Knoxville Regional Travel Model Update 2012

Model Development and Validation Report

Prepared for the
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Introduction

The Knoxville Regional Transportation Planning Organization (TPO) contracted with Bernardin, Lochmueller & Associates, Inc., (BLA) to conduct an update of their travel demand forecasting model. The current version of the Knoxville Regional Travel Model (KRTM) is implemented in TransCAD, version 6.0, a GIS-based travel demand modeling software, using the software's scripting language, GISDK.

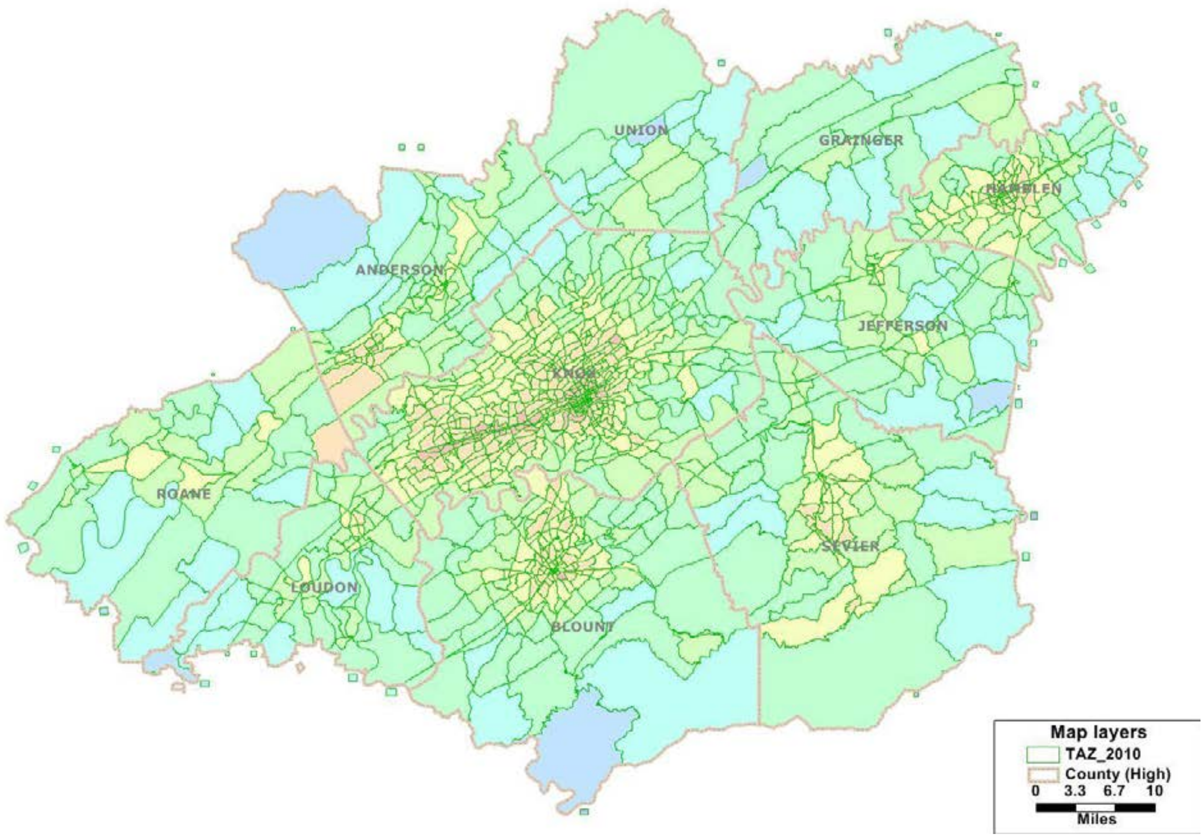

Figure 1 The Knoxville Regional Travel Model Study Area

The KRTM predicts average weekday traffic volumes for all roadway classes of Knox, Blount and Hamblen counties and major arterials and collectors in Anderson, Jefferson, Sevier, Loudon, Union, Roane, and Grainger County. The model's roadway network covers over 7,500 lane miles in total over an area of 3,725 square miles represented by 1,186 traffic analysis zones. The current version of the model also predicts the Knoxville Area Transit (KAT) average weekday system ridership and the number of average weekday bicycle and pedestrian trips within the region.

The current model update was undertaken to accomplish three goals. The first goal was to update and revalidate the model to a new 2010 base year taking advantage of new Census and employment information and the latest traffic counts. The second goal was to incorporate within the regional model Hamblen County, which was previously modeled separately by the Lakeway Area Metropolitan Transportation Planning Organization (LAMTPO) and provide instead a subarea model for their use. The third goal was to develop scripts to post-process the model results to create inputs necessary for the EPA's new MOVES emission model. Under the same contract, BLA also prepared socioeconomic county control totals for the region to assist in the development of land use forecasts.

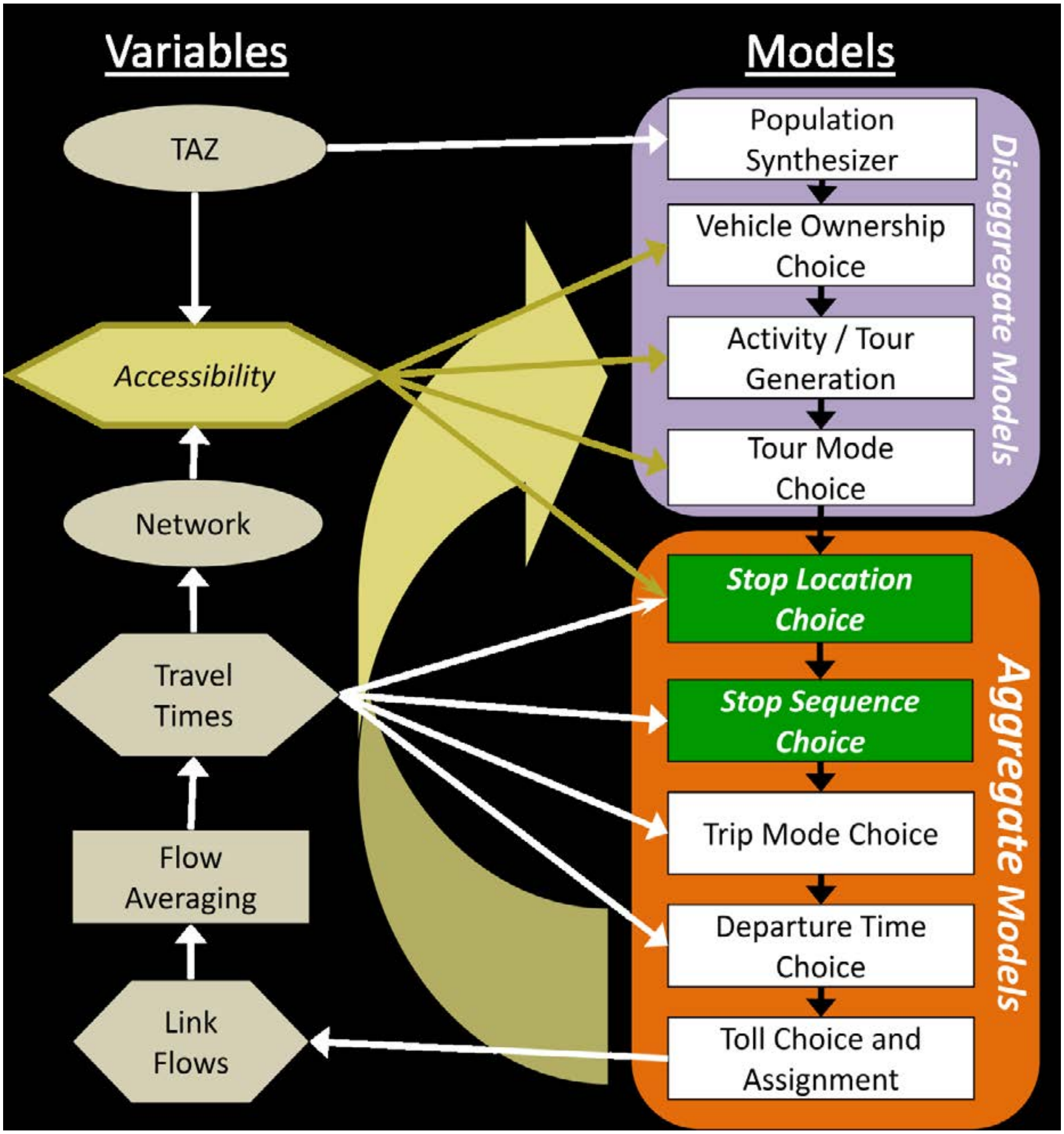

Figure 2 The Knoxville Regional Travel Model's Hybrid Design

This update did not involve major updates to the core model components or the 'hybrid' architecture first adopted in the 2009 model update. The overall architecture of Knoxville's hybrid model is illustrated in Figure 2. For an overview of the Knoxville model's architecture and the details of its components please refer to the Knoxville Regional Travel Demand Model Update 2009: Model Development and Validation Report.

This report focuses on the 2012 update, documenting the revalidation of the regional model to the 2010 base year and the incorporation of the Morristown area. The report reviews and documents the calibration of each of the model's major components.

Tour and Stop Generation

The Knoxville Regional Travel Model (KRTM) has a hybrid design using elements of activity based model architecture during generation. The model creates a disaggregate synthetic population of households in the region based on the demographic information associated with the traffic analysis zones (TAZs).

The new 2010 TAZ layer has been updated with household and population estimates from the 2010 Decennial Census, with additional zonal household demographic information from the 05-09 American Community Survey. Zonal employment data was estimated from a combination of sources, including Dun & Bradstreet, using the 2009 Bureau of Economic Analysis (BEA) totals factored to 2010 based on a linear growth rate as a control.

The synthetic population is developed in two steps. First, a set of ordered response logit models predict for each variable (household size, number of workers, K12 students, presence of seniors, and income) the number of households which have each level of that variable (one person, two persons, etc., zero workers, one worker, two workers, etc.). Second, iterative proportional fitting is used to develop the synthetic population based on a seed population file of households and the marginal distributions for each variable provided by the logit models. The use of shadow prices in the generation of the marginal distributions guarantees that the synthetic population created by iterative proportional fitting will fit the control totals set by the TAZ layer (BLA Inc. 9).

A new seed population file was tested using the 08-10 ACS PUMS data. However, initial results showed many zones did not converge during the iterative proportional fitting step resulting in an over estimate of population. Currently, the former seed file based on the combined travel survey data from 2000 and 2008 is being used. The seed file has been edited so that all records are used for the entire model region, rather than designating records for use in smaller regions of the TAZ layer. Using one region for the seed file helped the results of the synthetic population converge to the zonal marginal totals.

The estimation of vehicle availability is accomplished by a separate disaggregate ordered response logit choice model. Unlike the aggregate ordered response logit models used in the population synthesizer, this model does not include average zonal vehicle availability as an input/control variable or shadow prices to ensure consistency with an input variable. Inputs to this model come from the population synthesizer for individual households. The model is also sensitive to the proximity of transit service, urban design factors, and gas price (BLA Inc. 16-19). Analysis showed that when adjusted for inflation back to 2006 dollars, the 2010 average regular gasoline price was $2.41 for the Knoxville region, nearly the same as the $2.40 price used in the 2006 base model.

Table 1 shows the results of the 2010 base year synthetic population compared with control totals from the Census and ACS.

Table 1 Synthetic Population Results

Demographic Variable	2010 KRTM Synth Pop	2010 Census from TAZ Layer	05-09 ACS Zonal Averages X Households from TAZ Layer
HH	396,156	396,156	
HH Population	958,490	958,227	
Avg HH Size	2.42	2.42	
Workers	449,938		449,952
Workers Per HH	1.14		1.14
K12 Students	159,880		159,886
Students Per HH	0.40		0.40
% of HH with Senior present	25.1%		25.1%
Vehicles	740,614		765,045
Veh_Per_Person	0.77		0.80
Veh_Per_HH	1.87		1.93

The synthetic population results closely converged to the TAZ layer demographics. The vehicle availability model did under predict region wide vehicles by 3.2% when compared to the TAZ layer's average zonal vehicles multiplied by zonal households. Since the households came from the decennial census, a second check using households from the 2005-2009 ACS source data showed region wide vehicle ownership at 736,724 in aggregate, closely matching the vehicle availability model. An additional vehicle population projection data point of 762,920 was provided by TDEC, which was developed as an interim estimate for input to the current EPA vehicle emissions model MOVES and is closer to the TAZ layer estimate indicating that the synthetic population's vehicle population may indeed be approx. 3% low. An attempt to use a data set from the University of Tennessee that was developed from vehicle registration data was inconclusive, as the data set did not include Grainger, Hamblen, and Union counties.

Table 2 shows the difference between the KRTM Synthetic population from base year 2006 and 2010 while distinguishing between growth associated with the additional model coverage area and growth observed in the area which was modeled during the base year 2006. Table 3 shows the household income stratification of the synthetic population vs. the 05-09 ACS.

Table 2 Synthetic Population Growth 2006-2010

Variable	2006 KRTM Synth Pop Old Coverage Area	2010 KRTM Synth Pop Old Coverage Area	2010 KRTM Synth Pop New Coverage Area	2010 KRTM Total Synth Pop	Total Synth Pop Change 2006-2010
HH	360,392	367,264	28,892	396,156	10%
HH Population	843,666	886,278	72,212	958,490	13.60%
Avg HH Size	2.34	2.41	2.5	2.42	3.40%
Workers	429,896	418,222	31,716	449,938	4.70%
K-12 Students	136,264	147,808	12,072	159,880	17.30%
% of HH with Senior Present	23.30%	24.90%	27.20%	25.10%	1.80%
HHs with Senior Present	83,971	91,449	7,859	99,435	18.4%
Vehicles	672,726	686,219	54,395	740,614	10.10%
Veh_Per_Person	0.8	0.77	0.75	0.77	-3.10%
Veh_Per_HH	2	1.87	2	1.87	0.2%
Low Income HH <$25K*	31.4%	29.6%	32.8%	29.8%	-1.6%
Med Income HH>$25K, <$50K*	29.9%	29.1%	29.1%	29.1%	-0.8%
High Income HH>$50K*	38.7%	41.3%	38.1%	41.1%	2.3%

*Annual HH Income in 2006 $

Table 3 Income Stratification

Variable	2006 KRTM Synth Pop Old Coverage Area	2010 KRTM Synth Pop Old Coverage Area	2010 KRTM Synth Pop New Coverage Area	2010 KRTM Total Synth Pop	Total Synth Pop Change 2006-2010	05-09 ACS	Difference from ACS
Low Income HH <$25K*	31.4%	29.6%	32.8%	29.8%	-1.6%	28.6%	1%
Med Income HH>$25K, <$50K*	29.9%	29.1%	29.1%	29.1%	-0.8%	27.4%	2%
High Income HH>$50K*	38.7%	41.3%	38.1%	41.1%	2.3%	44.0%	-3%

*Annual HH Income in 2006 Dollars

The growth of average household size is notable and suggests that increased household travel rates are to be expected. Growth in K-12 students outpaced overall population growth and higher household school travel rates are expected accordingly. Households containing a senior citizen grew 18.4% in absolute terms, and 1.8% relative to overall household growth. Growth in senior households has a negative effect on work tour and stop generation (BLA Inc. 26).

The income stratification of the synthetic population is closely apportioned to the 2005-2009 ACS data, slightly over estimating low and medium income households, while underestimating high income households by 3%.

The number of workers in the old model coverage area decreased in 2010, yet as shown below, employment increased. Comparing zonal employment between 2006 and 2010 indicates a decrease in basic and industrial employment in the region with growth in the retail and service sectors.

The shift in sector employment is in part due to a change in employment source data category definitions between 2006 and 2010. The 2010 KRTM employment categories were aggregated from NAICS employment codes whereas the 2006 model had used the older SIC codes. Table 4 shows the difference in definitions included in KRTM's four employment categories with regard to NAICS and SIC codes.

Table 4 SIC and NAICS Employment Category Changes

KRTM Employment Categories	SIC Categories used in 2006	NAICS Categories used in 2010
Basic	FARM EMPLOYMENT AGRICULTURAL SERVICES, OTHER MINING CONSTRUCTION	FARM EMPLOYMENT FORESTRY, FISHING, RELATED ACTIVITIES and OTHER MINING UTILITIES CONSTRUCTION
Industrial	MANUFACTURING TRANSPORT, COMM. & PUB. UTIL WHOLESALE TRADE	MANUFACTURING WHOLESALE TRADE TRANSPORTATION and WAREHOUSING
Retail	RETAIL TRADE	RETAIL TRADE ACCOMMODATION and FOOD SERVICES
Service	FINANCE, INS. & REAL ESTATE SERVICES FEDERAL CIVILIAN GOVT FEDERAL MILITARY GOVT STATE AND LOCAL GOVT	INFORMATION FINANCE and INSURANCE REAL ESTATE and RENTAL and LEASE PROFESSIONAL and TECHNICAL SERVICES MANAGEMENT of COMPANIES and ENTERPRISES ADMINISTRATIVE and WASTE SERVICES EDUCATIONAL SERVICES HEALTH CARE and SOCIAL ASSISTANCE ARTS, ENTERTAINMENT, and RECREATION OTHER SERVICES, EXCEPT PUBLIC ADMINISTRATION FEDERAL CIVILIAN GOVERNMENT FEDERAL MILITARY STATE and LOCAL GOVERNMENT

In addition to the code definition changes, it is plausible that the retail and service sector employment is attracting more workers from outside of the region in 2010, that more resident workers are working multiple jobs, and higher jobless rates from the 2008 recession persist, resulting in lower growth in resident workers as compared to employment. As a result, lower growth in home-based work travel is expected with an increase in home-based other travel. Table 5 shows the change in zonal employment between 2006 and 2010.

Table 4 Zonal Employment 2006-2010

Employment Type	2006 KRTM	2010 KRTM in Old Coverage Area	2010 KRTM in New Coverage Area	2010 KRTM Total	Total KRTM Change 2006-2010
Basic	51,575	48,173	3,065	51,238	-0.7%
Industrial	96,684	71,853	12,588	84,441	-12.7%
Retail	103,165	114,229	7,091	121,320	17.6%
Service	281,632	307,279	18,061	325,340	15.5%
Total	533,119	541,200	40,805	582,005	9.2%

The TAZ layer employment is shown here to provide context, though zonal employment itself is not used during generation directly. Zonal employment is implicit through the incorporation of an accessibility variable in the generation regression equations that describe each zone's accessibility to employment and services (BLA Inc. 27-28). Later on, during the first distribution step, stop location choice, zonal employment is an important term in the logit models that determine destination attractions. Additional care in calibrating the destination choice model will be needed to ensure the change in employment code definitions is accounted for, since the employment sectors have different parameters in the utility terms of the stop location choice logit models (BLA Inc. 43-45).

The KRTM produces person tours and stops at a household level. The number of tours and stops of each type is estimated for each household using multiple regression models utilizing a disaggregate synthetic household and vehicle population as well as zonal accessibility variables. The tour and stop types included in the model are shown in Table 6, for more detail please consult the full model documentation (BLA Inc. 20-24).

Table 5 Tour and Stop Types

Tour Type	Stop Type	Description
Work Tour	Work (low income <$25K)	Work outside of home if household income < $25k/year (in 2006 dollars)
	Work (other)	Work outside of home if household income > $25k/year
	University/Education (Non-UT)	School - junior college, college / university, vocational school
	Other	Other Activities on Work Tours
UT Tour	Studies at UT	Studies at U. of Tennessee
	Other Activities on UT Tours	Other Activities on UT Tours
School Tour	School	School – Daycare to high school
	Other Activities	Other Activities on School Tours
Non-Work Tour	Short Maintenance (<30min)	Less than 30 minutes duration & Shopping (incidental or major), Personal Business, Medical / dental, Service pass., Chg mode
	Long Maintenance (>30min)	30 minutes or longer & Shopping (incidental or major), Personal Business, Medical / dental, Service passenger, Change mode
	Discretionary	Volunteer Work, Eat Out, Social / Recreational, Civic, Church Activities, Loop trips

Table 7 shows the tour and stop types generated by the model and compares the quantity generated from 2006 vs. the new 2010 base year.

Table 6 Total Tours and Stops Generated 2006 vs. 2010

Tour & Stop Generation	2006 Base	2010 Base Old Coverage Area	2010 Base New Coverage Area	2010 Base Total	Total Change 2006-2010
HH	360,392	367,264	28,892	396,156	10%
Work Tours	353,677	344,923	25,671	370,594	5%
Work Stops (lo inc)	84,190	74,541	6,040	80,582	-4%
Work Stops (other)	352,468	352,014	25,638	377,652	7%
College Stops (non-UT)	8,228	8,510	678	9,188	12%
Other Stops	333,978	327,859	22,652	350,511	5%
School Tours	160,589	178,054	15,002	193,056	20%
School Stops	164,315	182,184	15,350	197,535	20%
Other Stops	73,341	80,418	6,629	87,047	19%
Other Tours	518,874	568,726	46,631	615,357	19%
Short Maintenance Stops (<30min)	422,103	467,383	38,483	505,866	20%
Long Maintenance Stops	262,084	291,873	24,040	315,912	21%
Discretionary Stops	322,591	350,047	28,192	378,239	17%

Growth in work tours was the lowest, reflecting the marginal growth in overall resident workforce. Low income work stops showed a net decrease even with additional households indicating that low income workers in particular were affected by workforce contraction more than other income groups. Growth in college stops on work tours is the result of enrollment increases at community colleges across the region. School tours and stops grew the most, caused by strong growth in K-12 student population, which was greater than the rate of overall population growth. Other tours also showed high growth, caused by an increase in non-workers that included a slight uptick in the percentage of households with seniors.

The household generation rates in the 2010 KRTM are shown below in Table 8. Trips are calculated by adding tours and stops together. For comparison, average rates from the following sources are included: the NCHRP 365 report on Travel Estimation, the combined Travel Survey used in the estimation of the previous Knoxville model, the trip generation rates from the previous Knoxville Model base year 2006, the 2009 National Household Travel Survey Add-On for Tennessee, and those records from the 2009 NHTS Add-On from the Knoxville region. The base year 2010 trip rates have gone up from base year 2006, but remain within an acceptable range of other comparative estimates.

Table 7 Household Generation Rates

	NCHRP 365 Averages	Knoxville Combined HH Survey from 2000 and 2008	Previous Knoxville Model Base Year 2006	NHTS 2009 TN Statewide	NHTS 2009 Add-On for Knoxville Area	KRTM 2010
Tours/HH/Day	3.47	2.86	2.87	2.99	2.66	2.98
Stops/HH/Day	5.54	5.51	5.62	6.2	5.27	5.81
Trips/HH/Day	9	8.37	8.49	9.18	7.93	8.79
Stops/Tour	1.6	1.93	1.96	2.07	1.98	1.95

The NHTS sample for the Knoxville region is less than 300 households, hence those estimates may contain somewhat more error. Greater confidence can be had in the rates for TN as a whole, mainly because the sample size is much larger at 2,552 surveys. Also, the sampling scheme and weights were developed at a statewide level and therefore the statewide weights could slightly skew results in a regional sample. The increase in trip rates observed in base year 2010 compared with base year 2006 are attributable to the increase in household size of 3.4%, a demographic shift towards a higher percentage of students resulting in a greater rate of school tours, and an increase in non-workers including seniors that led to greater rates of other tours. The increased rates of school and other tours were greater than a decrease observed in work tour rates.

Special Generators

The KRTM has two special generator sub models for University of Tennessee Tours and Visitors tours. The UT Tours model uses a regression equation that factors UT student residents and University enrollment by zone (BLA Inc. 28). The 2010 TAZ layer was updated with resident student and enrollment data. Few additional resident UT student residents were added from zones in the new model coverage area in Hamblen County.

The visitor model is also a regression model that factors zonal hotel rooms and rental units in Sevier County (BLA Inc. 28). Increases in constructed lodging were added to the zonal layer, in particular in Sevierville, where approximately 890 hotel units were added. The hotel occupancy rate from the previous base year, 82%, which was based on July of 2006, was initially reduced in light of data from Pigeon Forge indicating a summer 2010 occupancy rate of 61%, (Pigeon Forge Department of Tourism 2010). However, during network assignment calibration, a trend of under-loading resulted in a return to the previous 82% rate, which provided a better 2010 calibration for modeled road volumes. Table 9 shows the UT and Visitor tour and Stops.

Table 8 Daily UT and Visitor Tours and Stops

Tour & Stop Generation	2006 Base	2010 Base Old Coverage Area	2010 Base New Coverage Area	2010 Base Total	Change 2006-2010
UT Tours	23,835	24,114	55	24,169	1%
Campus Stops	24,367	24,652	56	24,708	1%
Other Stops	18,580	18,797	43	18,839	1%
Visitor Tours	27,555	28,099	-	28,099	2%
Visitor Stops	41,332	42,148	-	42,148	2%

LAMTPO Model Comparison

Since the KRTM 2010 Base year now includes the entire area previously modeled by the LAMTPO model, a comparison of the two models is instructive as a QA/QC check. Figure 3 shows the geographic area of the LAMTPO model overlaid on the KRTM coverage area.

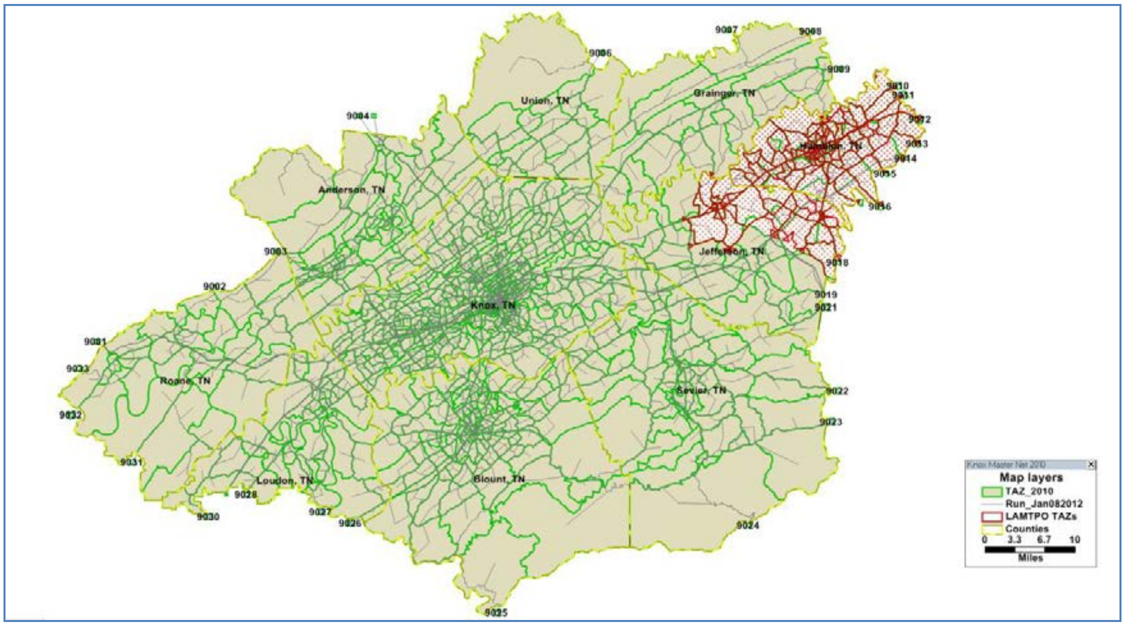

Figure 3 The LAMTPO Model Area Shown Within the KRTM Area

The area includes Hamblen County and a large portion of north eastern Jefferson County. Table 10 compares the zonal demographic information in the two models. Differences result from both 2006-2010 population growth and apparent employment decline, but are also likely due to data source discrepancies, particularly for employment. Still, the zonal demographics of the two models were similar enough to warrant a comparison of trip generation rates.

Table 9 LAMTPO Model vs. KRTM Zonal Demographics

Variable	2006 LAMTPO Model	2010 KRTM Synthetic Population (Zones in LAMTPO Area)	Difference KRTM-LAMTPO
HH	32,800	33,386	1.8%
HH Population	80,202	83,556	4.2%
HH Size	2.45	2.50	
Workers	38,210	36,680	-4.0%
Employment	56,021	48,541	-13.4%
K12 Students	N/A	13,962	
% of HH with Senior present	N/A	25.8%	
Vehicles	61,485	62,730	2.0%
Veh_Per_Person	0.77	0.75	-2.1%

The LAMTPO model is a trip based model that uses regression equations to generate HBW, HBO, and NHB trips (WSA 10). The generation rates in the model were informed by a Lakeway Area Households

Survey conducted in 2009 that sampled 498 households, as well as the 2009 NHTS Add-On for small and non -MSA areas in Tennessee. Household trip rates from the LAMTPO model have been converted to tours and stops in Table 11 below for comparison.

Table 10 LAMTPO Model vs. KRTM Generation Rates

	Lakeway Survey	LAMTPO Model 2006 Base	2010 KRTM (Zones in LAMTPO Area)
Tours/HH/Day	2.77	3.10	3.03
Stops/HH/Day	6.06	6.09	5.83
Trips/HH/Day	8.83	9.19	8.86
Stops/Tour	2.19	1.97	1.92

The overall household tour and trip generation rate was slightly higher in the LAMTPO model area when compared with the overall KRTM model. This was reflected in the LAMTPO Model as well as the KRTM, at just over 3 tours per household. The stops per tour and trips per day in the KRTM are slightly lower than the LAMTPO model, though overall the generation rates between the two models are quite close.

External Trips

The KRTM generates external travel with input files for auto and truck external-external (EE) origins and destinations, as well as an external-internal (EI) productions input file. The model uses a process of modeling internal attractions with regression equations that include employment, households, and lodging. After internal attractions are generated, a doubly constrained gravity model is used to connect EI trips to external stations (BLA Inc 91).

For the 2010 update, external stations at the edge of the old model located in Hamblen and Grainger Counties were moved to reflect the new extent of the model. There are 12 new external station locations. By subtracting the loss of 8 previous station locations that are now internal to the model, a net gain of 4 external stations resulted bringing the total to 33.

Table 11 New External Station Locations

New External Stations		
2010 Station Number	Name	County Location at Model Perimeter
9007	US 25E	Claiborne
9008	SR 131	Hancock
9009	Highway 11W	Hawkins
9010	US 11E	Hawkins
9011	St Clair Rd	Hawkins
9012	E Andrew Johnson Hwy	Hawkins
9013	Mountain Valley Rd	Greene
9014	I-81	Greene
9015	Fish Hatchery Rd	Greene
9016	Enka Hwy	Cocke
9017	Spencer Hale Rd	Cocke
9033	US 70	Cumberland
Old Station Locations Now Internal to the Model		
	Name	County Location at Model Perimeter
	SR 131	Grainger
	US 11 W	Grainger
	SR 375	Grainger
	US 11 E	Hamblen
	Hwy 341	Hamblen
	Hwy 66	Hamblen
	I-81	Hamblen
	US 25E	Hamblen

In terms of EE travel, the most significant new stations on roads that were not previously modeled as externals (as opposed to stations that were simply moved to a new location further out on the same road) are at US25E and nearby US11W in Grainger County (stations 9007 and 9009 respectively). At these two stations, most of the new EE travel occurs between each other, 52%. Likewise a station was added at US 70, parallel to the I-40 station entering Roane County (station 9033), where much of the new EE travel is to/from nearby US 27,67% (station 9032).

Figure 4 shows the location of the 2010 KRTM external stations with new or moved stations shown in red.

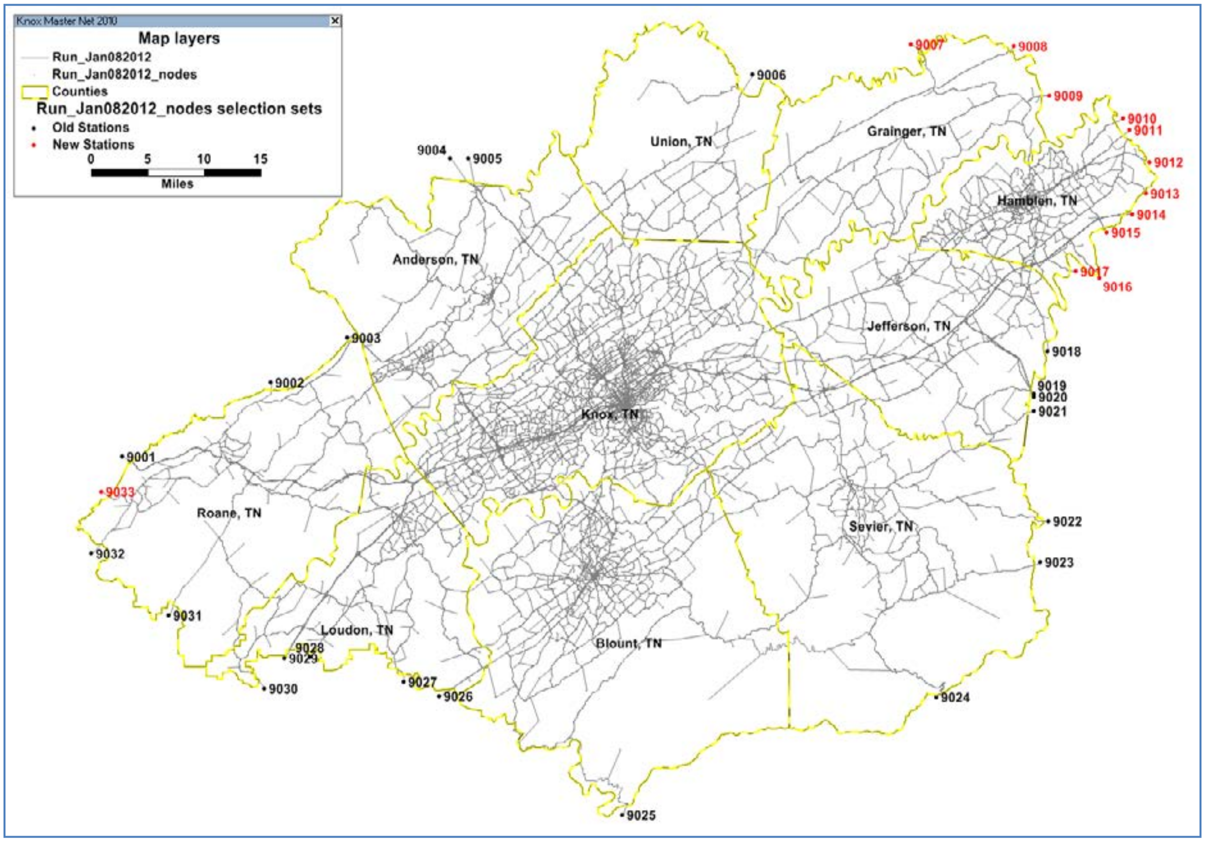

Figure 4 2010 KRTM Base Year External Stations

Tour Mode Choice

The tour mode choice model update consisted of creating new input networks for walk and transit as well as well a re-organization of the way the model creates transit impedance during the transit network skimming process. The transit skim changes in the main KRTM model were motivated by a desire to be more consistent with the new transit add-on tool that was developed concurrently with this main model update by The Corradino Group. The transit add-on tool is designed to run after the main model for detailed transit forecasts by transit route and uses a separate trip mode choice model as documented in the report *Knoxville Transit Model User Guide* (Corradino 2012).

The KRTM tour mode choice approach to a simplified transit forecast based on largely on accessibility variables will continue to be useful for planning purposes where zonal transit and walk mode shares are of interest, but transit route specific ridership forecasts are not needed. Full documentation on the KRTM's tour mode choice model methodology is available in the main model's technical documentation (BLA inc. 31-42).

Updates to the Non-Motorized Network

The 2010 non-motorized network is used to estimate walk times from zone to zone and was made from a 2010 GIS layer of all streets in the updated model coverage area with the exception of interstate highways. During the non-motorized skimming process, the shortest walk path between each zone is obtained to calculate the various walk accessibility variables to/from each zone. Walk speed continues to be estimated at an average of 3mph. Another important variable in the tour mode choice model is the sidewalk percentage of each zone. This was updated with a new sidewalks and greenways layer created by KRTPO that consisted of an updated and more complete network of sidewalk and pedestrian path coverage than was available in 2006. A comparison of sidewalk coverage between the 2006 and 2010 models is shown below, indicating that overall percentage of sidewalks in the model increased from 9.9% to 11.5%.

Table 12: Sidewalks as a Percentage of Road Miles

	2006 TAZ Layer Old Coverage Area	2010 TAZ Layer Old Coverage Area	2010 Zones in New Coverage Area	2010 Zones in LAMTPO Model Coverage Area Only	2010 KRTM TAZ Layer Total
Non-Motorized Network Road Miles	16,817	16,932	1,466	1,644	18,398
Sidewalk and Greenway Length in miles	1,660	1,929	184	224	2,113
Sidewalk Percent	9.9%	11.4%	12.5%	13.7%	11.5%

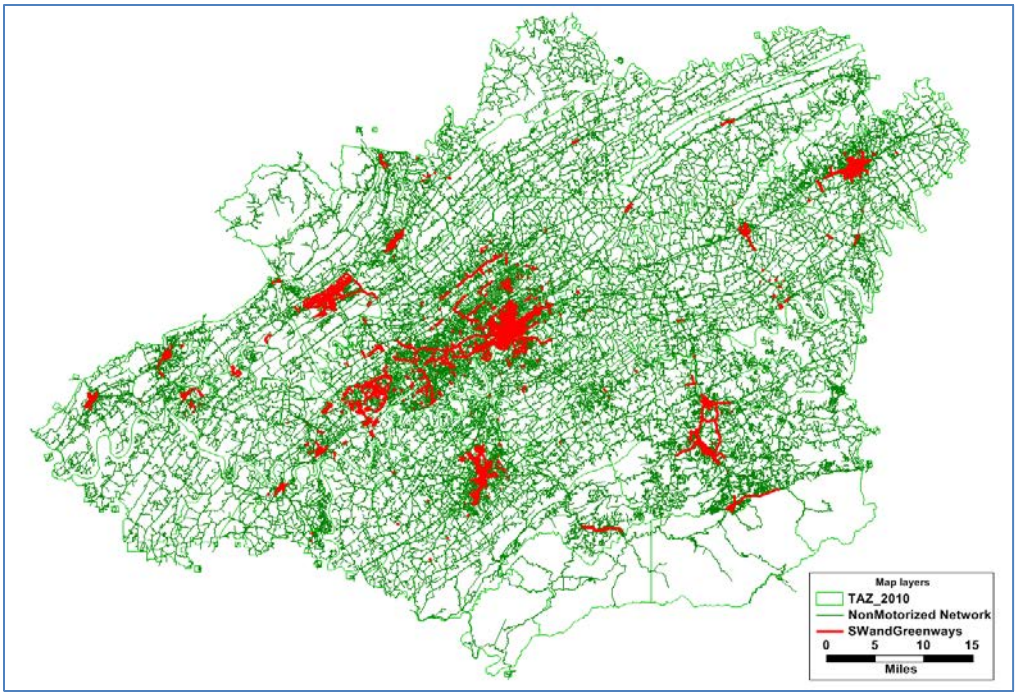

Figure 5: The Non-motorized Network and Sidewalks and Greenways Layer

Updates to the Transit Network and Skim Process

The transit network reflecting the KATS bus route system was updated by KRPTO to reflect the 2010 system. The footprint and coverage area of the bus system remained nearly the same as before, meaning the area within a half-mile walking distance to transit was essentially unchanged. New to this model update, is the designation of park and ride nodes on the highway layer as part of the Corradino transit add-on tool. Additionally, the KRTM model's tour mode choice model now utilizes the same peak walk and drive transit skims from the transit add-on tool for the estimation of the lowest generalized cost transit path between zones in the transit coverage area. The lowest generalized cost transit paths are then used to calculate each zone's transit accessibility variables, which are then used by tour mode choice to estimate zonal transit share. The transit coverage area for tour mode choice has been expanded from the half mile buffer around each bus route to include zones within a 5 mile radius around each park and ride station. The 5 mile radius was chosen as being the longest radial distance that still gave a reasonable estimation of daily transit ridership using the tour mode choice model. With KRTM's modified transit skim procedure, the tour mode choice model will be sensitive to service changes such as premium transit and park and ride lots. This will allow the main model's tour mode choice model to remain more consistent with the transit add-on tool over time.

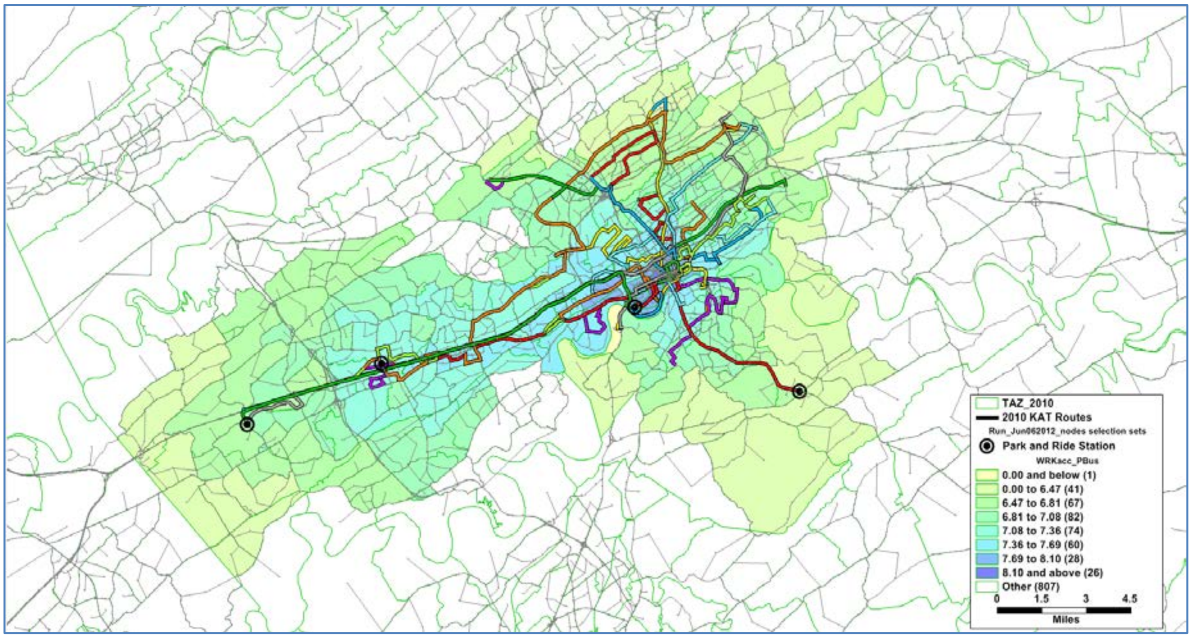

Figure 6 The 2010 KATS Route System with Transit Work Tour Accessibility by Zone Shown in the Background

The resulting tour mode shares were checked against the 2006 model as well as the shares from the 2000 and 2008 household travel surveys on which the KRTM is based. Results showed that for work, school, and other tours a minor shift toward walking and transit occurred. This is the result of the increase in walk accessibility from added sidewalk coverage and the new approach to the tour mode choice transit skims that includes drive access skims and additional accessibility area around the park and ride nodes. The magnitude of the tour mode shift showed reasonable change when compared to the 2006 model and survey targets so as not to warrant a major re-calibration of the modal bias constants.

Table 13: Tour Mode Shares by Tour Type

	Work Tours			UT Tours			School Tours			Other Tours		
	Survey	2006 Model	2010 Model	Survey	2006 Model	2010 Model	Survey	2006 Model	2010 Model	Survey	2006 Model	2010 Model
Auto	98.79%	98.77%	98.48%	90.01%	79.06%	82.56%	81.15%	81.15%	81.07%	98.19%	98.18%	97.84%
Transit	0.62%	0.64%	0.75%	1.95%	3.74%	2.49%	0.18%	0.18%	0.14%	0.10%	0.11%	0.12%
Walk/Bike	0.60%	0.59%	0.78%	8.05%	17.20%	14.96%	1.07%	1.08%	1.29%	1.71%	1.71%	2.04%
School Bus							17.59%	17.58%	17.51%			

In the case of the university tours, a shift towards auto was observed of approx. 3.5%. Causes of this include the splitting of zones in the UT campus area that resulted in a finer zonal fidelity, but also marginally longer distances between campus zones in the model. In addition, the off campus student population had a weighted average distance of about 1 mile further away from campus as compared to the 2006 model. Since the probability of auto in tour mode choice increases with distance from campus, this appears to have raised the auto share of UT tours. As explained in the full model documentation, the UT tours mode split was not calibrated to the household travel survey because of the small sample size of UT tours. The resulting 2010 UT mode split is still between the two bookend data points used during the 2006 model calibration, the household survey and the *Indiana University Travel Demand Survey (BLA Inc. 40).*

As stated in the main model documentation (BLA Inc. 40), the visitor tours mode share is fixed in the KRTM and remain so in this update. The shares are from The Lake Tahoe Resident and Visitor Model (PB, 2007) and are 90.05% auto, 1.31 % transit, and 1.51% Walk/Bike.

The estimated transit ridership resulting from the tour mode choice mode shares are shown below. The estimated daily weekday transit ridership was 10, 126. This assumes a system wide transfer rate of 1.3 boardings per linked trip. While this is 10% over the averaged 2010 observed ridership target, given the added tour mode choice sensitivity to drive accessibility, these results should be a worthwhile trade off as compared to keeping the tour mode choice model sensitive to walk access only. When detailed transit forecasts are needed, KRPTO will now use the Corradino's Transit Add-on tool, yet the main model's tour mode choice will still remain a useful tool to estimate walk and transit zonal mode share and can also provide a second data point for system ridership potential.

Table 14: 2010 Transit Ridership Results

	2006 KRTM	2010 Observed*	2010 KRTM	Estimated vs. Observed
Transit Person Trips	7,100		7,789	
Estimated Weekday Transit Boardings (unlinked trips)	9,220	9,194	10,126	10.1%

*2010 Observed Ridership is an average of Oct. 2010 and Oct 2011 due to route system changes in August 2010.

Trip Distribution

Trip distribution is accomplished in Knoxville's hybrid model through a double destination choice framework comprised of stop location choice and stop sequence choice. In the first step, stop location choice, travelers choose where they will stop on various tours (e.g., their work location, where they will stop on the way to and from work, etc.). In the second step, stop sequence choice, the chosen stop locations are connected to form trips (e.g., from home the traveler will go to Starbucks first, then from Starbucks to work).

For more background on the theory and details of the destination choice model specifications refer to the Knoxville Regional Travel Demand Model Update 2009: Model Development and Validation Report. This update did not include any substantial changes to the destination choice models. As with the 2009 calibration, only two variables' parameters were adjusted in calibration, the parameter on the term comprised of travel time interacted with residential accessibility which controls general willingness-to-travel and the intrazonal bias term. The original, statistically estimated values for these parameters, along with their 2009 and 2012 calibrated values are displayed in Table 15. Most of the destination choice models have fairly complex utility functions including a number of other terms, but these have remained unchanged from the estimated 2009 values. Most of the adjustments, particularly to the willingness-to-travel, were small, although some adjustments were needed, more so for the intrazonal biases to adjust for changes to the model including zone splits, the addition of new geography and minor changes in the impedances. The UT Campus stops are not included below because they do not require a destination choice model since their destination is known, by definition.

Table 15 Calibrated Stop Location Choice Parameters

	Travel Time x Residence Accessibility			Intrazonal Bias		
	Estimated	Calibrated 2009	Calibrated 2012	Estimated	Calibrated 2009	Calibrated 2012
Work Tours						
Work (lo inc)	-0.0114	-0.0137	-0.0156	0.0875	0.4872	0.5615
Work	-0.0101	-0.0103	-0.0108	-0.1310	0.8435	0.7909
College	-0.0064	-0.0112	-0.0113		-5.0000	0.0000
Non-work	-0.0156	-0.0148	-0.0154	1.8346	0.6641	0.2870
UT Tours						
Other	-0.0160	-0.0107	-0.0055	4.2305	0.6858	2.5000
School Tours						
School	-0.0238	-0.0257	-0.0284	0.9530	0.9580	1.4144
Other	-0.0216	-0.0210	-0.0222	1.9198	0.7853	0.4335
Other Tours						
Short Maintenance	-0.0221	-0.0329	-0.0198	-0.2101	0.9721	0.2733
Long Maintenance	-0.0167	-0.0205	-0.0217	0.0790	0.4864	0.1771
Discretionary	-0.0240	-0.0276	-0.0300	-0.0730	0.7572	0.4284

With these fairly minimal calibration adjustments, the model was able to produce trip lengths and intrazonal shares in good agreement with those observed from Knoxville's travel surveys. Table 16 presents the travel time between home and the stop locations and the percent of intrazonal stops for each stop type, as observed in the combined household survey for the region used to estimate the models and as produced by the calibrated models.

Table 16 Stop Lengths and Intrazonal Shares

	Mean Travel Time from Home (min)		Percent Intrazonal	
	Observed	Model	Observed	Model
Work Tours				
Work (lo inc)	15.3	14.9	3.3	3.3
Work	18.5	18.4	3.0	3.0
College	20.8	21.7	0.0	0.6
Non-work	14.6	14.4	4.2	4.5
UT Tours				
Other	15.9	14.6	4.2	3.1
School Tours				
School	10.1	9.9	11.3	11.3
Other	12.4	12.8	8.8	9.0
Other Tours				
Short Maintenance	11.7	10.7	7.6	6.3
Long Maintenance	15.0	15.2	3.4	3.6
Discretionary	14.2	15.7	6.6	6.7

The travel times and intrazonal percentages are in good agreement with the observed values from the survey. They were not calibrated to reproduce the observed values exactly as in the prior version of the model in part due to emerging research that suggests that over-calibrating to trip lengths can result in a worse model overall (See Ye, X., W. Cheng and X. Jia, A Synthetic Environment to Evaluate Alternative Trip Distribution Models, Presented at the 91st Annual Meeting of the TRB, January 2012).

The results of the work location choice models were also compared to Journey-to-Work data from the US Census Bureau. The most recent available Census Transportation Planning Package (CTPP) that provides county-to-county work flows is based on the 2006-2008 American Communities Survey (ACS). The flows are displayed in Table 17.

Table 17 Census Journey-to-Work Flows from ACS 2006-2008

	ANDERSON	BLOUNT	GRAINGER	HAMBLEN	JEFFERSON	KNOX	LOUDON	ROANE	SEVIER	UNION	Total
ANDERSON	19,040	315		30	25	**9,265**	105	975	15		29,770
BLOUNT	885	37,005				**13,910**	640	175	1,655		54,270
GRAINGER	50	55	3,175	2,130	570	**2,505**		15	425		8,925
HAMBLEN		150	305	20,355	1,860	720			455		23,845
JEFFERSON	20	100	75	3,835	10,000	**4,470**	35		**2,690**		21,225
KNOX	**11,810**	**6,725**	90	285	555	177,015	2,195	885	2,005		201,565
LOUDON	775	1,495				**5,990**	10,580	230	55		19,125
ROANE	4,380	230				3,855	1,095	11,005			20,565
SEVIER	215	1,010		345	320	**7,455**	125		29,670		39,140
UNION											0
	37,175	47,085	3,645	26,980	13,330	225,185	14,775	13,285	36,970	0	418,430

Due to limited sample sizes and disclosure protection rules, however, some data including all data for Union County was suppressed. It was therefore helpful to estimate a complete set of flows for the year 2010 by enhancing the CTPP 2006-2008 data with information from the more complete CTPP 2000 as well as more recent estimates of total county work flows from ACS for 2010. The resulting estimated 2010 flows based entirely on Census Journey-to-Work data are presented in Table 18.

Table 18 2010 County-to-County Work Flows from Census Journey-to-Work Data

	ANDERSON	BLOUNT	GRAINGER	HAMBLEN	JEFFERSON	KNOX	LOUDON	ROANE	SEVIER	UNION	Total
ANDERSON	20,480	319	*17*	32	26	**9,424**	114	1,108	15	*21*	31,557
BLOUNT	906	35,585	*0*	*82*	*43*	**13,431**	660	190	1,607	*11*	52,515
GRAINGER	50	51	3,223	2,125	550	**2,338**	*12*	16	399	*208*	8,970
HAMBLEN	*35*	146	324	21,253	1,880	706	*23*	*12*	448	*13*	24,839
JEFFERSON	20	95	77	3,892	9,813	**4,249**	36	*28*	**2,572**	*0*	20,782
KNOX	**12,240**	**6,550**	95	297	560	173,111	2,290	971	1,972	*577*	198,664
LOUDON	793	1,436	*0*	*11*	*32*	**5,779**	10,897	249	53	*0*	19,251
ROANE	4,618	228	*0*	*21*	*0*	3,839	1,162	12,269	*0*	*0*	22,137
SEVIER	225	994	*47*	363	326	**7,364**	132	*0*	29,471	*12*	38,934
UNION	*347*	*81*	*10*	*17*	*26*	*3,651*	*28*	*13*	*53*	*2,695*	6,921
	39,715	45,486	3,794	28,092	13,256	223,892	15,352	14,855	36,591	3,537	424,571

The modeled county-to-county work flows, presented in Table 19, agree very well. The level of agreement between these flows is, in fact, noteworthy. The commuting pattern exhibited in this ten county region is complex and asymmetrical. For instance, the reverse out-commute is dominant between Knox and Anderson Counties. The ability of the destination choice models to reproduce this pattern with the fidelity they exhibit is not to be taken for granted. Earlier trip-based gravity models of the region were not able to reproduce these patterns even with large k-factors. The destination choice models include no k-factors or any similar ad hoc factors that bias the model for or against particular OD pairs for no reason. The pattern is reproduced by the model completely on the basis of observed variables including travel times as well as accessibility variables and river crossings, land use mixtures, pay parking, etc.

Table 19 Modeled 2010 County-to-County Work Flows

Estimated 2010 ACS	ANDERSON	BLOUNT	GRAINGER	HAMBLEN	JEFFERSON	KNOX	LOUDON	ROANE	SEVIER	UNION	Total
ANDERSON	21,727	193	11	6	22	**7,447**	128	1,189	43	125	30,891
BLOUNT	872	36,664	17	17	62	**16,793**	1,579	308	1,918	13	58,243
GRAINGER	123	64	3,270	2,561	768	**2,684**	20	13	126	266	9,896
HAMBLEN	14	11	817	22,689	2,500	538	3	2	241	8	26,822
JEFFERSON	140	113	378	4,593	9,529	**4,593**	27	17	**2,680**	34	22,104
KNOX	**11,383**	**5,574**	559	188	735	183,831	2,542	1,566	1,374	822	208,574
LOUDON	714	1,623	6	4	13	**7,736**	9,016	1,592	48	6	20,758
ROANE	4,943	210	3	2	6	2,835	1,718	12,848	13	5	22,582
SEVIER	191	1,861	48	418	1,429	**7,212**	50	24	33,489	18	44,740
UNION	935	53	270	35	45	**2,897**	20	24	33	2,517	6,828
	41,040	46,366	5,380	30,513	15,110	236,565	15,101	17,582	39,966	3,815	451,438

While the stop location choice models continued to reproduce travel patterns very well for the region as a whole, the Knoxville regional stop location choice models did not initially do a particularly good job for non-work tour stops in the new Morristown area. Without further adjustments the models predicted stop locations too close to home in Morristown. Therefore, an adjustment was made to the travel time residential accessibility interaction variable in Hamblen County to produce stop locations more appropriately spaced from home. While this does raise some questions about the transferability of these models to predict travel behavior in Morristown in general, the ability of the work location choice models to reproduce CTPP commuting flows for Hamblen County with a high degree of accuracy offers an encouraging counterpoint.

The Knoxville regional model also includes a simple gravity model for visitor stops generated by tourists staying in Sevier County's tourism area from the Smoky Mountains and Gatlinburg north through Pigeon Forge to Sevierville. Lacking any local data, that model was borrowed from the Ohio Statewide Model.

In this update, it was adjusted in response to low traffic in Sevier County and the willingness-to-travel parameter on travel time was increased from -0.10 to -0.05 resulting in slightly longer trips and more tourism related traffic.

After the completion of the stop location choice models, the second step of Knoxville's double destination choice framework are the stop sequence choice models. These models are simpler than the stop location choice models as there sole purpose is to connect the predicted stops into trips, and ultimately, tours. For more information on Knoxville's stop sequence choice models, refer to the 2009 model development and validation report referenced previously. One peculiarity of these models worth repeating here is the meaning of travel time sensitivity in this context. After stop location choice, the stop locations have been determined, hence the sensitivity to travel time in stop sequence choice really just controls the relative length of home-based and non-home-based trips. Since home-based trips tend to be longer, on average, they actually take a positive travel time parameter; whereas, since non-home-based trips tend to be shorter, they take a negative parameter.

Table 20 Stop Sequence Choice Model Parameters

	Travel Time		Intrazonal	
Trip Type	2009 Model	2012 Model	2009 Model	2012 Model
Work Tours - Home-Based Trips	0.070	0.069	-1.743	-1.720
Work Tours - Non-Home-Based Trips	-0.194	-0.185		
UT Tours - Home-Base Trips	0.000	0.000	-3.963	-3.963
UT Tours - Non-Home-Base Trips	-0.055	-0.055		
School Tours - Home-Based Trips	-0.080	-0.080	-3.912	-4.269
School Tours - Non-Home-Based Trips	-0.119	-0.110		
Other Tours - Home-Based Trips	0.030	0.029	-2.064	-2.096
Other Tours - Non-Home-Based Trips	-0.146	-0.117		

The stop sequence choice parameters are displayed in Table 20. Some adjustments were made to the original values from the 2009 model development, but they were small. Table 21 displays the resulting average trip lengths and interzonal percentages and the observed values from the combined regional survey. With the minor adjustments documented above, the models remain well calibrated, in good agreement with the survey.

Table 21 Stop Sequence Choice Model Calibration Statistics

	Average Travel Time		**Percent Diagonal**	
Trip Type	Observed	Model	Observed	Model
Work Tours	**14.9**	14.5	**5.1**	4.0
Work Tours - Home-Based	16.3	16.1	4.1	5.0
Work Tours - Non-Home	12.4	11.7	7.0	2.1
UT Tours	**15.0**	10.6	**1.2**	1.6
UT Tours - Home-Base	16.3	10.8	0.6	2.0
UT Tours - Non-Home	12.1	9.9	2.7	0.3
School Tours	**10.5**	10.5	**10.7**	8.8
School Tours - Home-Based	10.3	10.2	11.0	10.3
School Tours - Non-Home	11.2	12.2	9.8	0.6
Other Tours	**12.1**	11.9	**8.5**	5.5
Other Tours - Home-Based	12.7	12.7	7.6	7.4
Other Tours - Non-Home	10.6	9.9	10.8	1.2

Trip Mode Choice

As in activity-based models, Knoxville's regional model develops mode splits and vehicle occupancies in two stages, tour mode choice and trip mode choice. While tour mode choice assigns the dominant mode for the tour and largely determines mode splits between transit and auto, trip mode choice is important for splitting auto travel into single occupant vehicle (SOV) and high occupancy vehicle (HOV) trips as well as identifying walk trips on auto-based tours, as when a person drives to and from work but walks to and from lunch midday.

A review of Knoxville's 2009 trip mode choice model by Dunbar Consulting produced a recommendation to eliminate the multiple HOV classes in favor of a simpler scheme with a single HOV class. In response to this recommendation the trip mode choice models were re-estimated from the original survey data using this scheme. The new model specifications are presented below in Table 22 through Table 27.

Table 22 Work Tour Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Alternative Specific Parameters			
CONSTANT	Walk	-8.3507	*
CONSTANT	HOV	-5.2394	*
LnWalkTime	Walk	-0.9544	-3.2642
Zonal Average Household Size	HOV	0.382	6.2559
K-12 Enrollment	HOV	0.0003	6.9309
Employment to Population Ratio	HOV	-0.0019	-2.9363
General Accessibility	DriveAlone	-0.0819	-3.7213
Intersection Approach Density	Walk	0.0008	1.7378
Gas Price (2006 $)	Walk	1.7234	2.9396
-- Model Statistics			
Log Likelihood at Zero		-8603.9381	
Log Likelihood at Constants		-3037.7239	
Log Likelihood at Convergence		-3482.0213	
Rho Squared w.r.t. Zero		0.5953	

*Constants were adjusted in calibration. The original estimated values were -8. 1845 for walk, -6.4800 for HOV.

Table 23 Work Tour Non-Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Alternative Specific Parameters			
CONSTANT	Walk	-4.1133	*
CONSTANT	HOV	-1.7371	*
WalkTime	Walk	-0.0551	-5.2483
Employment to Population Ratio	HOV	-0.0014	-2.7322
Intersection Approach Density	Walk	0.0007	3.5787
Percent Pay Parking	Walk	4.6914	5.1745
Percent Pay Parking	HOV	0.945	2.0421
Gas Price (2006 $)	Walk	0.728	3.2965
Gas Price (2006 $)	HOV	0.2242	3.4314
-- Model Statistics			
Log Likelihood at Zero		-4956.6986	
Log Likelihood at Constants		-2030.9258	
Log Likelihood at Convergence		-2256.9768	
Rho Squared w.r.t. Zero		0.5447	

*Constants were adjusted in calibration. The original estimated values were -4.3257 for walk, -3.3156 for HOV.

Table 24 School Tour Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Logsum Parameters			
Drive		0.7769	constrained
-- Alternative Specific Parameters			
CONSTANT	Walk	-1.8050	*
CONSTANT	HOV	-0.7769	*
WalkTime	Walk	-0.0234	-3.6705
Zonal Average Household Size	HOV	0.1686	1.4871
K-12 Enrollment	Walk	0.0003	1.9752
General Accessibility	HOV	0.0508	1.872
-- Model Statistics			
Log Likelihood at Zero		-3134.9913	
Log Likelihood at Constants		-2498.361	
Log Likelihood at Convergence		-2868.9366	
Rho Squared w.r.t. Zero		0.0849	

*Constants were adjusted in calibration. The original estimated values were -1.517 for walk, -1.4932 for HOV.

Table 25 School Tour Non-Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Logsum Parameters			
Drive		0.7093	constrained
-- Alternative Specific Parameters			
CONSTANT	Walk	-2.5221	*
CONSTANT	HOV	-0.7332	*
WalkTime	Walk	-0.0434	-2.8182
K-12 Enrollment	Walk	0.0003	1.5146
Gas Price (2006 $)	Walk	0.7781	1.7504
-- Model Statistics			
Log Likelihood at Zero		-942.9249	
Log Likelihood at Constants		-765.4386	
Log Likelihood at Convergence		-868.2207	
Rho Squared w.r.t. Zero		0.0792	

*Constants were adjusted in calibration. The original estimated values were -2.7998 for walk, 0.2756 for HOV.

Table 26 Other Tour Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Alternative Specific Parameters			
CONSTANT	Walk	-4.8577	*
CONSTANT	HOV	-0.4572	*
WalkTime	Walk	-0.008	-2.9291
Zonal Average Household Size	HOV	0.1143	3.3696
Zonal Average Vehicle Ownership	Walk	-0.5917	-2.8215
Zonal Percent of HH with Seniors	Walk	-1.9187	-1.7424
Tourist TAZ	Walk	0.5151	1.0181
Tourist TAZ	HOV	0.43	4.1341
Percent Pay Parking	Walk	0.8474	1.#IO
Percent Pay Parking	HOV	0.8474	1.8385
Gas Price (2006 $)	Walk	1.3209	4.2616
Gas Price (2006 $)	HOV	0.0677	2.1235
-- Model Statistics			
Log Likelihood at Zero		-13668.6753	
Log Likelihood at Constants		-9789.4925	
Log Likelihood at Convergence		-11368.7602	
Rho Squared w.r.t. Zero		0.1683	

*Constants were adjusted in calibration. The original estimated values were -4.485 for walk, -1.8086 for HOV.

Table 27 Other Tour Non-Home-Based Trip Mode Choice Model

Variable	Alternative	Parameter	t-statistic
-- Alternative Specific Parameters			
CONSTANT	Walk	-3.7155	*
CONSTANT	HOV	0.1672	*
WalkTime	Walk	-0.0168	-3.2439
Employment to Population Ratio	HOV	-0.0011	-2.8089
Percent Pay Parking	Walk	4.4276	2.7863
Percent Pay Parking	HOV	1.3371	2.4474
Gas Price (2006 $)	HOV	0.2709	5.4371
-- Model Statistics			
Log Likelihood at Zero		-5754.1179	
Log Likelihood at Constants		-3988.2919	
Log Likelihood at Convergence		-4933.536	
Rho Squared w.r.t. Zero		0.1426	

*Constants were adjusted in calibration. The original estimated values were -3.5136 for walk, -1.6492 for HOV.

Comparison with the 2009 trip mode choice models will show that the models are very similar in both specifications and parameter estimates as would be expected given the same base data, although a few marginally significant variables fell out of the specifications with the simplified mode alternatives. This last fact provides some evidence that Dunbar's comments may have been at least partially right in suspecting some over-specification in the original models. Moreover, the new simplified models were easier to calibrate to both observed mode shares and vehicle occupancies. Table 28 displays the observed and modeled vehicle occupancies and it is clear the model is reproducing the observed occupancies well.

Table 28 Trip Mode Choice Calibration Statistics

		Walk	SOV	HOV	Vehicle Occupancy
WHB	Observed	0.15%	82.55%	17.30%	1.12
	Modeled	0.15%	82.57%	17.28%	1.11
WNH	Observed	1.89%	78.37%	19.74%	1.11
	Modeled	1.90%	78.35%	19.74%	1.15
SHB	Observed	1.46%	17.00%	81.54%	1.91
	Modeled	1.43%	18.26%	80.30%	2.02
SNH	Observed	2.17%	21.51%	76.32%	2.04
	Modeled	2.16%	22.96%	74.88%	1.93
OHB	Observed	0.40%	42.98%	56.62%	1.52
	Modeled	0.40%	43.11%	56.49%	1.48
ONH	Observed	1.01%	38.87%	60.13%	1.49
	Modeled	1.00%	39.62%	59.38%	1.55

Network Assignment

In the final step of the travel model, the vehicle trip tables for each class are assigned to the model network. External automobile trips and single and multiple unit trucks are loaded first, on the assumption that they do not divert do to congestion. Then, local automobile trips are assigned routes through the network on the "user equilibrium" assumption that only minimum congested travel cost routes are used. The Knoxville regional model makes use of TransCAD 6.0's origin-based algorithm to solve for the user equilibrium solution to a greater precision (0.0001 relative gap) in less time. More precise or more tightly converged assignment solutions are more stable and have more localized sensitivity.

The previous version of the model included a simple improvement to just the truck assignment. In the absence of detailed information on truck prohibitions, load limitations, overhead clearance, turning radii and other detailed design and operational characteristics that impact truck route choice, a simple distance-based penalty was developed on the basis of the functional classification system with the assumption that higher functional class roadways would generally have design characteristics more appealing to trucks. This penalty term was added to the generalized cost for multi-unit trucks used in assignment.

The values of the penalties were developed heuristically, through trial and error, testing a variety of simple schemes and values. Although the overall statistical improvements were modest, there were significant improvements on several key routes and major origin-destination patterns in the area. Figure 8 and Table 32 present one extreme example. The fastest and shortest distance route from I-75 north of Knoxville to I-40 west of Knoxville is a combination of several state highways and a local road, Frost Bottom Road. However, from traffic counts it is evident that most trucks traveling between I-75 to the north and I-40 to the west do not use this route.

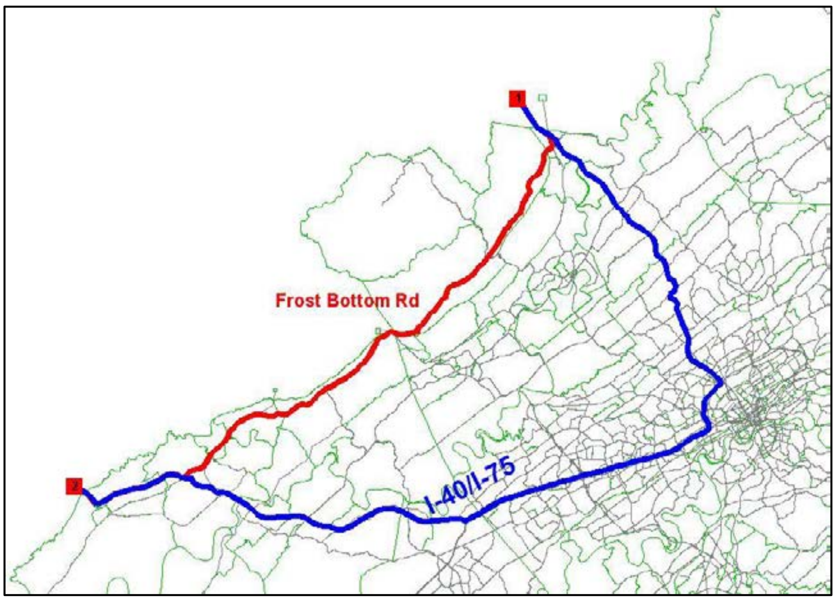

Figure 7 Example of Competing Routes between I-75 and I-40

Table 29 Generalized Costs for Competing Routes in Knoxville Example

Route	Travel Time (min)	Distance (mi)	Penalty (min)	Generalized Cost (min)
Frost Bottom Rd	*60.2*	*48.0*	61.3	121.5
Interstates I-40/I-75	66.7	73.5	37.0	*103.6*

The simple functional class-based penalty scheme presented above results in the realistic route choice following the designated interstate system and avoiding local roads and discontinuous state highways. Whereas assignments based only on travel time and distance always favored the Frost Bottom Road route, the generalized cost with the penalty shows the clear preference for the Interstates.

The new model built upon the success of the functional class-based penalties for multi-unit trucks and includes a complex generalized cost function with length penalties which vary by functional class for each vehicle class: cars, single unit trucks and multi-unit trucks. Higher penalties on lower functional classes capture drivers' preference to avoid lower class facilities and their lack of knowledge of lower class roads.

In this model update a genetic algorithm was used to statistically estimate the penalties based on their ability to reproduce observed traffic counts on the network rather than by simple trial and error. The procedure "evolves" a solution by making many assignments with different randomly generated parameters. Sets of parameters that result in poor loading errors (as measured by the %RMSE) are discarded, while parameters that produce good results survive and are recombined to find the best parameters for reproducing the observed truck counts. The random generation of new "mutant" parameters also informally incorporated Bayesian statistics by drawing from distributions which were conditioned on previous results as well as an original prior distribution.

Table 30 Length Penalties in Minutes per MIle by Vehicle Class and Functional Class

	Cars	Single Unit Trucks	Multi-Unit Trucks
Local Streets/Roads	1.71	2.70	25.50
Minor/Urban Collectors	0.78	2.24	21.17
Rural Major Collectors / Urban Minor Arterials	0.54	1.79	16.93
Rural Minor Arterials / Urban Principal Arterials	0.33	1.34	12.70
Rural Principal Arterials / Urban Freeways	0.25	0.89	8.38
Interstates	0.13	0.44	4.19

The length penalties estimated by the genetic algorithm are presented in Table 30 and Figure 8. Several logical patterns can be observed in the results. First, greater penalties are observed for lower functional classes. This corresponds to drivers' preferring higher class facilities, which stands to reason. (The parameter estimation was constrained to ensure that lower functional classes received equal or greater penalties than higher functional classes and assumed a linear pattern to start.) Second, drivers' preference to avoid low class facilities varies depending on their vehicle. Car drivers mainly prefer to avoid local roads and streets, and exhibit some preference for higher functional classes beyond that, but not an especially strong preference. Multi-unit truck drivers, on the other hand, prefer each successively higher functional class significantly more. This result is plausible, since trucks are affected by issues such as vertical clearance and turning radii that cars are not; whereas, cars' bias towards higher functional class facilities is likely mostly reflective of their imperfect knowledge of the network and lack of consideration of all possible routes using low class roadways. Third, the multi-unit trucks value saving distance much more relative to saving time as compared to single unit trucks and cars. This is generally reasonable and expected because fuel consumption is more based on distance, large trucks consume much more fuel per mile than smaller vehicles and are often more concerned with minimizing their operating costs than cars. Single unit trucks also value distance more than compared to cars, which generally are more concerned about minimizing travel time than travel costs.

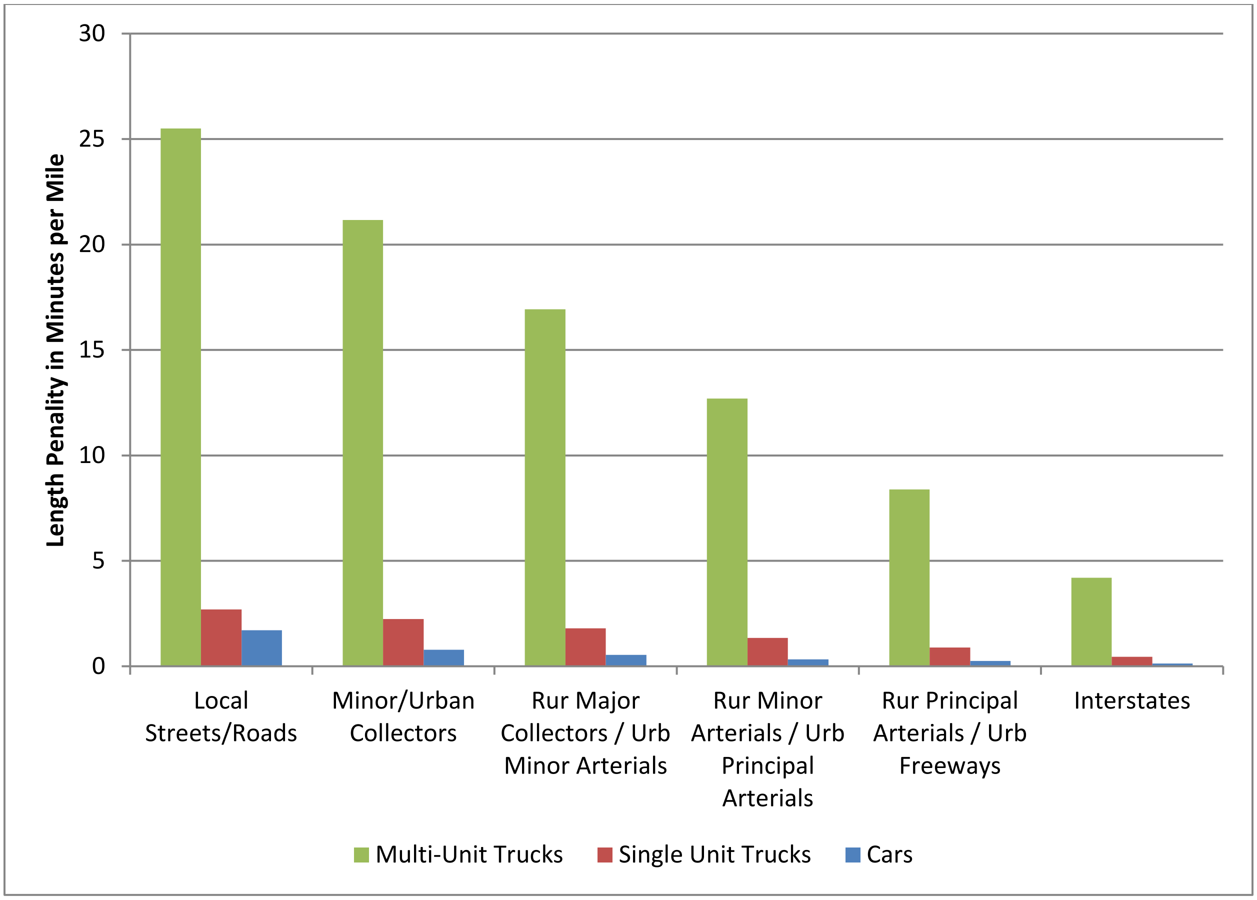

Figure 8 Patterns in Length Penalties across Functional Classes and Vehicle Classes

Table 31 Volume Delay Functions

	Alpha	Beta
Freeways	1.30	7.24
Partial Access Controlled	9.90	3.79
Signal Controlled	9.80	3.10
Special - Bridges	8.89	3.15
Special - Curves	8.00	4.00
All Other	0.99	4.36

The genetic algorithm also estimated turn penalties, truck PCE factors and volume delay function parameters for the assignment. The left turn penalty was estimated at 39.8 seconds of delay, while the right turn penalty was estimated at only 2.6 seconds of delay. Passenger car equivalencies of 1.4, 1.9 and 3.6 were used for four tire commercial vehicles, single unit and multiple unit trucks, respectively. The estimated volume delay functions are displayed in Table 31 and Figure 9. Functions were estimated for several broad categories of facilities as well as a few special facilities, such as bridges.

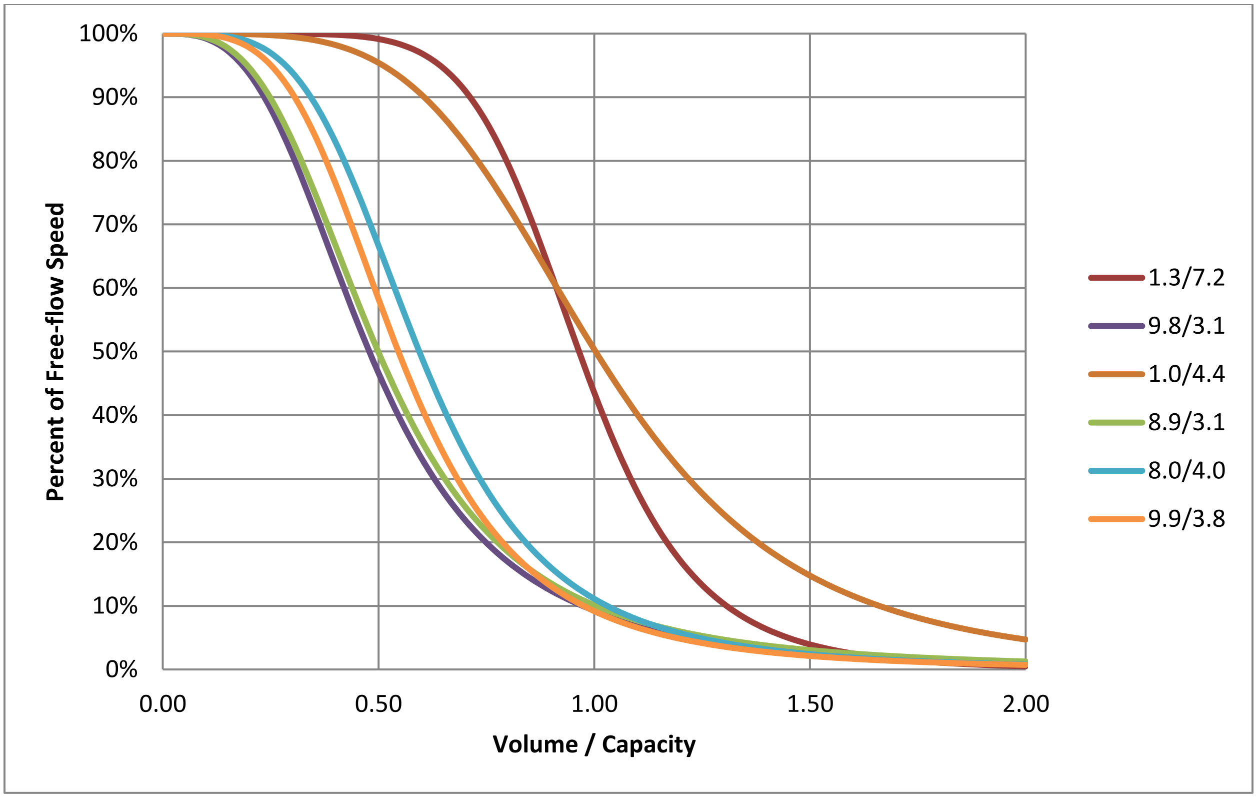

Figure 9 Volume Delay Functions

Total link daily volumes from the base year am, pm and off-peak assignments were validated by comparing the percentage difference between observed traffic count and estimated model volume on the link. The calibration/validation checks were performed based on *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee.* It recommended conducting the following checks using the criteria suggested by Federal Highway Agency (FHWA).

Criteria for acceptable errors between observed and estimated traffic volumes vary by facility type, according to the magnitude of traffic volume usage. For example, higher volume roadways have stricter calibration guidelines than those with lower volumes.

A new CAL_REP module was developed using the Geographic Information System Developer's Kit (GIS-DK) script language to create maps with a color theme based on loading error and a scaled symbol/width theme on absolute error as well as to report model performance for the:

- network as a whole,
- functional classes,
- volume group ranges,
- designated screenlines,
- designated corridors,
- area types, and
- counties.

Error statistics reported and used for diagnosing the possible sources of model error are:

- percent root mean square errors,
- systemwide average error,
- mean loading errors and percentage errors, and
- total VMT and percentage errors.

Attention is always needed to the traffic counts, themselves, since the validation is only as good as the counts. In the course of the model's validation, several bad counts/count errors were identified and removed or corrected in coordination with the TPO and TDOT. Interestingly, the interstate counts seemed to have the most issues. The two most significant and notable were the counts for I-81 which were recalculated by TDOT (being based on ramp counts, not actual counts on the mainline) and the truck counts on I-40 through Knoxville. There may be additional problems with some of the 2010 interstate counts on I-40 and I-75 which do not agree well with counts from early years, but they have been retained in the absence of better information. The model generally agrees better with the older counts and its error statistics would be lower if the new interstate counts are revisited.

Calibration and validation efforts always begin by trying to address any systematic global issues first and then proceeding to address more specific problems with particular subareas, corridors or individual links. In the course of this validation effort, the only two global adjustments were made:

- Some trip mode choice models were adjusted to reduce sensitivity to fuel prices since changes in fuel prices between 2006 and 2010 indicated some over-sensitivity to fuel price in vehicle occupancies.
- The genetic algorithm described above made adjustments to volume delay functions to improve the model's overall goodness-of-fit.

The limited number and nature of these global adjustments is a positive indication for the core validity of the model suggesting that the 2006 model was well calibrated.

A number of issues, however, were identified which affected particular subareas or corridors and the following actions were taken:

- The interaction between travel time and accessibility was altered for Hamblen County only to produce longer trip lengths to correct for under-loading specifically in the Morristown area.
- Different cost sensitivity parameters where assigned to various external stations in the distribution of internal-external trips. For instance, it was necessary to decrease the cost sensitivity for I-81 and I-40 east so that a reasonable portion of their external-internal trips would reach Knoxville.
- The visitor tour generation rate was increased to address under-loading in the tourism areas of Sevier County.
- A variety of centroid connectors were adjusted, mostly in Hamblen County.

The *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee* identifies several guidelines for demonstrating that a model is well calibrated. However, as the document itself is clear to state, the fulfillment of these guidelines does not ensure that a model is well validated nor does the failure of a model to meet every target or standard mean the model is necessarily not well calibrated. The tables below correspond to the standards adopted by TNMUG. In each case they compare the modeled traffic volumes to observed traffic counts. A variety of error statistics are used. Most of the guidelines focus on the simple Percent Error. The Percent Root Mean Square Error (% RMSE) is also used and is the traditional and perhaps the single best overall error statistic for comparing loadings to counts. It has the following mathematical formulation:

$$\%RMSE = \frac{\sqrt{\frac{\sum(Count - Loading)^2}{Number\ of\ Observations}}}{Average\ Count} \times 100$$

Although none of the Tennessee guidelines currently require other error statistics, two additional error statistics have been included in some of the tables below. The Mean Absolute Percentage Error (MAPE) has also been included as complimentary to the RMSE and representative of the absolute error based goodness-of-fit statistics. It is becoming a common error statistic in many other forms of computer modeling. It complements the RMSE in that the RMSE treats larger volumes as more important (i.e., it's most important to have the Interstates rights, not so important to have local street right); whereas, the MAPE treats all observations/errors equally. So, in many cases in travel modeling the %RMSE will be lower than the MAPE indicating that the model does better on larger facilities. The MAPE is calculated using the following formula:

$$MAPE = \frac{\left|\frac{Count - Loading}{Count}\right|}{Number\ of\ Observations}$$

The (student) t-statistic has also been included in some cases. The t-statistic indicates whether or at what level of confidence the difference between the model and the counts is statistically significant. The value of the t-statistic that indicates a significant difference between the model and the counts depends on the number of observations. Tables and calculators are widely available on the internet (Excel also includes this functionality). However, for large samples (more than 100 observations), a t-statistic of about 2.6 indicates 99% confidence that there is a significant difference and a t-statistic of about 2.0 indicates 95% confidence and about 1.7 indicates 90% confidence. However, higher t-statistics are required for the same level of confidence with fewer observations. So, for instance, for a category with only 10 counts, a t-statistic of 3.2 is required to reach the 99% confidence level.

Table 32 Volume to Count Ratios/Percent Error by Functional Class

	Area	# of Obs.	Mean Count	Mean Load	% Error	TNMUG Standard Acceptable	TNMUG Standard Preferable	% RMSE	MAPE	t
Freeways	Urban	114	71,397	71,335	**-0.1%**	**+/- 7%**	**+/- 6%**	13.3%	14.4%	0.0
	Rural	83	42,156	44,386	**5.3%**			14.4%	13.0%	0.6
Principal Arterials	Urban	200	24,379	24,094	**-1.2%**	**+/- 15%**	**+/- 10%**	19.0%	16.2%	-0.2
	Rural	40	11,756	12,378	**5.3%**			19.4%	12.5%	0.4
Minor Arterials	Urban	237	10,057	9,256	**-8.0%**			31.4%	31.9%	-1.4
	Rural	80	7,733	8,014	**3.6%**			21.4%	22.5%	0.4
Collectors	Urban	226	4,471	3,941	**-11.9%**	**+/- 25%**	**+/- 20%**	58.5%	47.3%	-1.5
	Rur Maj	148	3,089	3,551	**14.9%**			49.7%	51.4%	1.6
	Rur Min	144	1,518	1,456	**-4.1%**			73.5%	64.6%	-0.4
Locals	Urban	61	3,151	2,897	-8.1%	none	none	69.2%	99.9%	-0.5
	Rural	22	1,576	826	-47.6%			77.5%	59.7%	-2.5
All	Urban	838	19,811	19,346	-2.3%			23.9%	34.9%	-0.3
	Rural	517	10,248	10,781	5.2%			27.2%	41.8%	0.5
	All	**1615**	**14,388**	**14,389**	**0.0%**			**27.1%**	**37.9%**	**0.0**

Table 32 displays the volume to count ratios or percent errors for the model by functional class together with the Tennessee standards. The model clearly meets the standards for all classes. Based on the t-statistic, none of the classes are meaningfully different in the model versus the counts except possibly for rural local roads which appear significantly under-loaded, based on the limited sample of 22 counts. The minor overloading in rural areas is likely due in part to the sparseness of the network and coarseness of the zones in these parts of the model. Overall, however, the model appears well-calibrated with an overall RMSE notably less than 30% and better than any of the previous versions of the Knoxville regional model.

Table 33 Volume to Count Ratios/Percent Error by Volume Group

AADT	# of Obs.	Mean Count	Mean Load	% Error	TNMUG Standard Acceptable	TNMUG Standard Preferable		% RMSE	MAPE	t-stat
0 - 1000	159	613	864	**41.0%**	**+/- 200%**	**+/- 60%**		154.2%	96.3%	3.3
1001 - 2,500	283	1,687	1,903	**12.8%**	**+/- 100%**	**+/- 47%**		78.5%	58.7%	2.6
2,501 - 5,000	297	3,714	3,740	**0.7%**	**+/- 50%**	**+/- 36%**		55.2%	39.7%	0.2
5,001 - 10,000	305	7,244	7,185	**-0.8%**	**+/- 29%**	**+/- 25%**		36.5%	27.7%	-0.3
10,001 - 25,000	317	15,355	14,667	**-4.5%**	**+/- 25%**	**+/- 20%**		26.1%	19.8%	-1.9
25,001 - 50,000	145	36,039	37,443	**3.9%**	**+/- 22%**	**+/- 15%**		16.8%	12.5%	1.2
> 50,000	111	83,422	82,744	**-0.8%**	**+/- 21%**	**+/- 10%**		11.4%	9.8%	-0.1

The volume to count ratios/percent errors by volume group are given by Table 33. Comparison of the percent error with the acceptable range indicates that the model far exceeds the calibration minimum criteria for all volume ranges. The table also displays the expected general pattern of higher errors on lower volume groups and decreasing errors on higher volume groups. Tennessee also has standards for %RMSE by volume group (but for different groupings of volumes) which are displayed in Table 34 which shows that again, all standards are met.

Table 34 Root Mean Square Error (RMSE) by Volume Group

AADT	# of Obs.	Mean Count	Mean Loading	% RMSE	TNMUG Standard		% Error	MAPE	t-stat
0 - 5000	737	2,272	2,420	**70.4%**	**115%**		6.5%	59.1%	1.7
5001 - 9,999	305	7,244	7,185	**36.5%**	**43%**		-0.8%	27.7%	-0.3
10,000 - 19,999	270	14,189	13,670	**27.6%**	**30%**		-3.7%	20.5%	-1.6
20,000 - 39,999	143	28,854	29,403	**19.9%**	**25%**		1.9%	14.5%	0.5
40,000 - 59,999	87	48,902	51,288	**14.4%**	**20%**		4.9%	11.0%	1.3
> 60,000	73	97,828	94,597	**10.2%**	**19%**		-3.3%	8.5%	-0.4

Tennessee also has standards for volume to count ratios/percent errors on screenlines and cutlines. Figure 10 and Figure 11 illustrate the cutlines and screenlines for the model. The cutlines are unchanged. The old North Counties screenline was replaced with a new NorthEast Counties screenline, to help demonstrated that the flows into out of the northeast counties is correct with the addition of Hamblen County in this update of the model. Table 35 displays the errors for screenlines and cutlines. All of the screenlines meet the standard, as do two of the three cutlines. The Old #6 cutline, however, is slightly over the standard percent error. The underloading on the Old #6 cutline is almost entirely due to I-40. The counts on this section of I-40, however, are somewhat suspicious, being 22% higher than the 2006 counts. If the I-40 counts from 2006, 2007 or 2008 were used instead, the model would match this section of I-40 and the Old #6 cutline very closely.

Table 35 Volume to Count/Percent Error for Screenlines and Cutlines

	Area	# of Obs.	Count AADT	Model AADT	% Error	TNMUG Standard	% RMSE	MAPE	t-stat
Screenlines	Knox - Blount Border	7	219,353	232,337	**5.9%**	+/- 10%	7.7%	14.8%	0.1
	Knox & Blount Boundary	22	507,342	530,665	**4.6%**		22.1%	58.5%	0.1
	Knox Co Boundary	37	1,359,408	1,397,034	**2.8%**		17.1%	42.6%	0.1
	Blount Co Boundary	9	157,940	164,143	**3.9%**		10.7%	22.0%	0.1
	Rivers	18	482,057	508,843	**5.6%**		10.6%	20.5%	0.2
	Inner Knoxville	16	789,571	795,463	**0.7%**		15.1%	14.4%	0.0
	East Counties	10	182,368	176,064	**-3.5%**		15.5%	66.8%	0.0
	West Counties	9	275,692	267,530	**-3.0%**		9.5%	34.9%	0.0
	NorthEast Counties	12	186,342	200,243	**7.5%**		12.1%	62.0%	0.1
Cutlines	Old #2	7	242,470	253,185	**4.4%**	+/- 15%	16.0%	33.4%	0.1
	Old #6	4	188,607	157,313	**-16.6%**		22.6%	19.3%	-0.2
	Old #7	3	78,390	75,027	**-4.3%**		8.2%	4.6%	-0.1

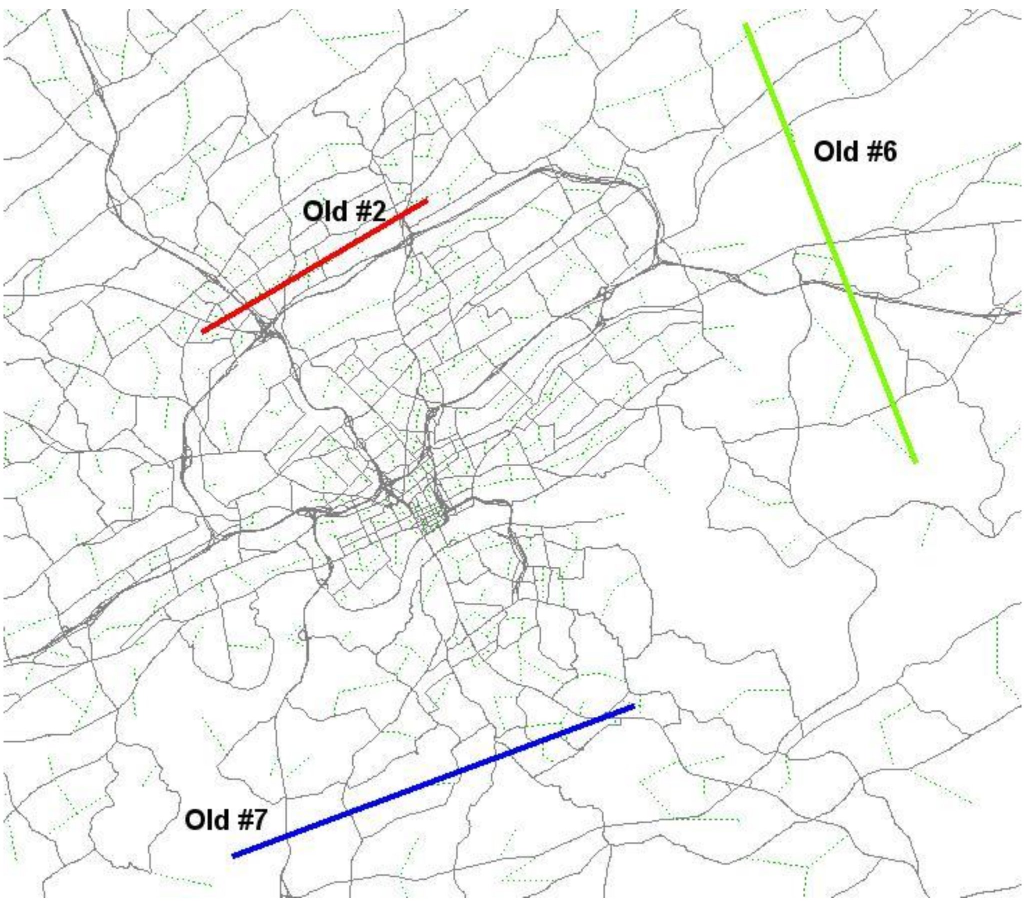

Figure 10 Calibration Cutlines from the Old MINUTP Model

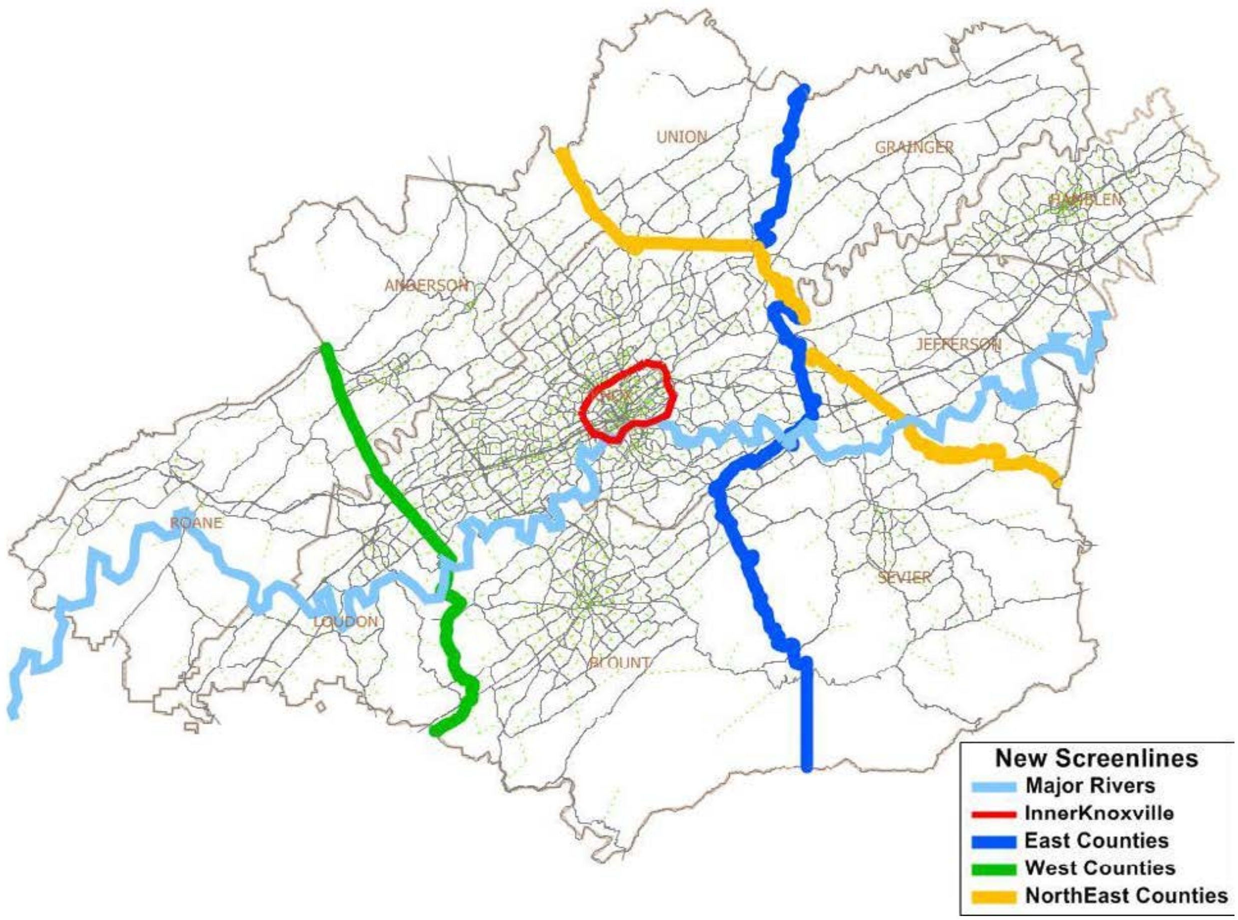

Figure 11 Regional Screenlines

The correlation coefficient estimates the correlation between the actual ground counts and the estimated traffic volumes, and can be obtained using the linear regression method. Tennessee specifies a minimum standard of 0.88 for the correlation coefficient as recommended by FHWA. The linear regression results of the Knoxville model are shown in Figure 12. The correlation coefficient is 0.949 which is significantly greater than the 0.88 minimum that was suggested by FHWA and the Tennessee standard as well as better than the previous version of the model. The results indicate a good performance of the model at the overall level.

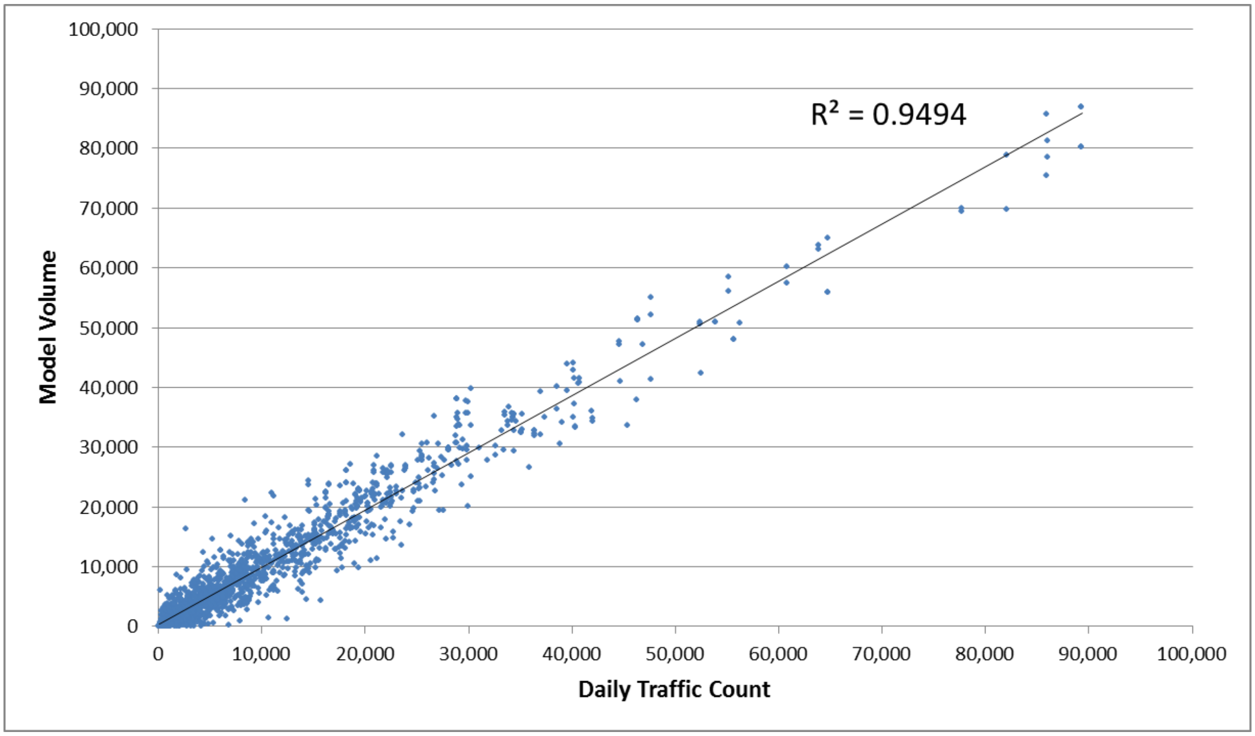

Figure 12 Correlation Coefficient and Daily Traffic Count vs. Model Volume

A breakout of model errors by county, provided in Table 36, offers further evidence of the model's validity and that it is not limited to only a particular geographic area. In particular, the RMSE for each county is essentially at or below the 30% standard applied across all facility types/volumes groups.

Table 36 Validation Statistics by County

AADT	# of Obs.	Mean Count	Mean Loading	% Error	% RMSE	MAPE	t-stat
Anderson	107	9,219	9,085	-1.5%	**26.3%**	51.4%	-0.1
Blount	199	9,323	9,081	-2.6%	**23.9%**	32.6%	-0.2
Jefferson	126	11,782	12,555	6.6%	**22.1%**	52.2%	0.3
Hamblen	157	7,595	6,993	-7.9%	**25.3%**	36.4%	-0.6
Knox	641	20,907	20,825	-0.4%	**25.6%**	37.9%	0.0
Loudon	108	15,207	15,811	4.0%	**23.0%**	36.8%	0.2
Roane	110	9,795	10,563	7.8%	**30.6%**	30.7%	0.4
Sevier	75	14,457	13,691	-5.3%	**21.9%**	28.2%	-0.3
Union	27	3,852	4,097	6.4%	**26.8%**	46.2%	0.2

The model meets all of the assignment validation standards set forth *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee* with the exception of one cutline which is still close to the standard and may be attributable to a suspicious count. The new 2010 model also performs better than the previous 2006 base year model (which performed better than all its predecessors). The 2010 model achieved a 27.1% RMSE and correlation coefficient of 0.95 compared to

28.1% RMSE and 0.92 correlation coefficient for the 2006 model. It is reasonable to conclude that the model is well calibrated and validated by observed traffic counts.

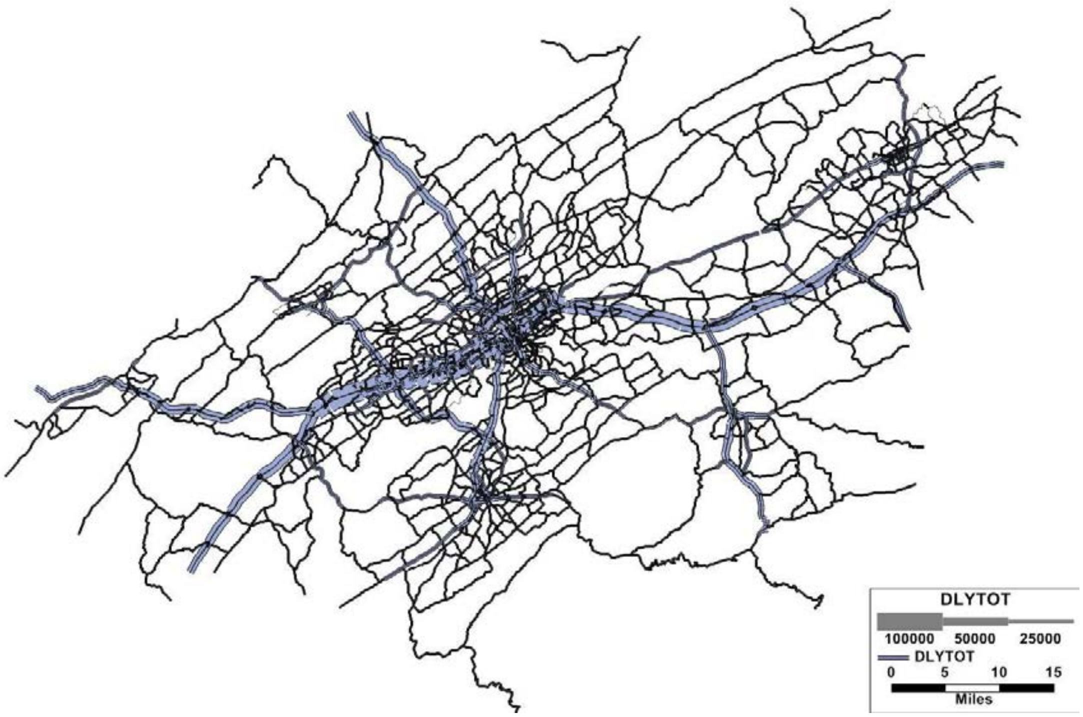

Figure 13 Knoxville Loaded Regional Network

Figure 14 Knoxville Loaded Network (central area detail)