow the user to aggregate the total travel on all available facilities in a corridor or travel market so that the model performance for the entire travel market can be assessed and analyzed. By providing an overview of corridor activity, the screenline comparisons provide insight to the modeler on how to calibrate and validate model performance on individual facilities within the given travel market. The target for this criterion was for the aggregate modeled volume to be within 10% of the aggregate observed volume for each screenline[6]. Figure 12 and Table 32 provide the results of the screenline validation.

[6] Wegmann, F & Everett, J, Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee

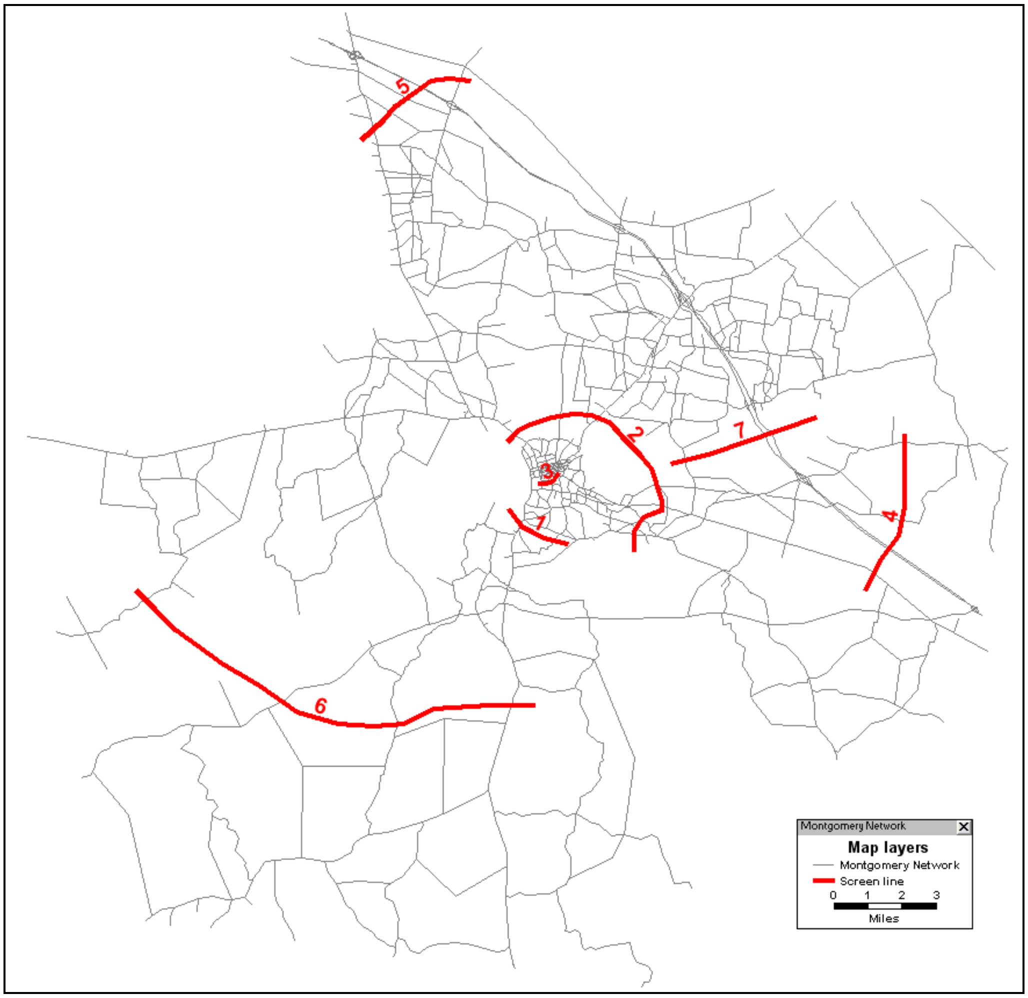

FIGURE 12: MONTGOMERY COUNTY (TN) SCREEN LINE

TABLE 32: COUNT VS. MODELED SCREENLINE VOLUME

Screenline	Percent of Count Σ	Count Links	Center Line Miles	Average Counted	RMSE	R^2
Other Links	99.44	162	147.77	7,663	37.94	0.88
1	110.48	2	1.46	16,170	18.89	0.98
2	98.31	7	4.16	19,781	39.67	0.72
3	95.05	3	0.63	8,887	31.81	0.59
4	99.11	5	12.70	10,666	9.84	0.99
5	96.25	4	6.93	13,728	12.62	0.95
6	88.12	4	4.76	4,855	16.35	0.97
7	95.64	3	5.22	21,750	15.64	-25.72

VOLUME RANGE

The final validation criterion is to compare observed verses modeled volumes within acceptable volume ranges. As shown in Table 33 and Table 34, the percent difference targets for this criterion is suggested by FHWA, and the percent RMSE targets for this criterion is suggested by TDOT[7] .

TABLE 33: PERCENT DIFFERENCE TARGETS FOR DAILY VOLUMES FOR INDIVIDUAL LINKS (FHWA)

Average Annual Daily Traffic	Desirable Percent Deviation
<1000	200
1,000-2,500	100
2,500-5,000	50
5,000-10,000	25
10,000-25,000	20
25,000-50,000	15
>50,000	10

TABLE 34: PERCENT RMSE TARGETS BY LINK VOLUME (TDOT)

Link Volume	% RMSE
0-4,999	115.757
5,000-9,999	43.141
10,000-19,999	28.272
20,000-39,999	25.383
40,000-59,999	30.252
60,000-89,999	19.199

Table 35 shows that the Clarksville model validation meets the criteria for each volume range. It should be noted that model results follow the FHWA range category, which is different from the count range category used for percent RMSE targets. The overall percent RMSE for links with counts less than 4,999 reach the target.

[7] Wegmann, F & Everett, J, Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee

TABLE 35: COUNT VS. MODELED BY LINK VOLUME

Count Range	Percent of Count Σ	Count Links	Center Line Miles	Average Counted	RMSE	R^2
0 - 999	158.16	37	53.59	505	134.33	-6.14
1,000 - 2,499	165.81	33	26.72	1,686	116.85	-16.81
2,500 - 4,999	104.32	28	21.11	3,905	68.43	-11.04
5,000 - 9,999	88.08	30	18.51	7,019	35.77	-2.96
10,000 - 24,999	92.55	52	60.07	17,462	22.82	-0.33
25,000 - 49,999	107.80	10	3.62	32,946	21.88	-1.90

Conclusion

This report provides a description of the Clarksville Travel Demand Model and the process used in model development. Throughout the development process, focus was maintained on providing a flexible tool that could be used for travel demand forecasting of various future year scenarios. At each stage of the model development process, priority was given to optimizing the predictive value of the model sets.

The model development process resulted in the construction of a functional, flexible travel demand model with components effectively scaled to current data availability and the analysis needs of the community. The model was calibrated and validated using a strategic approach based on consistent architecture, resulting in a planning tools with predictive value and credibility for use in future year analysis.

The criteria used for validation of the Clarksville Travel Demand Model are based on current FHWA, NCHRP and TDOT guidance and standards and represent reasonable measures for determining the accuracy and reliability of the model. The validation of the model described in the previous section accomplishes two goals. First, it demonstrates that the calibration tools used in the model process and assumptions are reasonable. Second, the validation provides Clarksville Area MPO and transportation professionals in the Clarksville area with confidence in the accuracy and reliability of forecast results obtained from the Clarksville Travel Demand Model.

No travel demand model is ever complete. The model evolves as the region grows, as goals are met, and policy objectives change. For this reason, The Consultant Team designed the Clarksville Travel Demand Model to be a flexible dynamic tool that could evolve and grow along with the needs of the region. As implemented, the Clarksville Travel Demand Model is a complete set of planning tools capable of performing the required transportation systems planning analyses and providing inputs for air quality analysis. The model will assist Clarksville

Area MPO in carrying out all required transportation system planning activities, as well as performing implementation scenario analysis for the Clarksville/Montgomery County study area.

APPENDIX

CAPACITY CALCULATION METHODOLOGY

This methodology conforms to the Highway Capacity Manual 2000 (HCM 2000). The capacity calculations are based on service flow rates for level of service E and for the peak direction and for system planning analysis purpose.

The methodology includes two sets of procedures for estimating capacity of facilities carrying traffic flows of “uninterrupted” and “interrupted” characteristics, respectively. Traffic control device (i.e. signals and stop signs) density is used to distinguish the two types of flows. If the traffic control density is below 0.5 signals or stop signs per mile, the facility is assumed to be an uninterrupted flow facility; otherwise, an interrupted flow facility.

UNINTERRUPTED FLOW FACILITY

The application of capacity procedures for uninterrupted flow facilities is based on facilities’ design characteristics, not by functional classification. Freeways are characterized by 4 or more through lanes, divided and full access control. Multilane highways have partial or no access control, which distinguish them from freeways. Rural two-lane highways are all rural sections that have two-lane two-way traffic with partial or no access control.

FREEWAY CAPACITY

STEP 1. CALCULATED FREE FLOW SPEED (HCM EQ. 23-1)

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$

Where,

$BFFS$ = base free flow speed; 70 mph for urban facilities, 75 mph for rural facilities

f_{LW} = adjustment factor for lane width

f_{LC} = adjustment factor for right shoulder lateral clearance

f_N = adjustment factor for number of lanes

f_{ID} = adjustment factor for interchange density

HCM Exhibit 23-4, 23-5, 23-6, 23-7 provide the recommended values for these adjustment factors.

STEP 2. CALCULATE HOURLY CAPACITY (BASED ON HCM EXHIBIT 23-3)

$$HourlyCapacity = 1{,}700 + 10 \cdot FFS; \text{for } FFS \leq 70$$

$$HourlyCapacity = 2{,}400; \text{for } FFS > 70$$

Where, $HourlyCapacity$ is in passenger cars per hour per lane (pcphpl).

Step 3. Calculate daily capacity

$$DailyCapacity = HourlyCapacity \cdot 24 \cdot N$$

Where,

$DailyCapacity$ = 24 hour capacity in vehicles per hour in one direction

N = Number of lanes in one direction

Multilane Highway Capacity

Step 1. Calculated free flow speed (HCM Eq. 21-1)

$$FFS = BFFS \quad f_{LW} \quad f_{LC} \quad f_{M} \quad f_{A}$$

Where,

$BFFS$ = base free flow speed; based on posted speed limits

f_{LC} = adjustment factor for lateral clearance

f_{M} = adjustment factor for median type

f_{A} = adjustment factor for access density

HCM Exhibit 21-4, 21-5, 21-6, 21-7 provide the recommended values for the adjustment factors above.

Step 2. Calculate hourly capacity (Based on HCM Exhibit 21-3)

$$HourlyCapacity = 1{,}000 + 20 \cdot FFS; \text{for } FFS \leq 60$$

$$HourlyCapacity = 2{,}200; \text{for } FFS > 60$$

Where, $HourlyCapacity$ is in passenger cars per hour per lane.

Step 3. Calculate daily capacity

$$DailyCapacity = HourlyCapacity \cdot 24 \cdot N$$

Where, all the adjustment factors have the same definition and calculation procedures as the freeway application.

Rural Two-Lane Highway Capacity

Step 1. Calculated hourly two-way capacity (HCM Eq. 21-1)

$$HourlyTwoWayCapacity = 3{,}200 \cdot PHF \cdot f_{HV} \cdot f_{G} - V_{NP}$$

Where,

f_{G} = adjustment factor for grades; calculated based on HCM Exhibit 20-7 and 20-13

V_{NP} = volume adjustment factor for no passing zones; calculated based on HCM Exhibit 20-11

All other adjustment factors are calculated using the same methods as aforementioned.

STEP 2. CALCULATED DAILY CAPACITY

$$DailyCapacity = \frac{HourlyTwoWayCapacity}{2} \cdot 24$$

INTERRUPTED FLOW FACILITY

When traffic control device density is above the threshold of 0.5 signals per mile, the capacity needs to be analyzed using the procedure for signalized intersections (stop sign controlled intersection is not provided due to the fact that state highway system is lack of that level of detail).

SIGNALIZED INTERSECTIONS

STEP 1. CALCULATE SATURATION FLOW RATE FOR LANE GROUP (BASED ON HCM EQ. 16-4)

$$S = S_0 N f_W f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} PHF$$

Where,

S = saturation flow rate for subject lane group, in vehicles per hour
S_0 = base saturation flow rate per lane, the default is 1,900 pcphpl
N = number of lanes in lane group
f_W = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles in traffic stream
f_g = adjustment factor for approach grade
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area
f_a = adjustment factor for area type
f_{LU} = adjustment factor for lane utilization
f_{LT} = adjustment factor for left turns in lane group
f_{RT} = adjustment factor for right turns in lane group
f_{Lpb} = pedestrian-bicycle adjustment factor for left-turn movements
f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements

The adjustment factors can be calculated based on HCM procedures. If no data available, factor $f_{bb}, f_{LU}, f_{Lpb}, f_{Rpb}, f_g$ can be set at 1.0, f_a can be set at 0.9 in CBDs and 1.0 in rural areas.

STEP 2. CALCULATE INTERSECTION APPROACH CAPACITY (BASED ON HCM EQ. 16-6)

$$C_A = \sum_i S_i \frac{g_i}{C}$$

Where,

C_A = intersection approach capacity, based on HCM Equation 16-6
S_i = saturation flow rate for lane group i
$\frac{g_i}{C}$ = effective green ratio for lane group i

Step 3. Calculate daily capacity

$$DailyCapacity = C_A \cdot 24$$

Signalized Intersections – Left & Right Turn Lane Data Not Available

Step 1. Calculate intersection approach capacity (Based on HPMS Field Manual App. N Eq. 29)

$$C_A = 1900 \cdot N \cdot f_{LW} \cdot f_{HV} \cdot PHF \cdot \frac{g}{C}$$

Where,

C_A = Hourly intersection approach capacity

N = number of lanes in one approach

f_{LW} = adjustment factor for lane width

f_{HV} = adjustment factor for heavy vehicles in traffic stream

PHF = peak hour factor; HCM recommends 0.92 for urban facilities and 0.88 for rural facilities

$\frac{g}{C}$ = effective green ratio; HCM recommends 0.55 principal arterial, 0.45 minor arterial, 0.40 collector

Step 2. Calculate Daily capacity

$$DailyCapacity = C_A \cdot 24$$

Capacity Adjustment Assumptions

TABLE 36: ADJUSTMENT FACTOR FOR LANE WIDTH

Lane Width	F_LW
12	0
11	1.9
10	6.6

TABLE 37: ADJUSTMENT FACTOR FOR RIGHT SHOULDER LATERAL CLEARANCE

Right Shoulder Width Freeway	Lanes2 F_LC	Lanes3 F_LC	Lanes4 F_LC	Lanes5 F_LC
6	0	0	0	0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3	2	1	0.5
0	3.6	2.4	1.2	0.6

Right Shoulder Width Multilane Hwy	Lanes2 F_LC	Lanes3 F_LC
6	0	0
5	0.4	0.4
4	0.9	0.9
3	1.3	1.3
2	1.8	1.7
1	3.6	2.8
0	5.4	3.9

TABLE 38: ADJUSTMENT FACTOR FOR NUMBER OF LANES

Number of Lanes	F_LN	Area Code
2	4.5	Urban
2	0	Rural
3	3	Urban
3	0	Rural
4	1.5	Urban
4	0	Rural
5	0	Urban
5	0	Rural

TABLE 39: ADJUSTMENT FACTOR FOR INTERCHANGE DENSITY

Area size	F_ID	Area_code	Model Code
0	0	Rural	1
1	1	Urban	11
2	1.3	Urban	11
3	1.7	Urban	11
1	1.7	Urban	12
2	1.9	Urban	12
3	2.1	Urban	12

TABLE 40: ADJUSTMENT FACTOR FOR HEAVY VEHICLES

Type	Range	Low	High	Level	Rolling	Mountainous
PassengerCarEQTrucks	0-600	0	600	1.7	2.5	7.2
PassengerCarEQTrucks	>600-1,200	601	1200	1.2	1.9	7.2
PassengerCarEQTrucks	>1,200	1201	1000000	1.1	1.5	7.2
GradeAdjustment	0-600	0	600	1	0.71	0.57
GradeAdjustment	>600-1,200	601	1200	1	0.93	0.85
GradeAdjustment	>1,200	1201	1000000	1	0.99	0.99

TABLE 41: ADJUSTMENT FACTOR FOR MEDIAN TYPE

Median description	F_M
undivided	1.6
divided (including TWLTL)	0

TABLE 42: ADJUSTMENT FACTOR FOR ACCESS DENSITY

Access Point Density	F_A
0	0
10	2.5
20	5
30	7.5
40	10

TABLE 43: ADJUSTMENT FACTOR FOR GRADES

Range	Low	High	Level	Rolling	Mountainous
0-600	0	600	1	0.71	0.57
>600-1,200	601	1200	1	0.93	0.85
>1,200	1201	0	1	0.99	0.99

TABLE 44: VOLUME ADJUSTMENT FACTOR FOR NO PASSING ZONES*

Range	Low	High	NPZ0	NPZ10	NPZ20	NPZ30	NPZ40	NPZ50	NPZ60	NPZ70	NPZ80	NPZ90	NPZ100
0-100	0	100	0	0	0	0	0	0	0	0	0	0	0
101-300	101	300	0	0.3	0.6	1	1.4	1.9	2.4	2.5	2.6	3.1	3.5
301-500	301	500	0	0.9	1.7	2.2	2.7	3.1	3.5	3.7	3.9	4.2	4.5
501-700	501	700	0	0.8	1.6	2	2.4	2.7	3	3.2	3.4	3.7	3.9
701-900	701	900	0	0.7	1.4	1.7	1.9	2.2	2.4	2.6	2.7	2.9	3
901-1,100	901	1100	0	0.6	1.1	1.4	1.6	1.8	2	2.1	2.2	2.4	2.6
1,101-1,300	1101	1300	0	0.4	0.8	1	1.2	1.4	1.6	1.8	1.9	2	2.1
1,301-1,500	1301	1500	0	0.3	0.6	0.8	0.9	1.1	1.2	1.3	1.4	1.6	1.7
1,501-1,700	1501	1700	0	0.3	0.6	0.7	0.8	1	1.1	1.2	1.3	1.4	1.5
1,701-1,900	1701	1900	0	0.3	0.5	0.6	0.7	0.9	1	1.1	1.1	1.2	1.3
1,901-2,100	1901	2100	0	0.3	0.5	0.6	0.6	0.8	0.9	1	1	1.1	1.1
2,101-2,300	2101	2300	0	0.3	0.5	0.6	0.6	0.8	0.9	0.9	0.9	1	1.1
2,301-2,500	2301	2500	0	0.3	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1	1.1
2,501-2,700	2501	2700	0	0.3	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1	1
2,701-2,900	2701	2900	0	0.3	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9
2,901-3,100	2901	3100	0	0.3	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8
3,101-3,300	3101	3300	0	0.3	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7
>3,300	3300	0	0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

*If data not available $V_{NP} = 0$