MTP 2040 Appendix A
Regional Travel Demand Model 2040

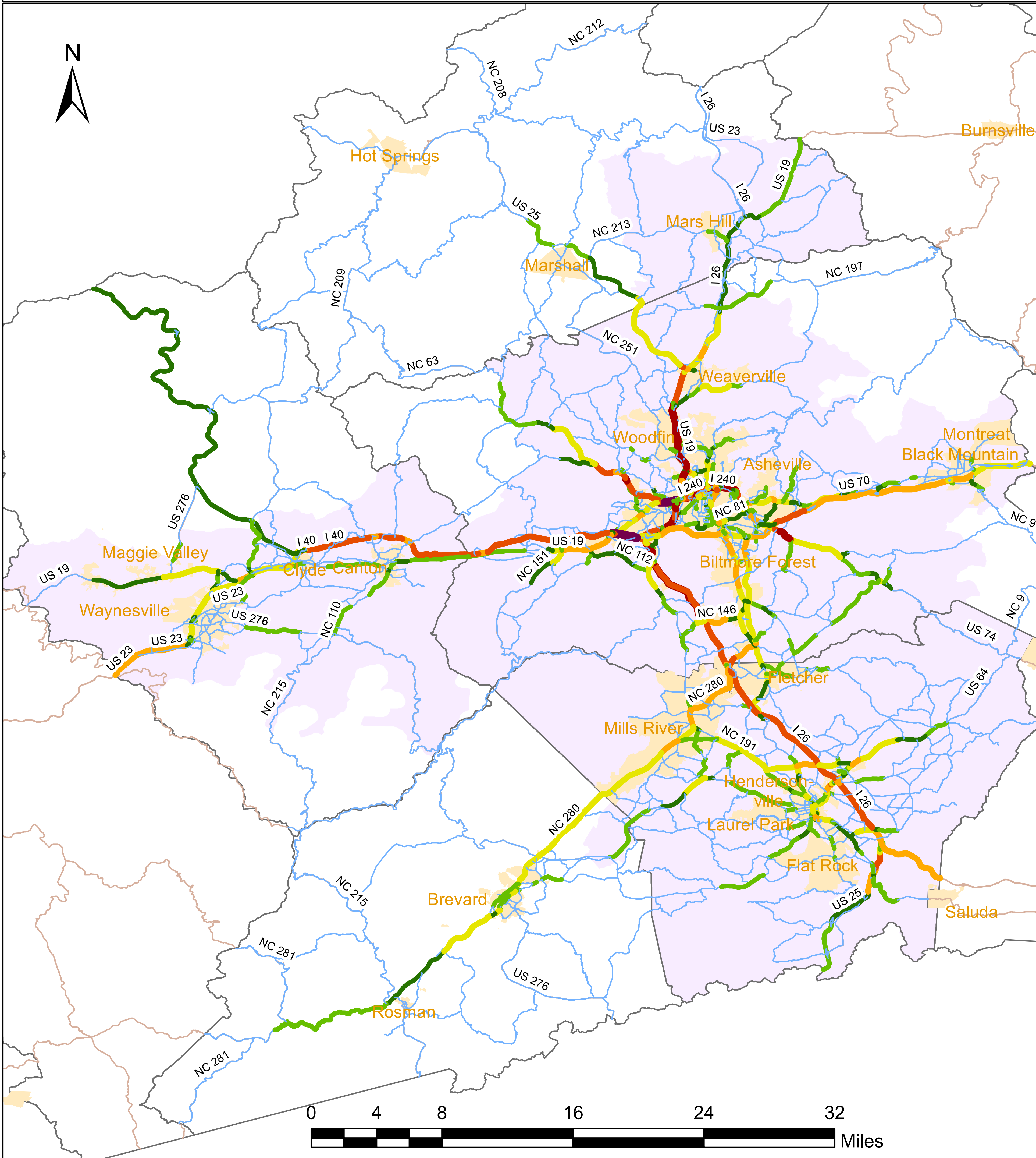
French Broad River MPO collaborated with NCDOT Transportation Planning Branch on development of the Regional Travel Demand Model for the Metropolitan Transportation Plan 2040. MTP 2040 Project List by horizon was used to forecast traffic flows for 2040. PB World was the consultant team selected by NCDOT to develop the Travel Demand Model update.

Regional Household Travel Survey results, including a Transit Ridership Survey sub-set of the Household Travel Survey (see Appendix B) and future land use, population and employment projections (see Appendix C) were utilized in developing the data for the Regional Travel Demand Model 2015-2040. GroWNC "Business as Usual" development scenario was utilized when projecting land use changes and allocating expected household and employment growth across the region.

Travel Demand Model maps for traffic flows and volume over capacity shown on the next two pages should be used with caution—future traffic flow volumes are not the actual traffic forecasts for those roadways; rather they represent a "desired" traffic flow; given the congestion and available parallel routes, many travelers are likely to seek and choose alternate routes as the primary route becomes more congested.

Travel Demand Model 2040 Development Report follows after the maps, and describes in further detail the data and assumptions that went into the model development.

FBRMPO Travel Demand Model 2040
MTP 2040 Projected Traffic Flows



PROJECTED 2040 TRAFFIC FLOWS

- 0 - 10, 000
- 10,001 - 15,000
- 15,001 - 20,000
- 20,001 - 30,000
- 30,001 - 40,000
- 40,001 - 50,000
- 50,001 - 60,000
- 60,001 - 84,367
- Interstate, US and NC Routes
- Municipal Boundaries
- FBRMPO Planning Boundary

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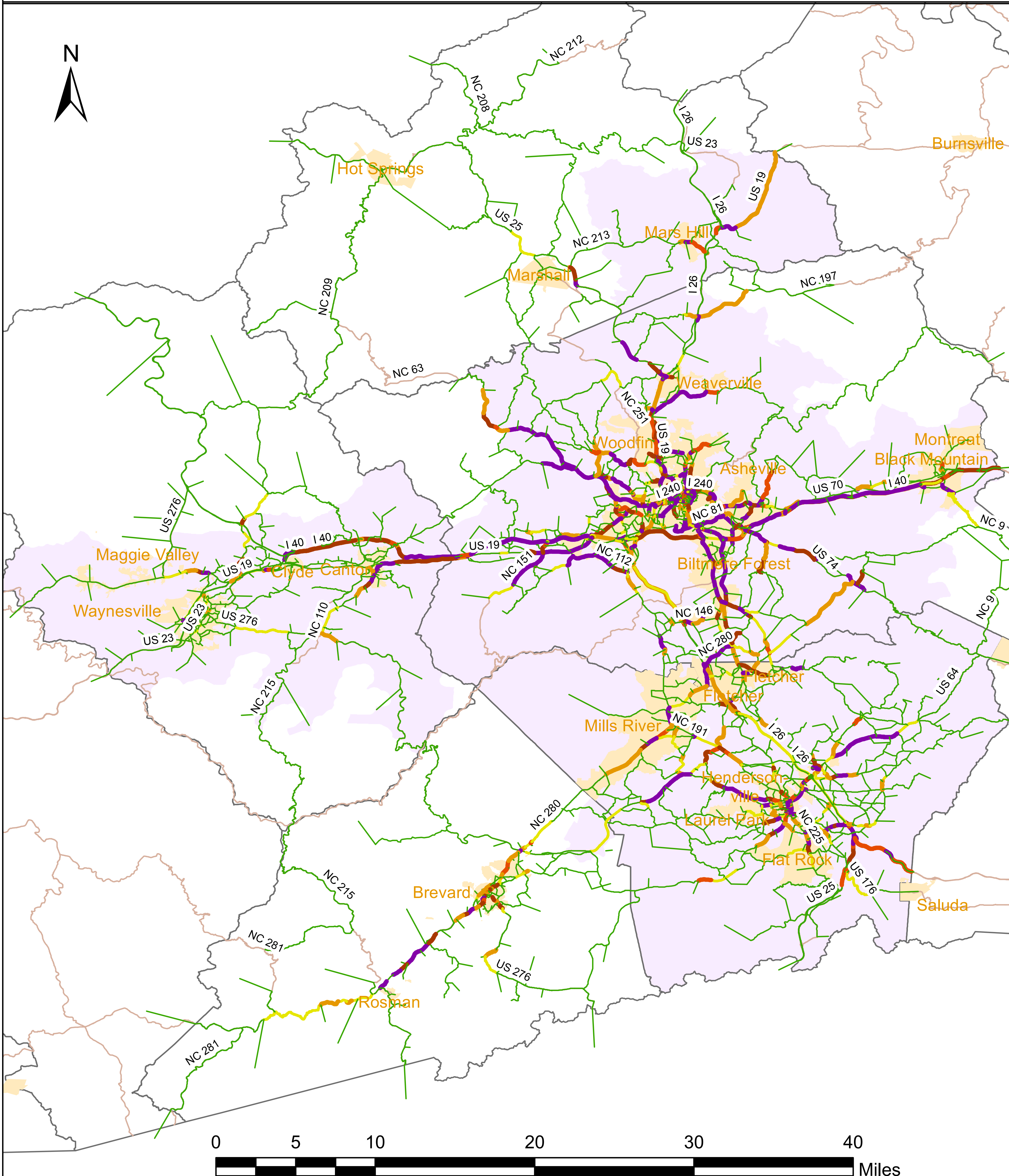
FRENCH BROAD RIVER

METROPOLITAN PLANNING ORGANIZATION

Disclaimer: Traffic Flow Estimates for 2040 shown above are from the Regional Travel Demand Model forecasts for 2040, based on draft FBRMPO MTP 2040 Project List (August 27, 2015 version).

FBRMPO Travel Demand Model 2040
MTP 2040 Projected Volume over Capacity



VOC

- 0.00 - 0.70
- 0.71 - 0.80
- 0.81 - 0.90
- 0.91 - 0.95
- 0.96 - 1.05
- 1.06 - 2.30
- Interstate, US and NC Routes
- Municipal Boundaries
- FBRMPO Planning Boundary

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METROPOLITAN PLANNING ORGANIZATION

Disclaimer: Volume over Capacity levels for 2040 shown above are from the Regional Travel Demand Model forecasts for 2040, based on draft FBRMPO MTP 2040 Project List (August 27, 2015 version).

FBRMPO Travel Demand Model

Model Development Report

Prepared for:

The North Carolina Department of Transportation

The French Broad River Metropolitan Planning Organization

Prepared by:

Systems Analysis Group
Parsons Brinckerhoff

February 6, 2015

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INTRODUCTION

This report documents the development of the French Broad River Metropolitan Planning Organization (FBRMPO) Model Development project. The model can be described as an advanced four-step trip based model. In addition to the traditional model steps of Trip Generation, Trip Distribution, Mode Choice and Travel Assignment, the FBRMPO model also includes several special market models to capture travel by Recreational Vehicles (RVs) and Visitors. The model design follows nationally accepted best practice and was estimated and calibrated using a locally collected household travel survey, transit on-board survey, and mobile phone data. The highway assignment was validated against comprehensive traffic counts and the transit assignment using observed transit ridership. The processing and analysis of the survey data are covered in separate technical memorandums and are available upon request from the North Carolina Department of Transportation (NCDOT) Transportation Planning Branch (TPB). Other enhancements to the FBRMPO model include a nested mode choice model with premium modes, time of day analysis, an auto ownership model, a destination choice model, a congested feedback loop, and post-processing reporting tools to assist in the analysis of model outputs. A flow chart of the model process is shown in Figure 1.

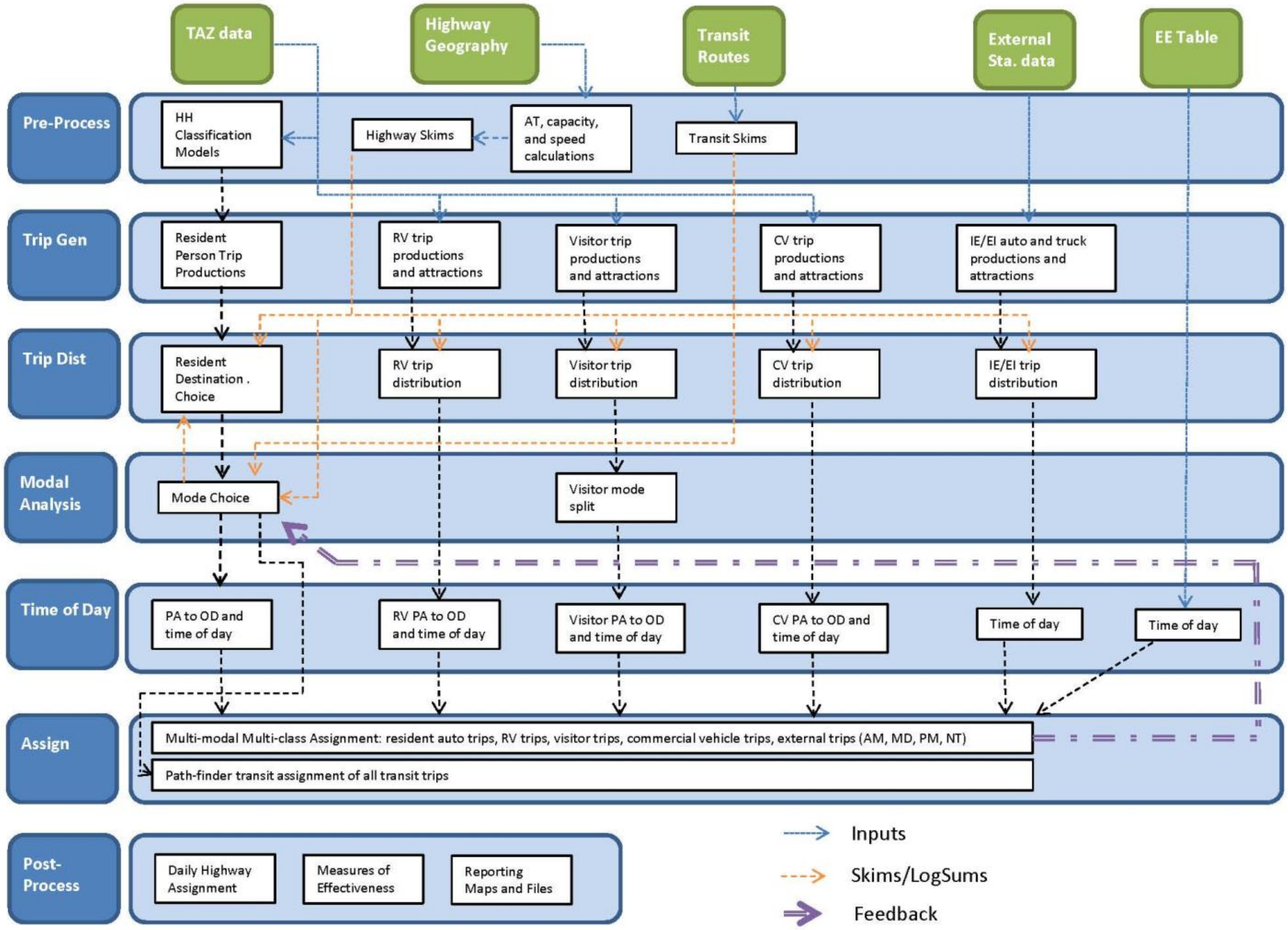


Figure 1 FBRMPO Model Flow Chart

Every attempt was made to preserve as much of the data disaggregation as possible throughout the model development effort. However, it was necessary to merge trip purposes at various steps in order to preserve the integrity of the survey data. The aggregation of trip purposes is described throughout this report at the relevant stages. Figure 2 provides an overall schematic of the initial trip purposes and the final trip purposes.

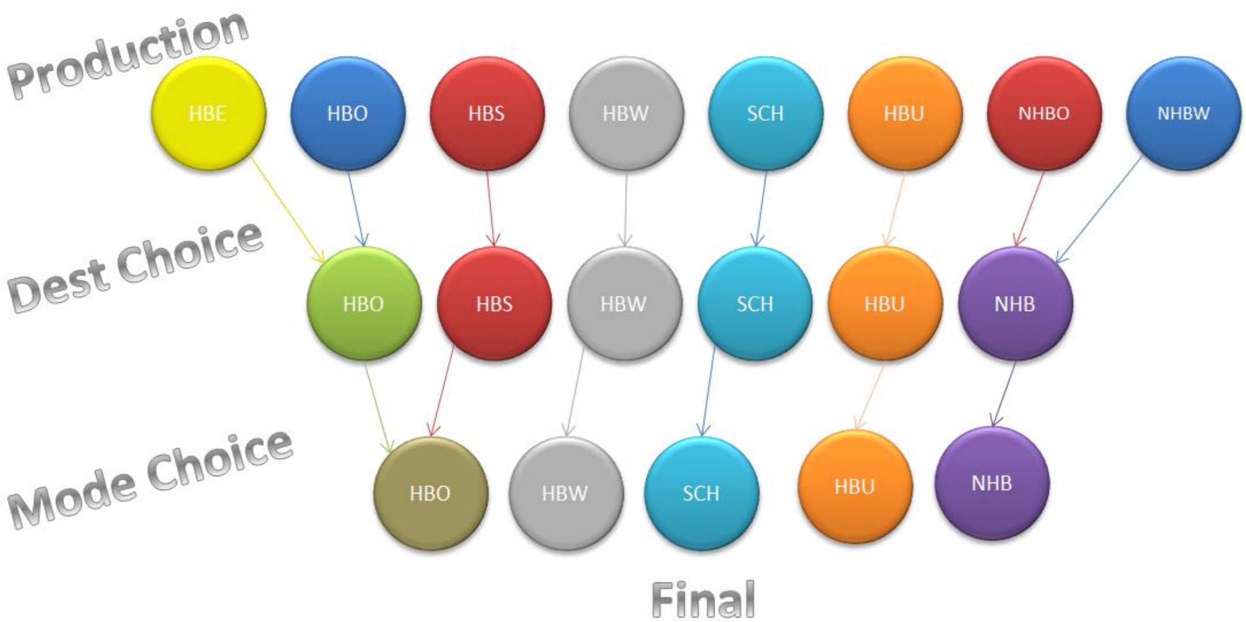


Figure 2 FBRMPO Model Trip Purposes by Model Stage

Please note that the documentation of this modeling effort deals with a large number of data tables. Invariably there may be slight inconsistencies between the numbers reported in the tables and the totals reported in the tables due to small rounding errors that are lost when the tables are copied into a Word format.

NETWORKS AND DATABASE DEVELOPMENT

TRAFFIC ANALYSIS ZONES AND ZONAL DATABASE

The FBRMPO model area covers the counties of Buncombe, Henderson, Haywood, Madison, and Transylvania. Figure 3 provides a map of the Traffic Analysis Zones (TAZs) defined for the FBRMPO model area. These TAZs were defined by FBRMPO staff using the 2010 Census geography. The TAZs were reviewed by Parsons Brinckerhoff for adequate level of resolution. No modifications to the original FBRMPO TAZs were made. The final TAZ structure includes 643 internal zones, numbered from TAZ 1 through TAZ 643. In addition, there are 29 external TAZs, numbered from TAZ 644 to TAZ 672 and represented as centroids in the highway network.

Several TAZs in the study area were identified by the FBRMPO staff as special zones or districts for the purposes of considering special trip generation rates during the development of the trip generation models. These are summarized in Table 1 and include a mix of colleges, hospitals, downtown districts, regional retail centers, and major tourist destinations.

Table 1 Special Zones/Districts in the FBRMPO region

Model TAZs	Name	County	Type
118, 171	AB Tech-Main Campus	Buncombe	College
387	Blue Ridge Community College	Henderson	College
630	Blue Ridge Community College	Transylvania	College
605	Brevard College	Transylvania	College
257	Haywood Community College	Haywood	College
530	Mars Hill College	Madison	College
229	Montreat College	Buncombe	College
128	UNC-Asheville	Buncombe	College
8	Warren Wilson College	Buncombe	College
69-79, 83, 85, 97-98	Downtown Asheville	Buncombe	Downtown district
341-343	Downtown Waynesville	Haywood	Downtown district
453-457	Hendersonville	Henderson	Downtown district
594-598, 600-601	Town of Brevard	Transylvania	Downtown district
253	Haywood Regional Medical Ctr	Haywood	Hospital
111	Mission Hospital/Memorial	Buncombe	Hospital
454	Pardee Hospital	Henderson	Hospital
519	Park Ridge Hospital	Henderson	Hospital
628	Transylvania Regional Hospital	Transylvania	Hospital
147	Veterans Affairs Medical Center	Buncombe	Hospital
102	Asheville Mall	Buncombe	Major retail
405	Biltmore Square Mall	Buncombe	Major retail
488	Blue Ridge Mall	Henderson	Major retail
161	Biltmore Park Town Center	Buncombe	Major retail
110	Biltmore Estate	Buncombe	Major tourist destination
588	Bracken Mtn Trails	Transylvania	Major tourist destination
122	Carrier Park	Buncombe	Major tourist destination
334	Cataloochee Ranch	Haywood	Major tourist destination
5	Craggy Gardens Visitor Center	Buncombe	Major tourist destination
556	Dupont State Forest	Transylvania	Major tourist destination
312	Graveyard Fields	Haywood	Major tourist destination
246, 248	Lake Junaluska, NC	Haywood	Major tourist destination
290, 293, 335, 336	Maggie Valley	Haywood	Major tourist destination
95,118	River Arts District	Buncombe	Major tourist destination
548	Sliding Rock	Haywood	Major tourist destination
136	The Grove Park Inn	Buncombe	Major tourist destination
36	The North Carolina Arboretum	Buncombe	Major tourist destination
206	Town of Hot Springs	Madison	Major tourist destination
166	WNC Farmers Market	Buncombe	Major tourist destination
151	WNC Nature Center	Buncombe	Major tourist destination
24, 28	Lake Toxaway	Transylvania	Major tourist destination
621	Brevard Music Center	Transylvania	Major tourist destination

Traffic analysis zones were classified as Urban, Suburban, and Rural using a Land Use Density Index shown below:

$$\frac{Households_i + (Employment_i * {}^{Total\ HHs}/_{Total\ Emp})}{Area_i}$$

Once calculated, the index values for all zones were analyzed to determine appropriate break points for urban, suburban, and rural area types. After testing a number of alternatives, the break points defined in Table 2 were set.

Table 2 Area Type Density Definitions

Classification	Density Index Range
Urban	3501 +
Suburban	501 – 3500
Rural	0 - 500

After this step, a final treatment was required: smoothing. Using a calculated value only leads to inconsistent area type assignments; a zone in the middle of downtown may be designated as rural if the density index is below 500. This does not make sense given what the area type is used for in the model. For example, the free flow speeds and capacities of the roads in that TAZ will be too high.

Smoothing is a simple process to correct for this. Starting with urban zones, a buffer is created around the TAZs. All zones that fall entirely inside this buffer have their area types changed to urban. The process is repeated with suburban zones, but only rural zones within the buffered area are modified. This leads to a distribution of area types that makes sense.

Using the 2010 housing and employment data, this process leads to the outcomes summarized in Table 3 and displayed in Figure 3.

Table 3 Base Year Number of TAZs by Area Type

Classification	Number of TAZs
Urban	143
Suburban	198
Rural	302

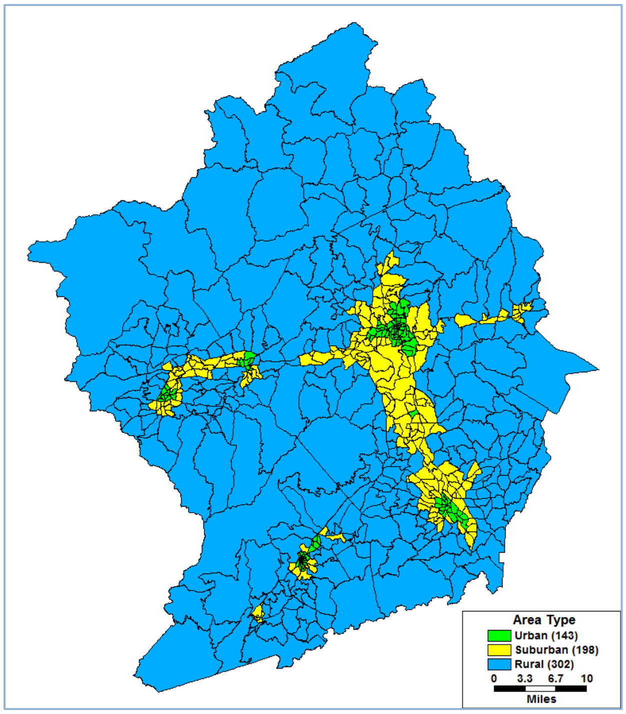


Figure 3 FBRMPO Traffic Analysis Zones by Area Type

HIGHWAY NETWORK AND SUPPORTING DATABASE

HIGHWAY NETWORK

The highway network for the FBRMPO model was based off the previously coded network for the region with expansion to include the revised urbanized area from the 2010 Census in addition to providing full coverage for the counties of Henderson, Haywood, Madison, and Transylvania. Roadway facilities were coded in the expanded model area to include all Interstate, NC, and US Routes. Arterial and collector facilities were added to assure a balance between the modeled roadway system and the traffic analysis zones and to provide key connectivity between routes. Centroid connectors were coded and revised as necessary to match the new TAZ system.

The network was coded with a set of input attribute data as defined in Table 4. Additional data fields required by the model are calculated using GISDK scripts, these fields are summarized and defined in Table 5. Once the network was coded in TransCAD, several checks were made for connectivity, directionality, range of attribute values, shortest paths, and trip loading on centroid connectors, freeways, and ramps. These checks resulted in the need for numerous edits and corrections. NCDOT and FBRMPO staff also performed a review of the network and associated attributes recommending numerous updates that were incorporated into the final network.

Table 4 User Input Highway Attribute Data

Field Name	Description
ID	TransCAD generated unique ID
Length	TransCAD generated length
Dir	TransCAD generated field to assign a link as 2-way (0), 1-way in the direction of the topology (1), or 1-way opposite the direction of the topology (-1)
Street Name	Common street name
Route Number	Common route name
COUNTY	County name
FUN_CLASS	Functional Classification: 0 = not classified 1 = Interstate 2 = Principal Arterial Other Freeway 3 = Principal Arterial Other 4 = Minor Arterial 5 = Major Collector 6 = Minor Collector 7 = Local
CTP_Type	Comprehensive Transportation Plan roadway type corresponding to the CTP code
CTP_CD	Comprehensive Transportation Plan code: 1 = Freeway 2 = Expressway 3 = Boulevards 4 = Other Major Thoroughfares 5 = Minor Thoroughfares 99 = Centroid Connectors
TERRAIN_CD	Terrain code: 0 = centroid connectors 1, 2 = not used 3 = challenging 4= normal 5 = ideal (not used in Asheville)
DIVIDED_CD	Roadway divided type code: 0 = undivided 1 = divided 2 = two-way left turn lane (TWLTL)
SPD_LIMIT	Posted speed limit
AB_LANES	Number of lanes
BA_LANES	

Table 4 (cont.) User Input Highway Attribute Data

Field Name	Description
Lane Width	Default lane width used to calculate capacity
Trucks	Daily truck percentage from NCDOT, not used in the model
Directional Travel	Describes roadway as one-way or two-way. Informational only, not used in the model.
Directional Separation	Describes type of separation, i.e. divided, undivided, etc. Informational only, not used in the model.
Mode	Used to indicate mode allowed
Walkmode	Used to indicate links available for walking (1 if available for walking, 0 if not available for walking)
TruckRstr	Links with truck restriction
TIP Project	NCDOT maintained field denoting any associated TIP project, not used for model
Screenline	Flag showing screenline links, populated with the screenline number
Count Station ID	Count station ID associated with the traffic count database

Table 5 Calculated Highway Attribute Data

Field Name	Description
AREA_Type	Calculated values of area type
AREA_CD	Area type code: 1 = urban 2 = suburban 3 = rural
AB_phplcap	Calculated per hour per lane capacity (LOS E)
BA_phplcap	
TOT_phplcap	Calculated total link per hour per lane capacity (LOS E)
AB_AMCAP	Calculated AM capacity (LOS E)
BA_AMCAP	
TOT_AMCAP	Calculated Total AM capacity (LOS E)
AB_MDCAP	Calculated MD capacity (LOS E)
BA_MDCAP	
TOT_MDCAP	Calculated Total MD capacity (LOS E)
AB_PMCAP	Calculated PM capacity (LOS E)
BA_PMCAP	

Table 5 (cont.) Calculated Highway Attribute Data

Field Name	Description
TOT_PMCAP	Calculated Total PM capacity (LOS E)
AB_NTCAP	Calculated NT capacity (LOS E)
BA_NTCAP	
TOT_NTCAP	Calculated Total NT capacity (LOS E)
Alpha	BPR function alpha parameter
Beta	BPR function beta parameter
AB_FFSpd	Calculated free flow speed
BA_FFSpd	
AB_Time	Calculated free flow travel time
BA_Time	
AB_WalkTime	Calculated walk time
BA_WalkTime	
BUS_FFSPD	Local bus free flow speed
BUS_FFTIME	Local bus free flow time
XBUS_FFSPD	Express bus free flow speed
XBUS_FFTIME	Express bus free flow time
AB_Peak	Peak highway travel time from feedback of congested network
BA_Peak	
AB_Offpeak	Off peak highway time from feedback of uncongested network
BA_Offpeak	
AB_BUS_TIME	Calculated congested travel time for buses
BA_BUS_TIME	
AB_XBUS_TIME	Calculated congested travel time for express buses
BA_XBUS_TIME	
AB_RailTime	Calculated travel time for premium mode
BA_RailTime	

The final 2010 highway network is shown in Figure 4.

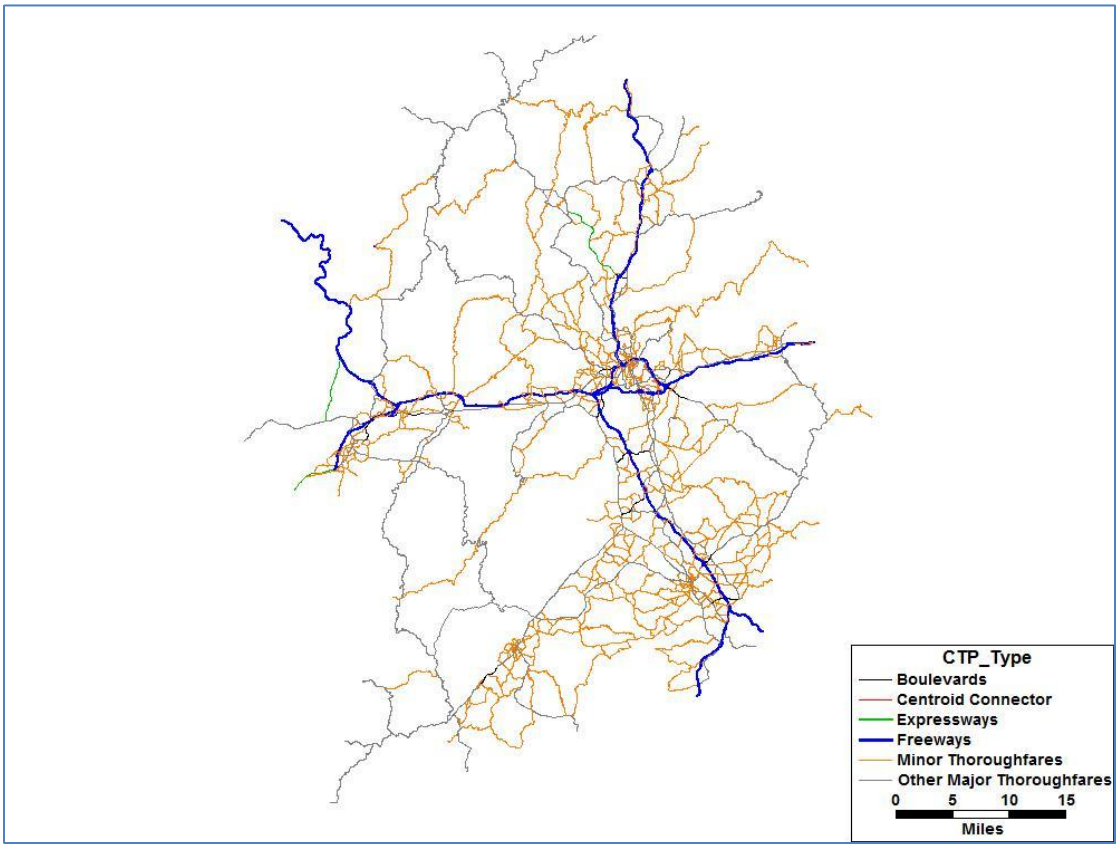


Figure 4 2010 FBRMPO Highway Network

Development and Checking of Highway Paths

A number of checks were made to the highway network in order to ensure that coding errors had been minimized. The first was to create a simple, Origin-Destination matrix that assumed one trip between every zone. This was then assigned to the street network. This method allowed the quick identification of zero-volume links. Normally, these links are caused by connectivity issues or by typos in the attribute data, which are then corrected.

The second check involved testing paths between zones manually. For a reasonable sample of zone pairs, the TransCAD shortest-path tool was used to perform manual checks. Figure 5 shows an example of minimum paths between two zones. The first is the path that minimizes travel time, while the second minimizes distance.

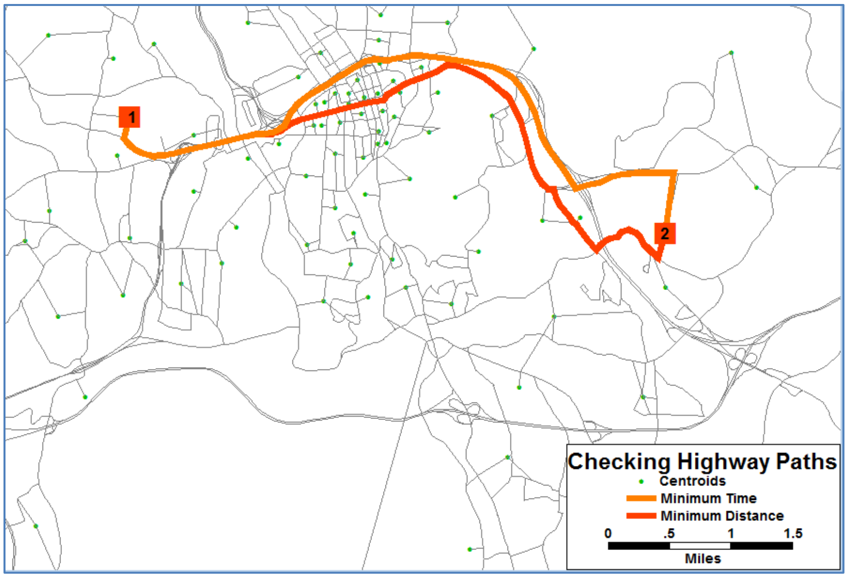


Figure 5 Example of Minimum Path for Selected Zones

The checking of network paths revealed the need to implement turn penalties on 90% of the ramps coded in the network in order to prevent vehicles from making wrong way turning movements.

Traffic Counts

NCDOT provided traffic count data factored to May 2010 to support the model development effort. In addition to collecting and factoring 126 special count locations to support screenlines, external stations, and key locations, NCDOT also provided factored coverage counts to support the modeling effort, approximately 730 of these locations will be used for model validation. Figure 6 shows the locations of traffic counts supporting the modeling effort along with the seven screenlines selected for the FBRMPO region.

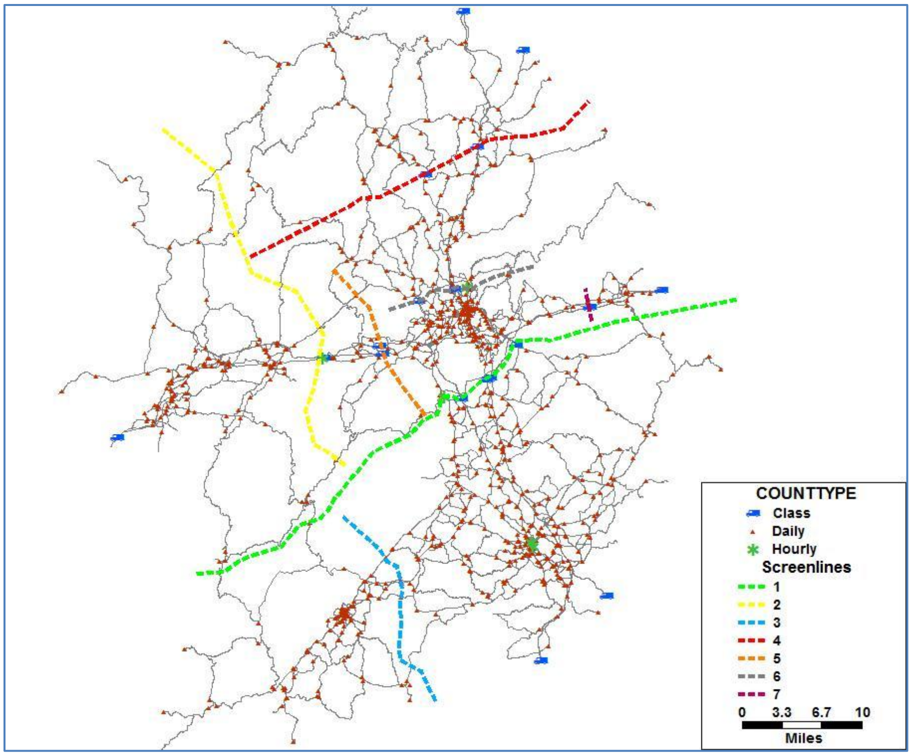


Figure 6 FBRMPO Traffic Count and Screenline Locations

The traffic count data was reviewed and validated confirming count data for all screenline crossing and external stations, and performing validation checks on the data to validate for reasonable data ranges by facility type and to identify outlier locations. No inconsistencies or outliers were identified during this review.

Finally, a count data table was developed including a unique count ID, highway network link ID, count type, count source, road on, location description, and average weekday count (AWDT) reflecting May 2010. This data table will be used in the validation of the highway assignment.

TRANSIT ROUTE SYSTEM AND SUPPORTING DATABASE

TRANSIT NETWORK

Following the final review and checking of the highway network, Parsons Brinckerhoff coded 40 fixed-route transit routes, 32 operated by the City of Asheville (ART) and 8 operated by the Town of Hendersonville (Apple Country Transit). In addition, an effective fare was calculated for each route. The effective fare is preferred over the stated fare as it takes into account discount programs offered by the transit operators. Table 6 provides a summary of the base year routes coded into the model, including route description, peak and off-peak headways, and effective fare.

Table 6 Base Year Transit Routes

Route ID	Route Name	Peak Headway	Off-Peak Headway	Effective Fare
1	170 EB	60	120	$0.50
2	170 WB	60	120	$0.50
3	N2 NB	60	60	$0.50
4	N2 SB	60	60	$0.50
5	E1 EB	60	30	$0.50
6	E1 WB	60	30	$0.50
7	C EB	75	75	$0.50
8	C WB	75	75	$0.50
9	N EB	60	60	$0.50
10	N WB	60	60	$0.50
11	N1 NB	60	60	$0.50
12	N1 SB	60	60	$0.50
13	N3 EB	30	30	$0.50
14	N3 WB	30	30	$0.50
15	E2 EB	60	60	$0.50
16	E2 WB	60	60	$0.50
17	S1 SB	60	60	$0.50
18	S1 NB	60	60	$0.50
19	S2 EB	60	60	$0.50
20	S2 WB	60	60	$0.50
21	S4 SB	60	60	$0.50
22	S4 NB	60	60	$0.50
23	W1 WB	60	60	$0.50
24	W1 EB	60	60	$0.50
25	W2 SB	60	60	$0.50
26	W2 NB	60	60	$0.50
27	W3 WB	60	60	$0.50
28	W3 EB	60	60	$0.50
29	W4 WB	60	60	$0.50
30	W4 EB	60	60	$0.50
31	S3 SB	90	90	$0.50
32	S3 NB	90	90	$0.50
33	White EB	60	60	$0.41
34	White WB	60	60	$0.41
35	Red SB	60	60	$0.41
36	Red NB	60	60	$0.41
37	Blue NB	60	60	$0.41
38	Blue SB	60	60	$0.41
39	Green EB	45	45	$0.78
40	Green WB	45	45	$0.78

The final transit network is shown in Figure 7.

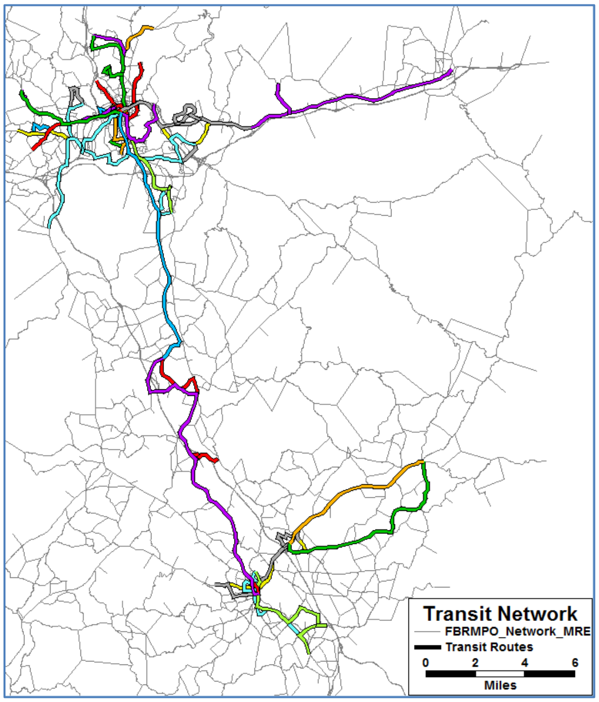


Figure 7 FBRMPO Transit Network

In addition, Figure 8 shows the modeled routes laid on top of the GIS received for each company, City of Asheville routes are shown as COA and Hendersonville routes are shown as Apple Country.

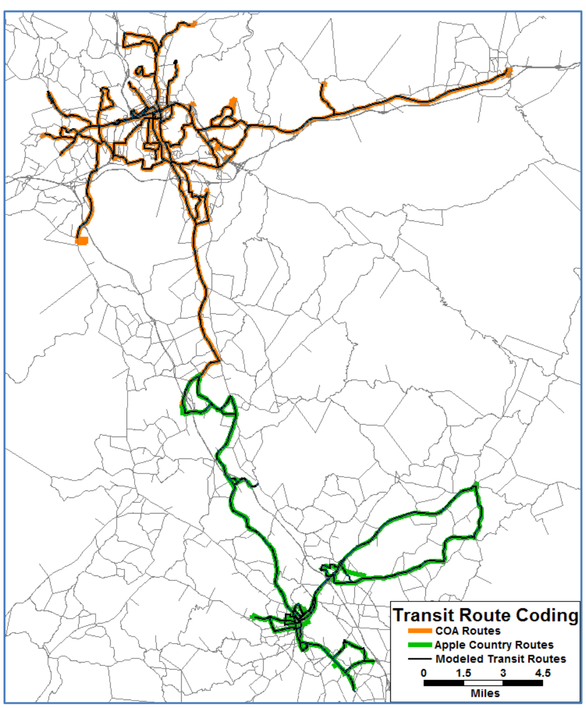


Figure 8 FBRMPO Transit Route Coverage by Agency

Access Links

Access links are needed to build walk and drive access paths to the transit route system. Traditional practice is the coding of straight-line access links from the zone centroid to the bus stops along the route, see Figure 9. Initial discussions with NCDOT suggested the application of the walk and drive access procedure developed by NCDOT and currently applied in the Triangle Region. Parsons Brinckerhoff initially integrated the script for applying this approach in the FBRMPO model, but later decided against using this approach due to the following considerations:

- Recent research (New Orleans, Indianapolis, and Phoenix) into using the traditional "starburst" approach to coding walk and drive access as compared to utilizing walk and drive times over the coded highway network has shown that the starburst coding poorly represents access, and subsequently, actual path assignment as observed in the assignment of the on-board survey data
- In the traditional approach, the access and egress connectors generated from the zone centroid to the bus stop are coded with a travel time reflective of the average walking speed and the distance of the connector (which may be capped for very long connectors). This approach results in walk access links that may be nearly indistinguishable from each other. This leads to inaccuracies in the best path selected by the transit path builder with respect to evaluating walk penalties.
- Problems may be encountered for one-way routes where access connectors get built only to the nearest one-way alignment, but not to the reverse direction for the route. Not having access to the same bus stop for both directions of the one-way route can lead to the building of paths that are longer than those actually observed, which can in turn impact ridership.
- Finally, the highway network coded for the FBRMPO region includes a code for terrain, and inherently captures geographic constraints and barriers that result in a lack of connectivity in the street system. The starburst approach would not automatically capture these unique characteristics requiring manual review and editing of the final link coding.

For the reasons outlined above, the approach recommended and implemented in the final FBRMPO model utilizes the full network coverage with walk and drive specific times for transit access.

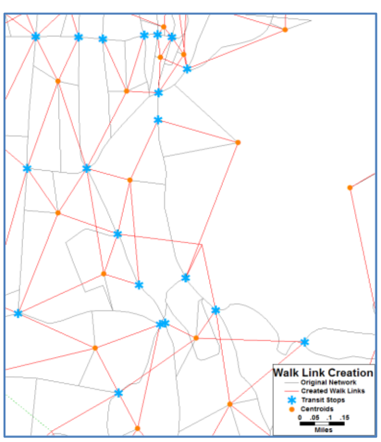


Figure 9 Traditional "Starburst" Approach to Transit Access

Transit Speeds

Transit speeds are computed through the use of a lookup table that applies a rule based system by facility type and area type to adjust to the speed of the bus relative to the speed on the highway. For example, there is no reduction in bus speed on a freeway facility as the bus does not make any stops and is able to travel along with the highway traffic. At the other end of the spectrum, urban arterials have the largest adjustment between highway speed and bus speed as the bus must stop not only to pick up and drop off passengers, but also for signalized intersections where the bus acceleration and deceleration play a larger role in average speed. The final bus speed relationship reflected in the model was informed by the final transit trip assignment and validation.

Development and Checking of Transit Paths

The observed trip tables developed from the on-board survey were assigned to the coded transit route system to verify the integrity of the coded transit network, including access links, and to help inform the adjustment of path building weights in the pathfinder algorithm. This process also helps to verify the integrity of the on-board survey, particularly the geo-coding of the survey trip records.

The results showed that the model is sensitive to walk access and egress times as expected. To identify the best weight to apply to walk time in the final setup, four different weights were tested as shown in Table 7. The overall difference across the four assignments with the different weighting factors in only 250 trips; however the magnitude of the difference between the observed and estimated boardings did vary across the four assignments.

Table 7 Reported Boardings by Route from Assignment of the Survey Trip Table

Route Name	Onboard Survey			Walk Weights = 1.0		Walk Weight = 1.5		Walk Weight = 2.0		Walk Weight = 2.5	
	Samp	Trips	Boardings	Boardings	Diff	Boardings	Diff	Boardings	Diff	Boardings	Diff
170	29	125	229	253	24	147	(82)	148	(82)	134	(95)
BLUE	10	77	96	155	59	155	59	137	41	133	37
CROSSTOWN	25	176	210	288	78	233	23	241	31	222	12
EAST1	134	767	967	716	(251)	810	(157)	814	(153)	855	(113)
EAST2	34	227	311	490	179	503	192	500	189	510	199
GREEN	1	1	1	7	6	7	6	7	6	7	6
NORTH	34	140	186	139	(46)	149	(37)	144	(42)	147	(39)
NORTH1	62	332	466	464	(2)	508	42	507	41	541	75
NORTH2	24	217	262	454	192	453	190	443	180	468	206
NORTH3	37	203	323	484	161	473	150	488	165	567	244
RED	14	73	119	105	(14)	105	(14)	88	(31)	92	(27)
SOUTH1	46	316	421	553	132	490	68	503	82	482	61
SOUTH2	27	114	134	261	127	215	81	253	119	245	111
SOUTH3	47	301	403	186	(217)	188	(214)	188	(214)	198	(205)
SOUTH4	40	196	303	247	(56)	399	96	428	125	449	146
WEST1	71	547	634	565	(70)	564	(70)	584	(51)	586	(48)
WEST2	47	287	380	486	106	541	161	546	166	575	195
WEST3	52	356	476	298	(178)	295	(181)	289	(187)	282	(194)
WEST4	19	106	167	207	41	194	27	188	21	188	22
WHITE	11	116	165	144	(21)	144	(21)	152	(13)	152	(13)
Total	764	4,676	6,255	6,502	250	6,576	321	6,649	394	6,833	578

The comparison showed that a weight of 1.5 produces the most reasonable ridership at the corridor level, though this weighting factor does result in a slight overestimation of trips on the north corridor routes, see Table 8.

Table 8 Reported Boardings by Corridor from Assignment of the Survey Trip Table

Corridor	Onboard Survey			Walk Weights = 1.0		Walk Weight = 1.5		Walk Weight = 2.0		Walk Weight = 2.5	
	Samp	Trips	Boardings	Boardings	Diff	Boardings	Diff	Boardings	Diff	Boardings	Diff
EAST	168	994	1,278	1,206	(72)	1,314	35	1,314	36	1,364	86
WEST	189	1,296	1,657	1,556	(101)	1,594	(63)	1,606	(51)	1,631	(26)
NORTH	157	892	1,237	1,541	305	1,584	346	1,581	344	1,723	486
SOUTH	160	926	1,261	1,247	(14)	1,292	31	1,373	112	1,374	112
170	29	125	229	253	24	147	(82)	148	(82)	134	(95)
CROSSTOWN	25	176	210	288	78	233	23	241	31	222	12
BLUE	10	77	96	155	59	155	59	137	41	133	37
WHITE	11	116	165	144	(21)	144	(21)	152	(13)	152	(13)
RED	14	73	119	105	(14)	105	(14)	88	(31)	92	(27)

It is not always the case that the transit path builder can match all paths reported in the on-board survey. This can be attributed to human nature, and the fact that the path builder has perfect knowledge of the minimum path, while users of the system do not. It is still useful to investigate a selection of the survey records that were assigned to paths other than those reported in the survey in order to rule out coding errors as the source of the difference.

The first example is for a trip reported on route EAST1 where the survey participant reported a transfer from WEST1 to EAST1, shown in Figure 10. However, the location of the origin and destination zones is actually closer to SOUTH2 route. The transit path builder sees this option as the minimum path and assigns the trips to SOUTH2, resulting in 3.4 trips being assigned to SOUTH2 instead of EAST1 or WEST1.

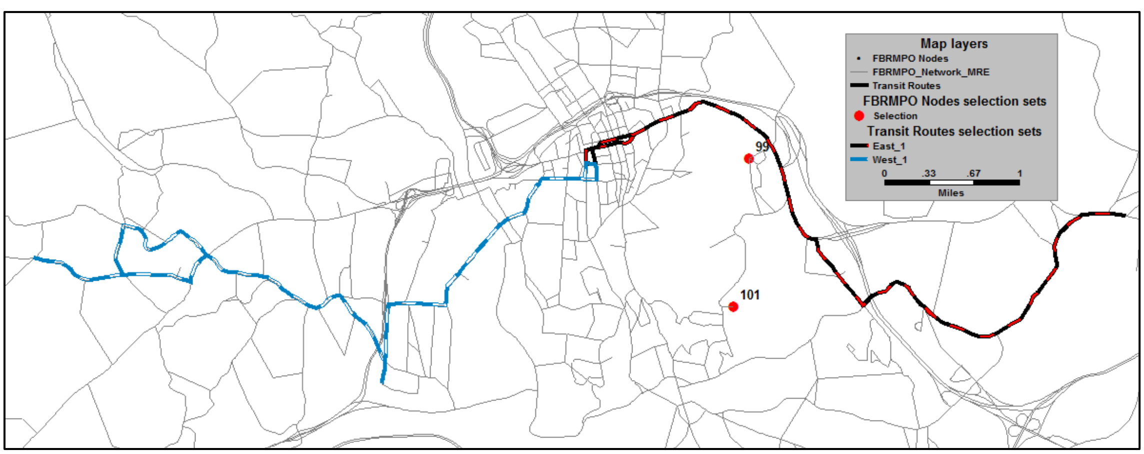


Figure 10 On-Board Assignment Example 1 – East 1 vs. West 1 Routes

The second example, Figure 11, shows an on-board survey path involving a transfer from NORTH3 to EAST1. However, the path builder identifies the top two best paths using NORTH3 with no transfers. Increasing the path combination factor to 0.3 shows the choice of one additional route, NORTH (not shown in the Figure). This review shows that most of the downtown trips that reported a transfer to or from NORTH and NORTH3 in the survey actually do not incur a transfer in the path builder.

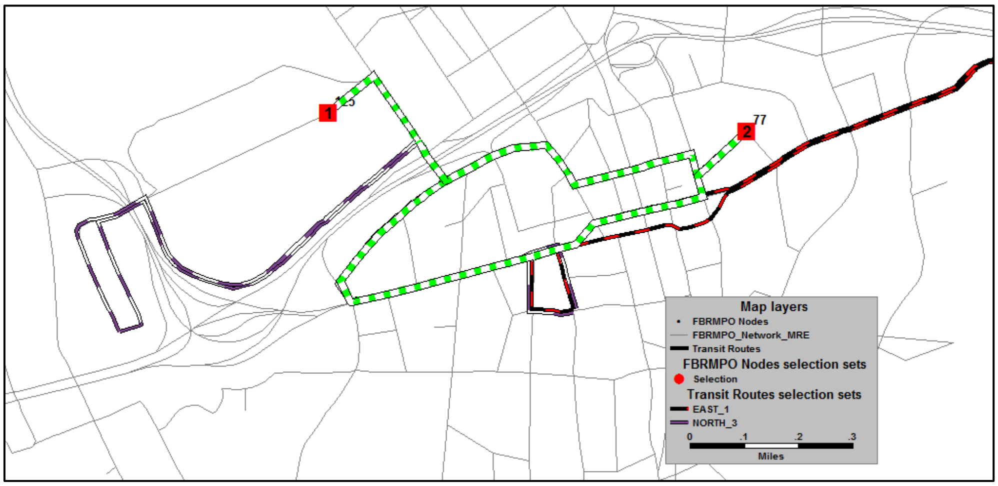


Figure 11 On-Board Assignment Example 2 – East 1 vs. North 3

In the final example, see Figures 12 and 13, the on-board survey shows a path involving a transfer from NORTH3 to SOUTH2, but the path builder picks a path with no transfers and a maximum egress walk of 1.1 miles. Decreasing the maximum walk egress time from 30 minutes to 10 minutes showed an alternative path involving a transfer to route SOUTH4 (not shown in the Figure). Another path was tested by setting the maximum egress time to 20 minutes, producing a third path involving WEST1 (not shown in the Figure), a path quite similar to the first path.

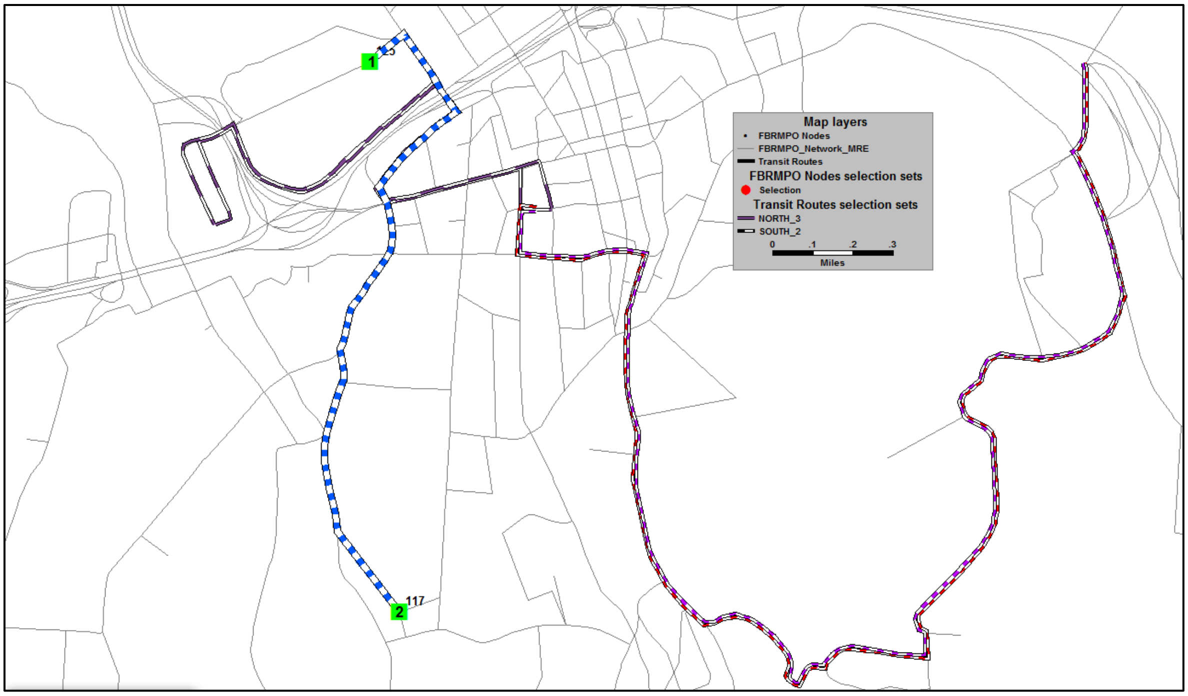


Figure 12 Maximum Walk Egress set to 30 Minutes

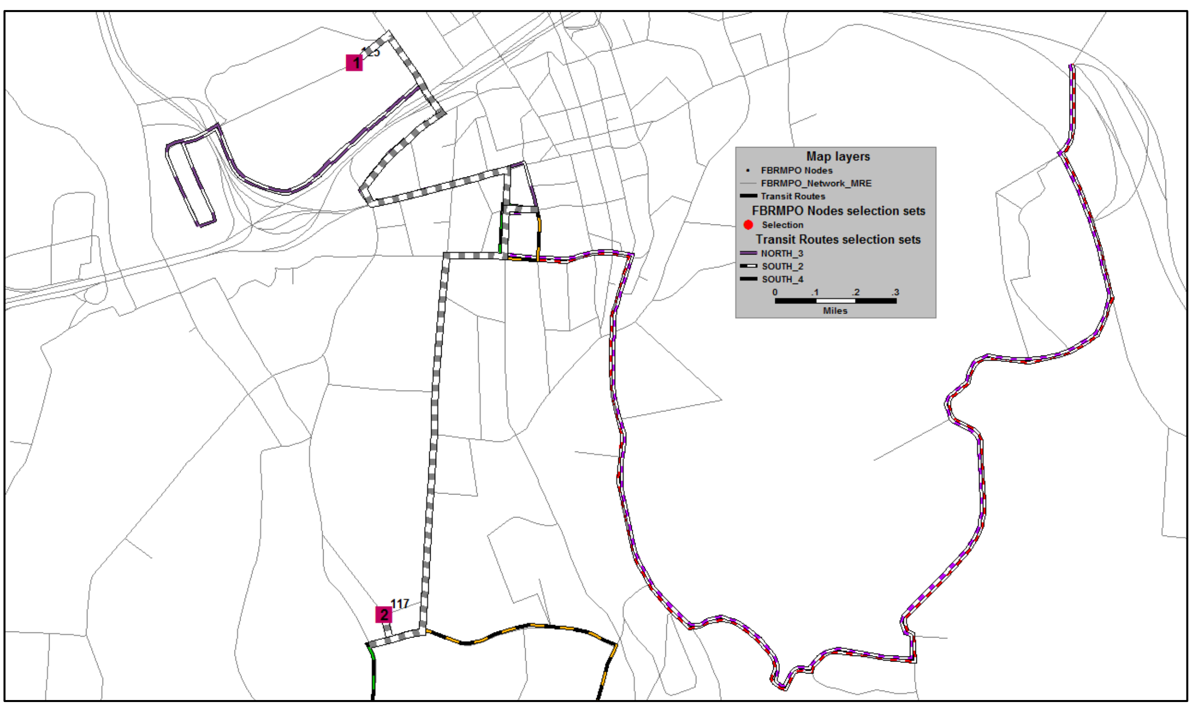


Figure 13 Maximum Walk Egress set to 10 Minutes

This process helps inform setting path building parameters and weights for in-vehicle time, access time, transfer time, boarding penalty, and transfer penalty. The initial weights for these parameters are summarized in Table 9.

Table 9 Initial Transit Path Builder Settings and Weights

Component	Weight/Setting
Combination Factor	0.1
Walk Weight	1.5
Maximum allow access/egress time	20 minutes
Global transfer weight	2.5
Value of Time	0.2
Dwell Time	0.5

SOCIO-ECONOMIC DATA

The socio-economic (SE) data was developed by the FBRMPO staff working with the local jurisdictions. The SE data provides information about demographic and land use characteristics in the region in terms of households, population, and employment. The SE data table also stores data calculated by the model during model application. The input SE data used in the FBRMPO model are defined in Table 10.

Table 10 Socio-economic Input Data Fields

Field Name	Description	User Input vs. Set Value
TAZ	Census TAZ ID	Set by MPO – do not edit
Model TAZ	Model TAZ ID	Set by Model – do not edit
PopHH	Total household population	User Input
PopGQ	Total group quarter population	
TotalPop	Total population	
HH	Total households	
MedInc	Zonal Median Income	
K12Enroll	K-12 student enrollment	
UnivEnroll	University student enrollment	
RV_Camp	Number of recreation vehicle hookups and camp sites	
Hotel	Number of hotel rooms	
BnB	Number of Bed and Breakfast accommodations	
Motel	Number of model rooms	
Cabins	Number of rental cabins	
Resort	Number of resort locations	
Ind	Number of industrial employees (NAICS = 111-115, 211-213, 221, 236-238, 311-339, 424, 481-484, 486, 488, 491-493, 562)	
Ret	Number of retail employees (NAICS = 441-444, 446, 448-453)	
HTRet	Number of high traffic retail employees (NAICS = 445, 447, 722)	
Off	Number of office employees (NAICS = 425, 454, 511-519, 521-525, 531, 533)	
Ser	Number of service employees (NAICS = 485, 487, 532, 611, 621-624, 711-713, 721, 811-814)	
TotEmp	Total employees	
ExtAWDT	External station average weekday traffic	
PctTruck	External station percent trucks	

The SE data summary for the FBRMPO model area is provided in Table 11.

Table 11 2010 and 2040 Socio-economic Data

SE Data	2010 Base	2040 Forecast	Change	% Change
Household Population	446,046	624,267	178,221	40%
Group Quarter Population	11,883		NA	
Households	194,305	273,017	78,712	41%
K – 12 Enrollment	63,155	63,155	-	0%
University Enrollment	21,393	21,393	-	0%
Hotel/Motel Rooms	8,802	12,396	3,594	41%
RV/Campsites	2,925	2,925	-	0%
Industry	46,116	60,255	14,139	31%
Retail	24,578	30,008	5,430	22%
High Traffic Retail	24,924	30,299	5,375	22%
Office	27,536	44,327	16,791	61%
Service	80,002	130,987	50,985	64%
Annual Visitors to Key Venues	5,271,368	6,846,196	1,574,828	30%

HOUSEHOLD CLASSIFICATION MODELS

A cross-classification approach to trip production models requires the use of a household submodel to disaggregate the household attribute data into the proper format required by the cross-classification model. Three auxiliary submodels were developed to forecast household distributions based upon average household size, number of workers, and income. A regression model was used to estimate the total workers per TAZ using average household size as the independent variable. A multinomial logit model was estimated for forecasting auto ownership using variables describing household characteristics along with other predictive variables including accessibility. The auxiliary submodels were developed using the U.S. Census American Community Survey (ACS) five year data. The following ACS tabulations were used:

- Table B08202: Household Size by Number of Workers in Household
- Table B08301: Means of Transportation to Work (for total workers)
- Table B19001: Household Income
- Table B19013: Median Household Income

The auto ownership model was estimated using survey data from the recently completed French Broad River (FBRMPO) household travel survey.

HOUSEHOLD SIZE

Household size marginals were set up for 1, 2, 3, and 4+ persons within the household. The smallest level of geography available with the detailed breakout of persons per household was the Census Tract. A customized spreadsheet was set up to process the raw records, pivot the results into an average household size lookup format, interpolate the results, set up stepped increments of 0.1, and finally to create a text lookup file for percentage of households in each of the four categories given the average household size in the zone. Table 12 below shows a sample of the household size output lookup table. Figure 14 shows the raw ACS data for the household shares by average size, and Figure 15 shows the smoothed household size curves.

Table 12 Household Size Lookup Table (sample)

AvgPerHH	Size 1	Size 2	Size 3	Size 4
1.00	1.000	0.000	0.000	0.000
1.01	0.990	0.010	0.000	0.000
1.02	0.981	0.019	0.000	0.000
1.03	0.971	0.029	0.000	0.000
1.04	0.961	0.039	0.000	0.000
1.05	0.952	0.048	0.000	0.000

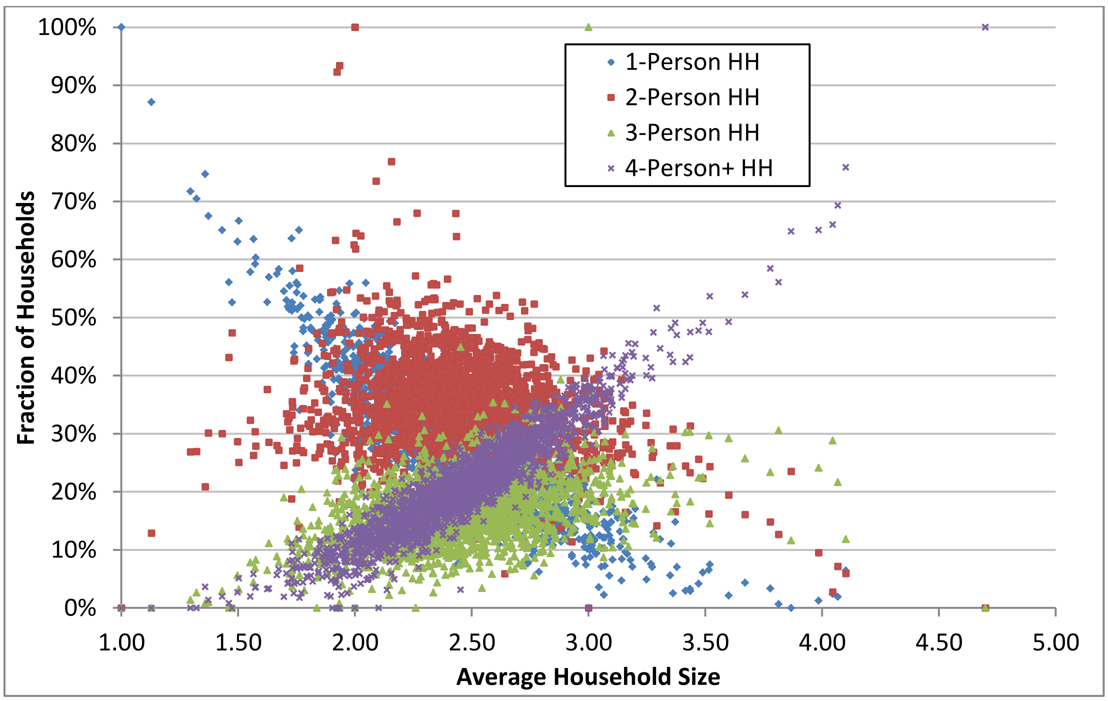


Figure 14 Raw ACS Data – Household Shares by Average Size

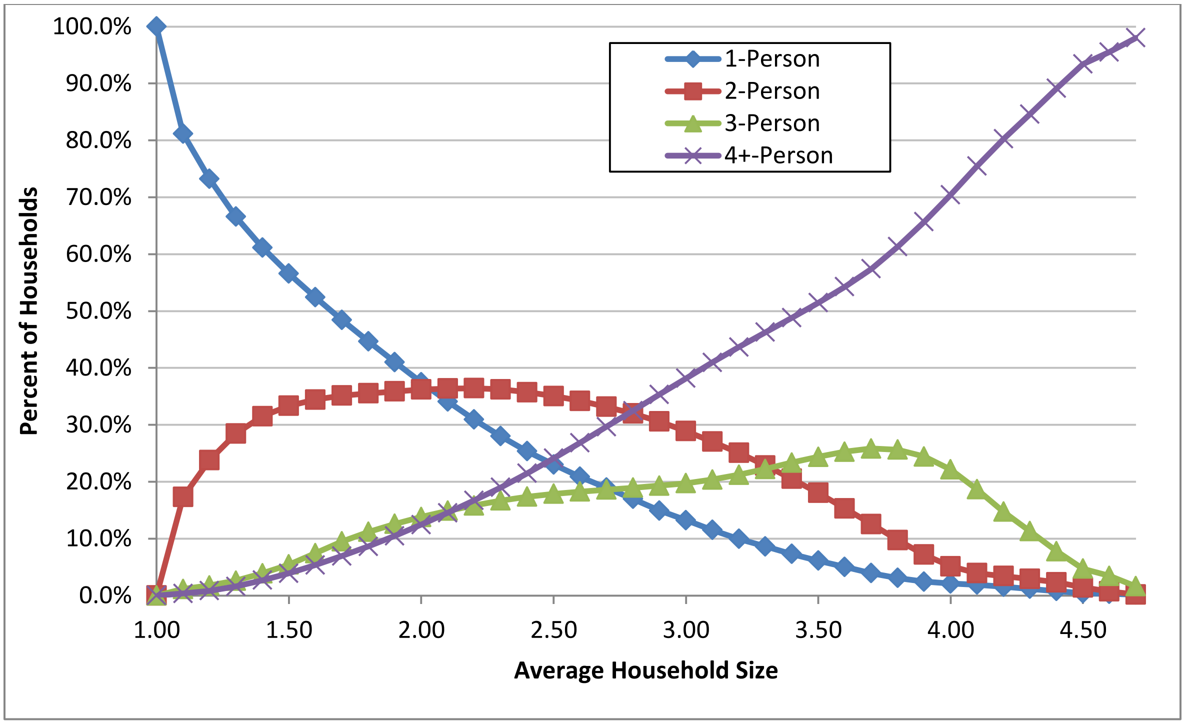


Figure 15 Smoothed Household Size Classification Curves

INCOME

The ratio of the median income in a zone to the median income of the FBRMPO region is a key zonal measure of trip making behavior in the FBRMPO travel demand model. Income ratio marginals were set up for the four income quartiles established through analysis of the household survey; these quartiles are defined in Table 13. The smallest level of geography available with the detailed breakout of median income was the Census Tract. A customized spreadsheet was set up to process the raw records, pivot the results into an income ratio by household size lookup format, interpolate the results to set up step increments of 0.1, and finally to create a text lookup file for percentage of households in each of the four income quartile categories given the income ratio in the zone. Table 14 shows a sample of the income ratio per household output lookup table. Figure 16 shows the raw ACS data for the household shares by income ratio, and Figure 17 shows the smoothed income ratio per household curves.

Table 13 Income Quartile Definitions

Income Quartile	Income Range
Inc1	Less than $30,000
Inc2	$30,000 – 50,000
Inc3	$50,001 – 75,000
Inc4	Greater than $75,000

Table 14 Income Ratio Lookup Table (sample)

Income Ratio	Inc1	Inc2	Inc3	Inc4
0.95	0.382	0.246	0.187	0.186
0.96	0.377	0.245	0.188	0.190
0.97	0.372	0.245	0.189	0.195
0.98	0.367	0.244	0.190	0.199
0.99	0.362	0.244	0.191	0.204
1.00	0.357	0.243	0.192	0.208

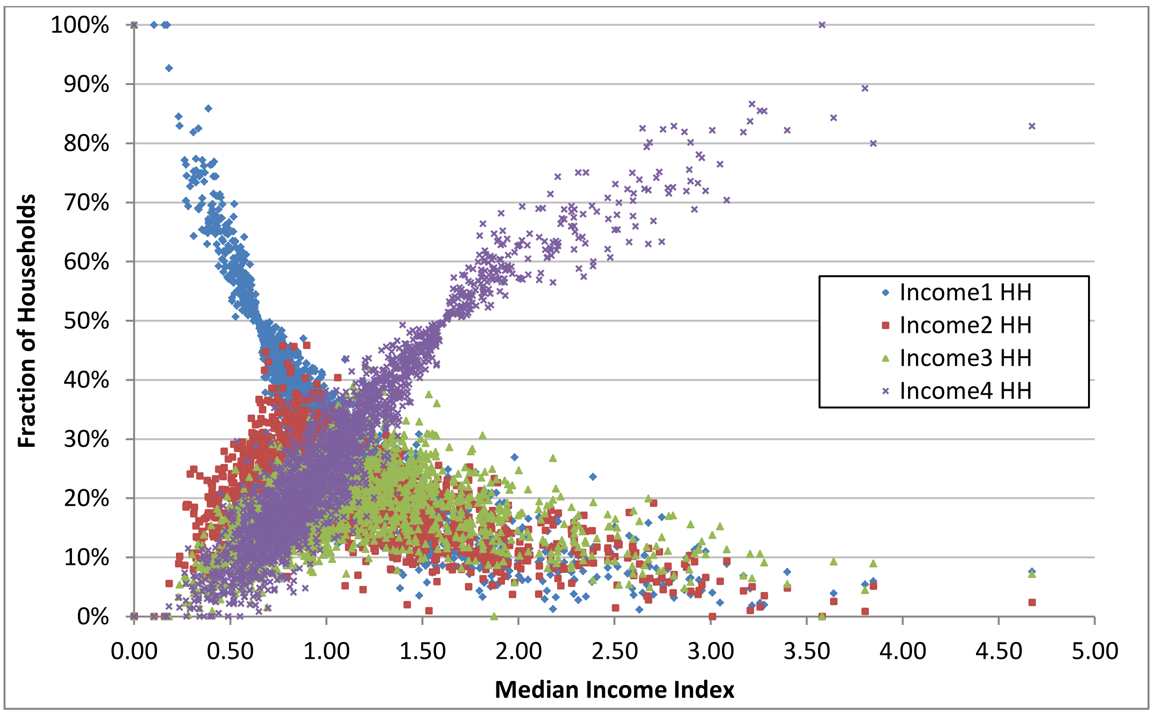


Figure 16 Raw ACS Data – Household Shares by Median Income Ratio

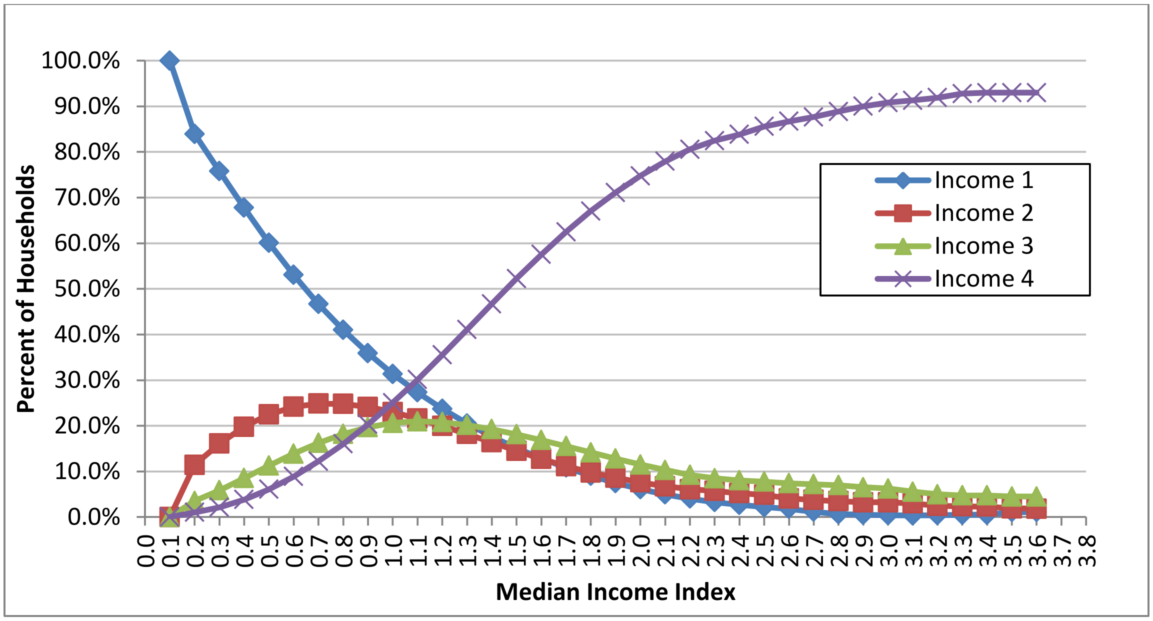


Figure 17 Smoothed Household Income Ratios per Household Classification

NUMBER OF WORKERS

Ideally the number of workers per TAZ is an input to the travel demand model and can be used to calculate the number of workers per household in order to estimate the number of 0, 1, 2, and 3+ worker households using the household worker submodel. Application of this approach for the FBRMPO required an additional step to estimate the number of workers by TAZ first. The primary driver behind estimating the number of workers by TAZ rather than using data directly from the U.S. Census was timing of the release of the updated ACS data and scheduling requirements for completing the travel demand model to support the long range transportation plan development schedule. At the time of model development, worker data from the Census was only available at the Tract level. Consideration was given to using a simple disaggregation method to allocate Tract level workers to the TAZ proportionate to the number of households. There was concern that this approach would not be sufficient to properly represent workers in the region. It was determined that a method that considered multiple variables would be preferred. A regression model was used to forecast workers by TAZ using various combinations of income, household size, and population as the independent variables. Unfortunately, after estimating these models it was found that the median income variable showed no statistical significance in estimating the total workers. Several additional models were tested with the final selected model using average household size. Table 15 summarizes the resulting worker model and the associated R^2 statistics. Figure 18 demonstrates the fit of the estimated model against ACS data.

Table 15 Worker Model Variables and Coefficients

Income Quartile	Income Range
Constant	-0.22
AverageSize	0.52
R^2	0.64

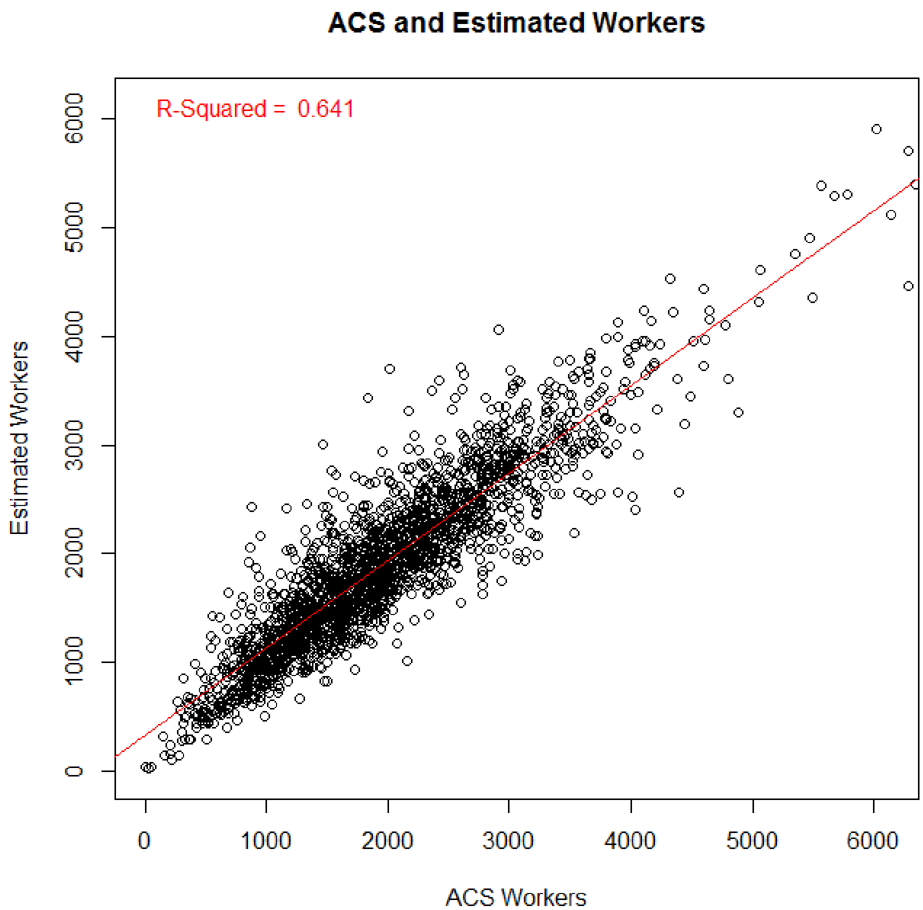


Figure 18 ACS versus Estimated Workers

To develop the workers per household submodel, the workers per household size marginals were set up for 0, 1, 2, and 3+ worker households. As with the other models, the smallest level of geography available with detailed breakout of workers per household was the Census Tract. A customized spreadsheet was set up to process the raw records, pivot the results into an average number of workers per household lookup format, interpolate the results to set up step increments of 0.1 and finally to create a text lookup file for percentage of households in each of the four worker categories given the average workers per household in the TAZ. Table 16 shows a sample of the workers per household output lookup table, Figure 19 shows the raw ACS data for the household shares by workers per household, and Figure 20 shows the smoothed workers per household curves.

Table 16 Workers per Household Lookup Table (sample)

AvgWorkerPerHH	Worker 0	Worker 1	Worker 2	Worker 3+
0.55	0.576	0.324	0.090	0.011
0.56	0.571	0.325	0.093	0.011
0.57	0.566	0.325	0.097	0.012
0.58	0.561	0.326	0.100	0.013
0.59	0.557	0.327	0.104	0.013
0.60	0.552	0.327	0.107	0.014

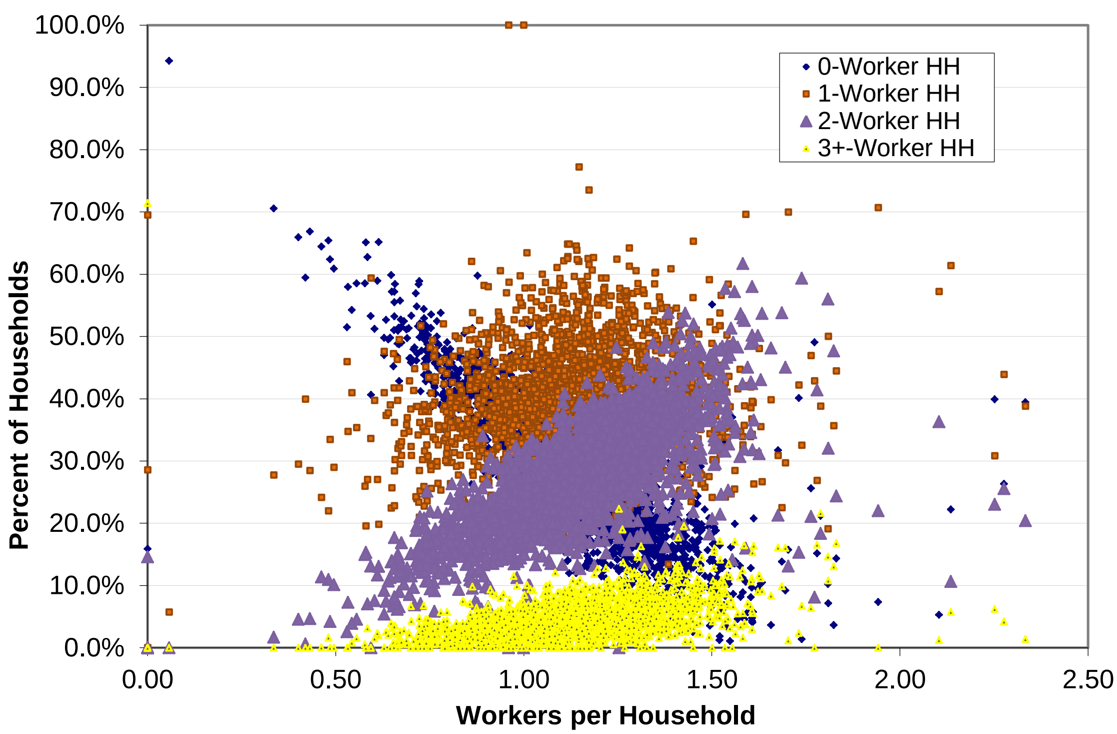


Figure 19 Raw ACS Data – Household Shares by Workers per Household

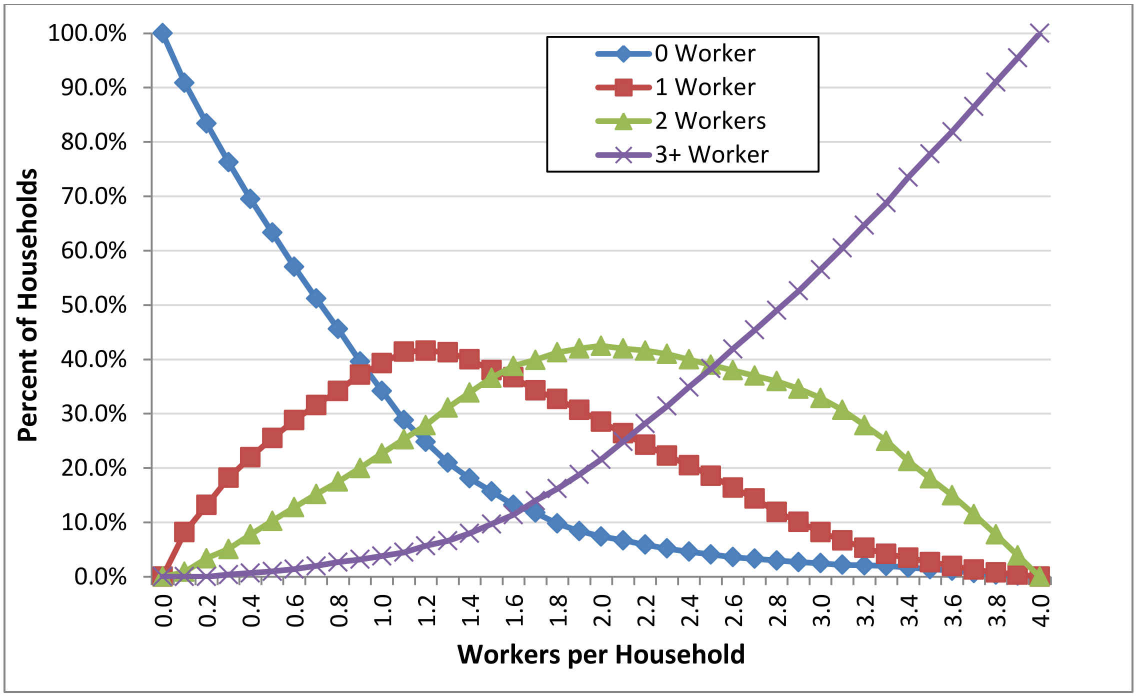


Figure 20 Workers per Household Classification

Application and Validation of Auxiliary Submodels

The household size, income, and worker models were applied and compared to ACS data. The results are summarized in Tables 17 - 20. Overall the model results match well the observed data.

Table 17 Household Size Submodel Estimated to Observed by County

	ACS Data				Modeled Data				Difference			
County	**SZ1**	**SZ2**	**SZ3**	**SZ4+**	**SZ1**	**SZ2**	**SZ3**	**SZ4+**	**SZ1**	**SZ2**	**SZ3**	**SZ4+**
Madison	2,005	3,293	1,396	1,388	2,579	3,078	1,351	1,477	1%	0%	0%	0%
Buncombe	31,950	36,804	15,857	16,298	31,937	35,687	15,592	17,128	-3%	3%	-2%	0%
Haywood	7,152	11,307	4,331	3,869	8,164	9,212	3,963	4,204	1%	-2%	-1%	0%
Henderson	12,806	18,318	6,142	7,914	14,180	16,112	7,113	8,014	1%	-1%	3%	-1%
Transylvania	4,260	5,887	2,054	1,713	4,904	5,106	2,139	2,223	1%	0%	0%	1%
Total	58,173	75,609	29,780	31,182	61,765	69,195	30,158	33,046	2%	-3%	0%	1%
Percent	30%	39%	15%	16%	32%	36%	16%	17%				

Note: slight differences may exist due to rounding

Table 18 Income Submodel Estimated to Observed by County

	ACS Data				Modeled Data				Difference			
County	IN1	IN2	IN3	IN4	IN1	IN2	IN3	IN4	IN1	IN2	IN3	IN4
Madison	3,169	1,719	1,619	1,575	3,519	1,900	1,455	1,621	0%	1%	0%	0%
Buncombe	33,513	22,675	19,289	25,432	34,519	21,389	18,276	26,234	0%	0%	1%	-1%
Haywood	9,446	5,906	5,385	5,922	9,277	5,648	4,680	5,963	-1%	0%	-1%	0%
Henderson	13,786	9,875	8,689	12,830	13,888	9,065	8,164	14,340	0%	-1%	0%	2%
Transylvania	4,964	3,252	2,398	3,300	5,444	3,105	2,497	3,343	1%	0%	1%	0%
Total	64,878	43,427	37,380	49,059	66,647	41,107	35,072	51,501	0%	1%	0%	0%
Percent	33%	22%	19%	25%	34%	21%	18%	27%				

Note: slight differences may exist due to rounding

Table 19 Workers per Household Submodel Estimated to Observed by County

	ACS Data				Modeled Data				Difference			
County	WK0	WK1	WK2	WK3	WK0	WK1	WK2	WK3	WK0	WK1	WK2	WK3
Madison	2,891	2,924	1,954	313	2,883	3,371	1,942	298	0%	0%	1%	1%
Buncombe	30,083	39,063	26,924	4,839	34,901	39,457	22,599	3,452	5%	-3%	-3%	-4%
Haywood	9,896	8,725	6,994	1,044	8,991	10,055	5,657	858	-2%	1%	-1%	1%
Henderson	16,421	15,898	10,803	2,058	15,543	17,889	10,411	1,605	-2%	1%	2%	0%
Transylvania	5,568	5,039	2,881	426	5,278	5,588	3,059	462	-1%	0%	1%	2%
Total	64,859	71,649	49,556	8,680	67,597	76,361	43,666	6,674	1%	3%	-3%	-1%
Percent	33%	37%	25%	4%	35%	39%	22%	3%				

Note: slight differences may exist due to rounding

Table 20 Estimated vs. Observed by District

	Household Size				Income				Workers			
District	**SZ1**	**SZ2**	**SZ3**	**SZ4+**	**IN1**	**IN2**	**IN3**	**IN4**	**WK0**	**WK1**	**WK2**	**WK3**
Waynesville	1%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CBD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Canton	-1%	0%	-1%	0%	0%	0%	-1%	0%	-1%	0%	0%	0%
Black Mountain	0%	0%	0%	0%	0%	0%	0%	0%	1%	-1%	0%	-1%
Dana	-1%	1%	1%	0%	0%	1%	1%	0%	0%	1%	1%	0%
Marshall	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	1%
Fines Creek	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Weaverville	1%	0%	1%	0%	1%	0%	0%	0%	0%	1%	0%	0%
Hendersonville	0%	0%	1%	-1%	0%	0%	-1%	1%	-1%	0%	0%	-1%
Ednyville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fletcher	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Mills River	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hot Springs	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Biltmore Forest	-1%	1%	-1%	-1%	0%	-1%	0%	1%	1%	-1%	-1%	1%
Flat Rock	1%	-1%	1%	-1%	0%	-1%	-1%	1%	-1%	0%	0%	1%
Cruso	0%	0%	-1%	0%	0%	0%	0%	1%	0%	0%	0%	1%
Fairview	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	-1%	-1%
Cecil	0%	0%	0%	0%	0%	0%	0%	0%	-1%	1%	0%	0%
Enka Candler	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Brevard	0%	0%	0%	1%	1%	0%	1%	0%	-1%	0%	1%	2%
Leicester	0%	0%	-1%	1%	0%	-1%	0%	0%	0%	0%	0%	0%
Maggie Valley	1%	0%	1%	1%	1%	1%	1%	0%	0%	1%	1%	0%
Green River	1%	0%	0%	0%	0%	0%	1%	0%	-1%	0%	1%	1%
Cataloochee	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	0%	0%
Rosman	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
North Asheville	-1%	0%	0%	0%	-1%	0%	0%	-1%	0%	-1%	-1%	-1%
North Downtown	-1%	0%	0%	0%	0%	1%	0%	-1%	1%	-1%	-1%	-1%
West Asheville	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	-1%
South Asheville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
East Downtown	-1%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%
West Downtown	-1%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%
East Asheville	0%	1%	1%	0%	0%	1%	1%	0%	1%	0%	0%	0%
Total	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

AUTO OWNERSHIP MODEL

The purpose of the auto ownership model is to estimate the number of autos owned by households in each TAZ. The FBRMPO model was developed based on household auto ownership characteristics observed in the household travel survey. The FBRMPO auto ownership model predicts the number of households with 0, 1, 2, or 3+ available vehicles. The model was estimated in a multinomial logit form using the ALOGIT software. The model was estimated using household survey records, but applied at the aggregate TAZ level. The auto ownership model looked at indicators for household size, household income, number of workers, accessibility, and population density. The results of the auto ownership model were compared to ACS data by county and district.

Estimation Process and Results

The FBRMPO Household Travel Survey formed the backbone of the auto ownership estimation data set. Other variables were derived using traffic analysis zone based measures of density and accessibility. Once the estimation data set was assembled and inventoried, the auto ownership estimation was able to proceed.

The utility (U_{az}) of having (a) autos available for a household of type (h) located in zone (z) is given by

$$U_{az} = \alpha_a + \sum\sum \beta_{hk} \times N_{hk} + \delta_a \times ACC_z + \gamma_a \times PopDen_z$$

All household attributes, listed below, are entered in the utility function as indicator variables; the density and accessibility terms are all linear in the parameters. The following variables were examined, proved to be significant in the utility functions, and were selected for the final model:

Household Variables (N_{hk}), where "h" is the household variable and "k" is the category

Household size: 1, 2, 3, 4 or more persons

Household income

- Low (less than $30,000)
- Medium-Low ($30,000-$50,000)
- Medium-High ($50,001-$75,000)
- High (greater than $75,000)

Number of workers in household: 0, 1, 2, 3 or more workers

Accessibility (ACC_z)

Population density ($PopDen_z$)

β_{hk} is the coefficient on the household variable h and category k

γ_a is the coefficient of population density by auto category

δ_a is the coefficient of accessibility for the auto category

The utility equations were estimated using the logit regression technique and ALOGIT software. The model estimation is an iterative process focused on meeting the following criteria:

1. All coefficients have logical signs
2. The included variables are logically related to the auto ownership choice
3. Coefficient values seem reasonable
4. Variables have acceptable t scores
5. Variables are consistently defined
6. The models achieve a good fit of the data

The resulting coefficients of the utility equations are presented in Table 21.

Table 21 Auto-Ownership Logit Model Coefficients

	Parameter	Coeff	SE	T-Stat
Constants	constant 2 (1 auto)	0.089		
	constant 3 (2 auto)	-2.387		
	constant 4 (3+ autos)	-5.578		
Size Coefficients	k2hhsize2 (2 auto coefficient for hh size 2)	1.8809	0.15	12.18
	k3hhsize2 (3+ auto coefficient for hh size 2)	3.0890	0.39	7.92
	k2hhsize3 (2 auto coefficient for hh size 3)	2.1282	0.22	9.86
	k3hhsize3 (3+ auto coefficient for hh size 3)	3.8623	0.42	9.17
	k2hhsize4 (2 auto coefficient for hh size 4+)	2.8993	0.26	11.35
	k3hhsize4 (3+ auto coefficient for hh size 4+)	4.4255	0.44	10.00
Worker Coefficients	k1nwork1 (1 auto coefficient for 1 worker)	1.1043	0.25	4.38
	k2nwork1 (2 auto coefficient for 1 worker)	0.8037	0.27	2.96
	k3nwork1 (3 auto coefficient for 1 worker)	0.8138	0.31	2.60
	k1nwork2 (1 auto coefficient for 2 worker)	0.4419	0.43	1.02
	k2nwork2 (2 auto coefficient for 2 worker)	1.4697	0.43	3.44
	k3nwork2 (3 auto coefficient for 2 worker)	2.0678	0.45	4.59
	k2nwork3 (2 auto coefficient for 3 worker)	-0.7614	0.47	-1.62
	k3nwork3 (3 auto coefficient for 3 worker)	0.6541	0.48	1.37
Income Coefficients	k1income2 (1 auto coefficient for income 2)	0.9511	0.26	3.64
	k2income2 (2 auto coefficient for income 2)	1.6094	0.29	5.59
	k3income2 (3 auto coefficient for income 2)	1.8001	0.35	5.15
	k1income3 (1 auto coefficient for income 3)	0.2789	0.35	0.79
	k2income3 (2 auto coefficient for income 3)	1.8144	0.37	4.97
	k3income3 (3 auto coefficient for income 3)	1.7454	0.42	4.15
	k1income4 (1 auto coefficient for income 4)	0.6689	0.44	1.53
	k2income4 (2 auto coefficient for income 4)	2.3650	0.44	5.35
	k3income4 (3 auto coefficient for income 4)	2.7177	0.48	5.64
Accessibility Coefficients	k1colsum (1 auto coefficient for auto logsum)	-0.0198	0.02	-0.84
	k2colsum (2 auto coefficient for auto logsum)	-0.0517	0.03	-2.04
	k3colsum (3 auto coefficient for auto logsum)	-0.0626	0.03	-2.27
Density Coefficients	k1popden	-0.0991	0.04	-2.79
	k2popden	-0.1366	0.04	-3.56
	k3popden	-0.2423	0.04	-5.67
Observations		2076		
Initial Likelihood		-2878		
Final Likelihood		-1869		
Rho-Squared w.r.t. Zero		0.3505		

The estimated coefficients and signs were reviewed and met the consistency and accuracy checks. For example, the population density variable influenced auto ownership negatively, meaning that higher densities increase the probability that a household will have lower car ownership. In contrast, the income group variable has a positive influence on auto ownership. Table 22 summarizes the results of the model application. The estimation of 0-vehicle households is higher than preferred, but acceptable. Over 20 different model specifications were evaluated and the selected model is the one that provides the best overall fit. The estimation process was limited by available measures of accessibility and mixed density. The results also capture some of the unique characteristics of the FBRMPO region, in that the estimated 0-vehicle households in Buncombe County where transit is most prevalent is within 4% of observed, with the largest error in the more rural counties. The geographic distribution of 0-vehicle households match well against observed concentrations of zero car households, see Figures 21 - 24.

Table 22 Validation of Auto-Ownership Model for the FBRMPO Region

	ACS Data	Modeled Data
0-vehicle	11,829	13,595
1-vehicle	63,131	62,130
2-vehicle	75,866	74,774
3+-vehicle	43,918	43,805

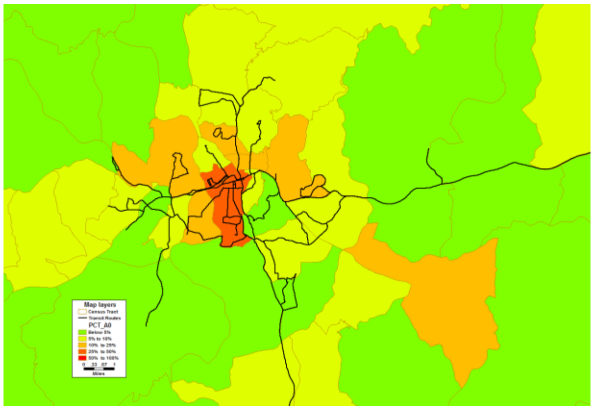


Figure 21 ACS 0-vehicle Households Downtown

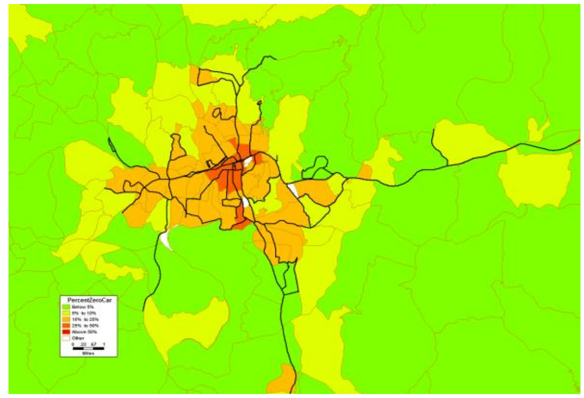


Figure 22 Model 0-vehicle Households Downtown

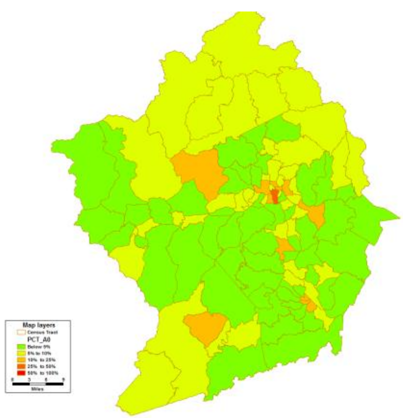


Figure 23 ACS 0-vehicle Households

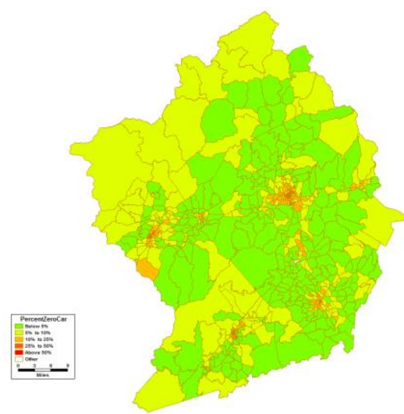


Figure 24 Model 0-vehicle Households

TRIP PRODUCTION MODEL

This section describes the development and validation of the trip production model. In terms of model sequence, this model represents the first step in the traditional 4-step process. The trip production model uses the results from the disaggregate curves and the auto-ownership models to estimate trip productions for households in each traffic analysis zone (TAZ). The outputs from the trip production model are fed into the destination choice models.

MODEL STRUCTURE

The trip production model is actually a series of rates by market stratification developed based on the 2013 FBRMPO Household Travel Survey. The rates were developed to estimate trip productions (the home end of the trip) based on household type. While numerous combinations of strata were tested, including one that considered auto sufficiency, the final trip production model was developed as a series of trip rates for different purposes cross-classified by household size, auto availability, and income for non-work purposes; and household workers, auto availability, and income for work purposes.

TRIP PURPOSES

The FBRMPO household survey provided adequate sample sizes to define seven trip purposes for the trip production model. These trip purposes are:

- Home-based work (HBW)
- Home-based escort (HBE)
- Home-based shopping (HBS)
- Home-based K-12 (SCH)
- Home-based other (HBO)
- Non-home-based work (NHBW)
- Non-home-based other (NHBO)

The HBE trip purpose was created by identifying trips where a person drops someone off at an activity and then returns home, an example would be a parent dropping a child off at school and then returning home. Prior to defining the trip purposes, certain trip segments are linked in order to better capture the primary trip purpose. For example, trip linking is performed for trip segments where the activity is less than 5 minutes, in these cases the short activity is linked out, and the first segment is linked with the last segment in order to create the overall trip purpose. An example of this is someone stopping to fuel their vehicle on the way to work. For an unlinked trip, the first segment would be a HBO trip and then the second segment would be a NHBW trip. Linking out the short middle activity gives the true trip purpose which is a HBW trip.

Since university trips are very specific with respect to where the trip is produced (student households) and where the trip is attracted (university campus), these trips are treated differently from other trip purposes as described in the section on University trips below.

Initial Trip Production Rates

The survey trip records were separated by trip purpose cross-classified by two income groups (INCOME), four auto ownership groups (AUTO), and four household worker groups (Worker) for HBW and NHBW trips. For non-work trips four household size groups (SIZE) were used in place of household workers. Once the trip records were parsed by trip purpose and household characteristics, the average trip rate was calculated for each cell of the matrix. If the average trip rate was not statistically significant due to small sample size in one particular cell, the data from the adjacent cells was merged and a new average trip rate was calculated based on the merged cells' data. The initial trip production rates by trip purpose are shown in Tables 23 – 29.

Table 23 HBW Initial Trip Rates.

		Worker		
INCOME	**AUTO**	**1**	**2**	**3**
Inc 1 + Inc 2	**0**	0.618	0.925	
Inc 1 + Inc 2	**1**	1.153	1.956	2.786
Inc 1 + Inc 2	**2**	1.291	3.319	1.927
Inc 1 + Inc 2	**3+**	0.566	2.051	2.746
Inc 3 + Inc 4	**0**	-	3.000	
Inc 3 + Inc 4	**1**	1.037	1.865	1.000
Inc 3 + Inc 4	**2**	1.305	2.131	3.133
Inc 3 + Inc 4	**3+**	1.302	2.604	2.567

Table 24 HBE Initial Trip Rates.

		SIZE			
INCOME	**AUTO**	**1**	**2**	**3**	**4**
Inc 1 + Inc 2	**0**	0.016	0.175	-	
Inc 1 + Inc 2	**1**	0.099	0.365	1.059	1.229
Inc 1 + Inc 2	**2**	0.113	0.105	0.343	1.486
Inc 1 + Inc 2	**3+**	-	0.013	0.831	
Inc 3 + Inc 4	**0**	0.006	0.038		
Inc 3 + Inc 4	**1**	0.055	0.221	0.496	0.990
Inc 3 + Inc 4	**2**	0.032	0.157	0.621	
Inc 3 + Inc 4	**3+**	-	0.094	0.165	

Table 25 HBS Initial Trip Rates.

INCOME	AUTO	SIZE 1	2	3	4
Inc 1 + Inc 2	0	0.117	0.203	-	
Inc 1 + Inc 2	1	0.470	0.925	1.288	0.627
Inc 1 + Inc 2	2	0.407	1.175	0.905	1.040
Inc 1 + Inc 2	3+	2.000	1.117	0.487	
Inc 3 + Inc 4	0	-	0.455		
Inc 3 + Inc 4	1	0.484	0.801	0.191	0.169
Inc 3 + Inc 4	2	0.171	0.946	0.802	
Inc 3 + Inc 4	3+	-	0.789	0.731	

Table 26 SCH Initial Trip Rates.

INCOME	AUTO	SIZE 1	2	3	4
Inc 1 + Inc 2	0	-	-	0.708	
Inc 1 + Inc 2	1	-	0.144	0.402	1.130
Inc 1 + Inc 2	2	-	-	0.203	1.647
Inc 1 + Inc 2	3+	-	-	0.695	
Inc 3 + Inc 4	0	-	-		
Inc 3 + Inc 4	1	-	0.128	0.474	1.568
Inc 3 + Inc 4	2	-	-	0.389	
Inc 3 + Inc 4	3+	-	-	0.354	

Table 27 HBO Initial Trip Rates.

INCOME	AUTO	SIZE 1	2	3	4
Inc 1 + Inc 2	0	1.159	1.587	2.465	
Inc 1 + Inc 2	1	1.204	1.692	2.110	1.722
Inc 1 + Inc 2	2	0.909	2.338	2.067	2.529
Inc 1 + Inc 2	3+	-	2.968	2.325	
Inc 3 + Inc 4	0	0.274	1.822		
Inc 3 + Inc 4	1	1.384	2.393	4.423	2.325
Inc 3 + Inc 4	2	0.576	2.836	2.190	
Inc 3 + Inc 4	3+	3.000	1.783	2.490	

Table 28 NHBW Initial Trip Rates.

INCOME	AUTO	Worker 1	2	3
Inc 1 + Inc 2	0	0.884	0.484	
Inc 1 + Inc 2	1	0.861	1.075	1.455
Inc 1 + Inc 2	2	0.860	1.760	1.643
Inc 1 + Inc 2	3+	1.059	1.780	3.254
Inc 3 + Inc 4	0	0.063	-	
Inc 3 + Inc 4	1	1.352	1.020	1.000
Inc 3 + Inc 4	2	0.890	2.073	1.702
Inc 3 + Inc 4	3+	0.852	2.119	2.824

Table 29 NHBO Initial Trip Rates.

INCOME	AUTO	SIZE 1	2	3	4
Inc 1 + Inc 2	0	0.756	0.645	1.415	
Inc 1 + Inc 2	1	0.964	2.067	1.890	0.697
Inc 1 + Inc 2	2	1.667	1.499	1.805	2.305
Inc 1 + Inc 2	3+	3.000	1.653	1.856	
Inc 3 + Inc 4	0	0.267	0.139		
Inc 3 + Inc 4	1	1.286	1.510	3.776	0.237
Inc 3 + Inc 4	2	0.701	2.213	1.015	
Inc 3 + Inc 4	3+	6.000	1.167	2.131	

The trip production rates in Tables 23 - 29 were checked for statistical significance and logical variable relationships. In several cases the trip production rates did not follow logical variable relationships and some cells still had a low number of observations due to the small household survey sample size and the large number of stratifications. These rates were further smoothed and adjusted to account for low samples and to create a final set of rates that follow logical variable relationships. Tables 30 - 36 show the trip production rates developed prior to application and calibration.

Table 30 HBW Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="3">Worker</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.618</td><td>1.380</td><td>2.290</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">1.153</td><td>1.956</td><td>2.586</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">2.830</td><td>2.627</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>2.846</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.618</td><td>1.380</td><td>2.290</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.423</td><td>1.865</td><td>2.586</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.318</td><td>3.133</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>3.567</td></tr>
</table>

Table 31 HBE Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.015</td><td>0.129</td><td>0.129</td><td>0.129</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.099</td><td>0.322</td><td>1.059</td><td>1.229</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td>0.105</td><td rowspan="2">0.511</td><td>1.486</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>0.013</td><td>1.486</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.015</td><td>0.038</td><td>0.038</td><td>0.038</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">0.048</td><td>0.221</td><td>0.496</td><td>0.990</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td>0.157</td><td rowspan="2">0.412</td><td>1.486</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>0.094</td><td>1.486</td></tr>
</table>

Table 32 HBS Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.104</td><td>0.288</td><td>0.788</td><td>1.038</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.470</td><td>0.925</td><td>1.236</td><td>1.254</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">1.161</td><td>1.288</td><td>1.532</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>1.288</td><td>1.857</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.104</td><td>0.288</td><td>0.788</td><td>1.038</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">0.484</td><td>1.001</td><td>1.856</td><td>2.031</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">1.202</td><td>2.040</td><td>2.052</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>2.040</td><td>2.660</td></tr>
</table>

Table 33 SCH Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td rowspan="4">-</td><td rowspan="4">0.032</td><td rowspan="4">0.383</td><td rowspan="4">1.612</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td rowspan="4">-</td><td rowspan="4">0.032</td><td rowspan="4">0.383</td><td rowspan="4">1.612</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td></tr>
</table>

Table 34 HBO Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>1.067</td><td>1.587</td><td>2.165</td><td>2.174</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">1.144</td><td>1.692</td><td>2.315</td><td>2.325</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">2.490</td><td>2.320</td><td>2.529</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>2.325</td><td>2.535</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>1.067</td><td>1.822</td><td>2.165</td><td>2.174</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.174</td><td>2.393</td><td>2.315</td><td>2.325</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.537</td><td>2.327</td><td>2.537</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>2.490</td><td>2.699</td></tr>
</table>

Table 35 NHBW Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="3">Worker</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.618</td><td>2.093</td><td>1.550</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">1.153</td><td>1.956</td><td>2.586</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">2.830</td><td>2.627</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>2.846</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.618</td><td>2.093</td><td>1.550</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.423</td><td>1.865</td><td>2.586</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.318</td><td>3.133</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>3.567</td></tr>
</table>

Table 36 NHBO Smoothed Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.756</td><td>0.900</td><td>1.415</td><td>1.869</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">1.093</td><td>2.067</td><td>1.890</td><td>2.058</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">1.536</td><td>1.805</td><td>2.305</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>1.856</td><td>3.200</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.756</td><td>0.900</td><td>1.415</td><td>1.869</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.154</td><td>1.510</td><td>2.540</td><td>3.202</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">1.917</td><td>2.660</td><td>3.361</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>2.880</td><td>3.421</td></tr>
</table>

These trip production rates were applied to the study area households to calculate a region wide average daily trip rate. This region wide average trip rate was determined to be 7.25 trips per household. When compared to other models, this rate appears to be somewhat low but still in a reasonable range.

UNIVERSITY TRIPS

Given the unique nature of university trips made by students, it is common practice in a trip based model to develop the university trip table directly using student home locations and university enrollment with an average trip rate estimated from the household survey, rather than to use trip rates by household characteristics to calculate trip productions, and then a gravity model or destination choice model to calculate trip distribution.

The total number of university students by zip code was provided by the FBRMPO staff. These student locations were proportionately disaggregated to the TAZ using the proportion of population in the TAZ. This process yields the total number of university students per TAZ. Also provided by the FBRMPO staff was university enrollment by TAZ. The allocation of student trips between zones uses this university enrollment data by TAZ.

An average university trip rate by student was calculated from the FBRMPO household survey as 0.4236 trips per student. In application, this trip rate will be applied to the number of university students by TAZ to get the number of HBU trip productions and a trip attraction rate is applied to the university enrollment by TAZ to get the HBU attractions. Total student trip productions must balance to total student trip attractions; therefore the trip production model uses this simple student trip rate from the household survey.

To create the university trip table, the productions and attractions by TAZ will be pared by allocating the productions from a given zone proportionally to the zones with university trip attractions. This university trip table will later be merged with the HBO trip purpose prior to mode choice model, time of day and highway assignment.

Seasonal Households

People living in seasonal households are an important market in the FBRMPO region. Depending on the time of year, these part time residents can have a notable impact on traffic around the region. In an attempt to better understand how travel made by part time residents differs from travel made by full time residents, the FBRMPO household travel survey asked a specific question designed to flag these seasonal households. Average trip production rates were calculated separately for full time and part time residents and compared to the average trip production rates calculated for recreational vehicle (RV) households to determine whether part time residents were more like full time residents or more like RV households. The purpose of this comparison was to make a decision about how best to treat seasonal households in the model.

Table 37 provides a summary of household trip rates for these three resident types. The comparison shows that the HBS trip is most like that of RV households, but not too dissimilar from full time households. This suggests that on average most households make the same average number of shopping trips. The average trip rates for the other trip purposes are quite different between the different resident types. This suggests that resident type does play a role in trip production rates for HBO and NHB trips. This finding supports the need to estimate trip productions separately for full time and part time residents, and not to combine seasonal households with RV households.

Table 37 Household Trip Rates by Resident Type.

Trip Purpose	Full Time Households	Seasonal Households	RV Households
HBS	1.9	1.6	1.6
HBO	3.4	2.6	1.4
NHB	2.9	4.3	1.7

A comparison of average trip length for the seasonal households also shows that seasonal residents are more closely aligned with the full time households than the RV households, with shorter shopping and home-based other trips on average.

Based on these findings the best approach for addressing travel by seasonal households within the current model framework is to calculate separate trip productions for the seasonal households, but then to merge them with the full time resident trips prior to distribution. This is the approach that will be implemented in the FBRMPO model.

Model Validation

The following comparison of modeled versus observed trips shows that the trip production model is reasonably calibrated to the survey observed trip productions overall and for the majority of the trip purposes, see Table 38. However, the estimated productions for the shopping, school, and non-home-based other trips are too high in comparison to the survey data suggesting the need to further adjust the trip production rates for these trip purposes. Note that while separate production rates are applied for the HBE, NHBO, and NHBW, the summaries below combine HBE with the HBO trip purpose and NHBO and NHBW into NHB in order to support the trip distribution model structure.

Table 38 Initial Comparison of Model versus Survey Trip Production

Trip Purpose	Observed Trip Productions (Survey)	Percent by Purpose (Survey)	Predicted Trip Productions (Model)	Percent by Purpose (Model)	Percent Difference in Productions (Survey versus Model)
HBW	227,574	17%	225,189	15%	-1%
HBO	388,832	29%	473,590	31%	2%
HBS	151,754	11%	220,259	14%	**45%**
SCH	62,229	5%	71,285	5%	**15%**
NHB	492,060	37%	537,640	35%	**9%**
TOTAL	1,322,449		1,527,963		8%

Adjustment factors were developed for the HBS, SCH, and NHBO (prior to combining NHBW and NHBO into NHB) trip purposes by taking the ratio of observed to estimated trips. These factors were applied to the trip rates for these purposes and the trip production model was applied with the new rates. The results for the combined trip purposes are shown in Table 39.

Table 39 Final Comparison of Model versus Survey Trip Production

Trip Purpose	Observed Trip Productions (Survey)	Percent by Purpose (Survey)	Predicted Trip Productions (Model)	Percent by Purpose (Model)	Percent Difference in Productions (Survey versus Model)
HBW	227,574	17%	237,813	18%	4%
HBO	388,832	29%	389,516	29%	0%
HBS	151,754	11%	158,757	12%	5%
SCH	62,229	5%	63,155	5%	1%
NHB	492,060	37%	497,844	37%	1%
TOTAL	1,322,449		1,347,086		2%

Application of the final adjustment factors shows a trip production model that is well calibrated overall and by trip purpose. HBO trips for both the survey and modeled trip productions by trip purpose are within the range typically expected, see Table 40. HBW trips are on the lower end of the scale for the FBRMPO region than that typically seen in other models, perhaps reflecting a higher number of retiree households. In contrast, the NHB trips are slightly higher than what is typically seen in other areas.

Table 40 Percent Trips by Trip Purpose

Trip Purpose	Survey	Model	Typical
HBW	17%	18%	18 – 25%
HBO	46%	45%	45 – 55%
NHB	37%	37%	20 – 30%

Final Trip Production Rates

The final trip production rates by trip purpose are shown in Tables 41-47.

Table 41 Final HBW Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="3">Worker</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.677</td><td>1.380</td><td>1.550</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">1.372</td><td>2.328</td><td>2.586</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">3.367</td><td>3.126</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>3.387</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.618</td><td>1.380</td><td>1.550</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.423</td><td>1.865</td><td>2.586</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.318</td><td>3.133</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>3.567</td></tr>
</table>

Table 42 Final HBE Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.015</td><td>0.129</td><td>0.129</td><td>0.129</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.099</td><td>0.322</td><td>1.059</td><td>1.229</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td>0.105</td><td rowspan="2">0.511</td><td>1.486</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>0.013</td><td>1.486</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.015</td><td>0.038</td><td>0.038</td><td>0.038</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">0.048</td><td>0.221</td><td>0.496</td><td>0.990</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td>0.157</td><td rowspan="2">0.412</td><td>1.486</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>0.094</td><td>1.486</td></tr>
</table>

Table 43 Final HBS Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.070</td><td>0.207</td><td>0.567</td><td>0.747</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.340</td><td>0.667</td><td>0.890</td><td>0.903</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">0.836</td><td>0.927</td><td>1.103</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>0.927</td><td>1.337</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.075</td><td>0.207</td><td>0.567</td><td>0.747</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">0.348</td><td>0.721</td><td>1.336</td><td>1.462</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">0.865</td><td>1.496</td><td>1.477</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>1.496</td><td>1.915</td></tr>
</table>

Table 44 Final SCH Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td rowspan="4">-</td><td rowspan="4">0.288</td><td rowspan="4">0.345</td><td rowspan="4">1.451</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td rowspan="4">-</td><td rowspan="4">0.288</td><td rowspan="4">0.345</td><td rowspan="4">1.451</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td></tr>
</table>

Table 45 Final HBO Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.854</td><td>1.270</td><td>1.732</td><td>1.740</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.915</td><td>1.354</td><td>1.852</td><td>1.860</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">1.992</td><td>1.856</td><td>2.024</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>1.860</td><td>2.028</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.854</td><td>1.457</td><td>1.732</td><td>1.740</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">0.939</td><td>1.914</td><td>1.852</td><td>1.860</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.030</td><td>1.862</td><td>2.029</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>1.992</td><td>2.159</td></tr>
</table>

Table 46 Final NHBW Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="3">Worker</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.781</td><td>1.000</td><td>1.200</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.861</td><td>1.075</td><td>1.455</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">1.768</td><td>1.643</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>2.827</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.781</td><td>1.000</td><td>1.200</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.149</td><td>1.020</td><td>1.455</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">2.091</td><td>1.702</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>2.827</td></tr>
</table>

Table 47 Final NHBO Trip Rates.

<table>
<tr><th rowspan="2">INCOME</th><th rowspan="2">AUTO</th><th colspan="4">SIZE</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>Inc 1 + Inc 2</td><td>0</td><td>0.680</td><td>0.810</td><td>1.274</td><td>1.682</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>1</td><td rowspan="3">0.984</td><td>1.860</td><td>1.701</td><td>1.852</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>2</td><td rowspan="2">1.382</td><td>1.625</td><td>2.075</td></tr>
<tr><td>Inc 1 + Inc 2</td><td>3+</td><td>1.670</td><td>2.880</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>0</td><td>0.680</td><td>0.810</td><td>1.274</td><td>1.682</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>1</td><td rowspan="3">1.039</td><td>1.359</td><td>2.286</td><td>2.882</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>2</td><td rowspan="2">1.725</td><td>2.394</td><td>3.025</td></tr>
<tr><td>Inc 3 + Inc 4</td><td>3+</td><td>2.592</td><td>3.079</td></tr>
</table>

DESTINATION CHOICE

This section describes the development of the destination choice models. The destination choice model replaces the gravity model commonly used in trip based models. There are several advantages for implementing a destination choice model in the FBRMPO region. A destination choice model is a logit model which allows for the consideration of a greater number of independent variables for estimating trip distribution, including the logsum variable output from the mode choice model. Unlike the gravity model, the destination choice model is sensitive to transit, income, and auto ownership. This greater sensitivity improves the resulting trip tables and overall model performance.

The destination choice model predicts the probability of choosing any given zone as the trip attraction end of a trip. The destination choice model is preceded by the trip production models, which forecast the number of trip productions by zone for different market segments, primarily identified by purpose and income. The destination choice model is applied for seven trip purposes and market segments:

- Home-based work (HBW) – low and high income markets
- Home-based other (HBO) – low and high income markets
- Home-based shop (HBS) – low and high income markets
- Non-home-based (NHB)

The low income market is used to capture households with income less than $50,000 (previously defined Inc1 and Inc2), and high income captures households with income of at least $50,000 (previously defined Inc3 and Inc4). Several trip purposes had to be aggregated during the development of the destination choice model due to insufficient samples by strata, see Table 48. Non-home-based work (NHBW) and non-home-based other (NHBO) were combined into one NHB trip purpose. The home-based escort (HBE) trips are combined with the home-based other (HBO) trips. This decision was based on a review of the individual trip records and a comparison of average trip lengths. See also the previously discussed Figure 2.

Table 48 Aggregation of Trip Purposes for Destination Choice

Production Model Trip Purpose	Destination Choice Model Trip Purpose
HBW-Inc1	HBW12 - low income market
HBW-Inc2	
HBW-Inc3	HBW34 - high income market
HBW-Inc4	
HBO-Inc1, HBE-Inc1	HBO12 - low income market
HBO-Inc2, HBE-Inc2	
HBO-Inc3, HBE-Inc3	HBO34 - high income market
HBO-Inc4, HBE-Inc4	
HBS-Inc1	HBS12 - low income market
HBS-Inc2	
HBS-Inc3	HBS34 - high income market
HBS-Inc4	
NHBO	NHB
NHBW	

The destination choice formulation is not used to distribute home-based K-12 school (SCH) trips and the home-based university (HBU) trips. The SCH trips use a gravity model formulation, and the HBU trip table is developed directly using student home locations and university enrollment data. The SCH and HBU trips are discussed separately later in this report.

Supporting Data

The 2013 FBRMPO Household Travel Survey constitutes the backbone of the estimation dataset. Information about trip characteristics obtained from the household survey includes trip production and attraction locations, trip purpose, household income, number of workers, persons per household, and auto ownership. While the survey provides considerable detail about trip-makers and their households, the models are limited to the attributes forecast by the trip production models. Mode choice logsums and distance skims from the FBRMPO model provide the information about impedance. In addition, important areas where trips start or end were identified. These areas represent key destinations such as the central business district (CBD) for both Asheville and Hendersonville.

In the FBRMPO model there are a large number of destination alternatives for every choice (i.e. over 600 model zones). Given the large number of destination alternatives, it is not feasible to include all possible alternatives in the estimation dataset. Instead, a sampling-by-importance approach was used to identify a subset of alternatives for each trip. The sampling-by-importance approach first requires the duplication of each trip record 10 times. From this expanded set of trip records, different choice sets with 30 alternatives each are selected from the universe of choices based on the size term and the distance. The size term (or variable) is equivalent to the attractions in a gravity model and is often calculated as a linear regression of trip attractions on various employment categories. The size term may also include terms other than employment, such as population, households, school enrollment, or any other indicator of the attractiveness of a zone.

The 2013 FBRMPO Household Travel Survey also provided the data summaries necessary for model calibration, including observed trip length frequency distributions and district to district trip tables. The Census Transportation Planning Products (CTPP) data based on the 2006-2010 5-year American Community Survey (ACS) data were also used in validating the HBW trip distribution.

Main Explanatory Variables

The following variables were examined and proved to be significant for many of the trip purposes. By allowing for the inclusion of multi-modal accessibilities and several other regional and trip market terms, the destination choice framework helps explain variation in travel across the region that was difficult to explain with a single gravity model impedance function:

- Mode choice logsum (composite accessibility across all modes between origin and potential destinations, output from FBRMPO mode choice model)
- Roadway distance between the origin and potential destinations (FBRMPO drive alone skims)
  - Linear distance
  - Distance squared
  - Distance cubed
  - Log of distance
- Household market attributes
  - Intra-zonal indicator
  - Attraction zone land use activity:
    - Total employment
    - Industrial employment (NAICS = 111-115, 211-213, 221, 236-238, 311-339, 424, 481-484, 486, 488, 491-493, 562)
    - Retail employment (NAICS = 441-444, 446, 448-453)
    - High traffic retail employment (NAICS = 445, 447, 722)
    - Office employment (NAICS = 425, 454, 511-519, 521-525, 531, 533)
    - Service employment (NAICS = 485, 487, 532, 611, 621-624, 711-713, 721, 811-814)
    - Total households

Model Structure and Estimation

The utility (U_{ij}) of choosing a trip attraction destination (j) for a trip produced in zone (i) is a function of mode choice logsums (LS), distance between zone *i* and zone *j*, distance factors, and an indicator variable for intra-zonal (IZ) production-attraction (PA) pairs. This is expressed as:

$$U_{ij} = \beta_{LS} * logsum + \beta_d * distance + \sum_{d=1}^{7} \beta_{DF_d} * (1\ if\ i\ and\ j \in d) + \beta_{IZ} * (1\ if\ i = j)$$

In the utility equation above, β_{DF_d} is the coefficient for distance factor *d*. Other distance terms such as distance squared or distance cubed enter the utility equation in exactly the same way as the distance term. For brevity those terms are not shown in the utility equations above. Also note that the beta coefficients are unique to each trip purpose.

Once the utility for each PA pair is obtained from the utility equation above, they are used to construct the probability using a multinomial logit model (MNL). The MNL probability expression is given by:

$$P_{ij} = \frac{\exp(U_{ij})}{\sum_k U_{ik}}$$

In the above expression, the index *k* takes all the available attraction zones in the region.

The destination choice utilities are a function of mode choice logsums, and they are applied consistently, in the sense that the same coefficients and constants that are used for mode split are also used for calculating the logsums. Shadow prices are used to constrain the HBW attractions to a particular zone to be proportional to the employment in that zone. This means that after the location probabilities are calculated on the basis of the utility functions, a shadow price is added to the utility of each destination with the objective of matching a pre-specified number of trip attractions to the zone. Employment is usually a standard input to travel models and is considered largely independent of the household travel survey. The shadow price addition is shown below:

$$U'_{ijm} = U_{ijm} + sp_j$$

In the equation above U_{ijm} is the base utility from production zone *i* to attraction zone *j* for purpose *m* and sp_j is the shadow price for attraction zone *j*. U'_{ijm} is the final utility.

ALOGIT software was used to perform the model estimation. Early on in the estimation process, it became apparent that the number of observations in the survey was too small to support a robust estimation given the number of trip purposes and market segments, even after aggregating the trip purposes from the trip production model. The model development team discussed further aggregation of the trip purposes in order to increase the number of observations in the estimation data file, but ultimately felt strongly about preserving the market segments for the HBW and HBO trip purposes due to the influence of income on mode choice, and on keeping HBS trips as a separate trip purpose since retail employment largely drives the distribution of these trips, and collapsing those trips into the HBO trip purpose would likely yield trip distribution results that did not represent the home to shopping trip as well as if the purpose were treated separately. Based on these factors, a decision was made to assert, rather than estimate, the initial coefficients. The model was then calibrated against the observed survey data.

The mode choice logsum coefficients were asserted based on experience with the estimation of other destination choice models, and typical values used in other metropolitan areas. All other coefficients were calibrated to obtain good fits with the calibration targets. The distance factors are constant terms added to the utility if the distance between production and attraction falls within a particular distance band. The seven distance factors, for the first seven distance bands were used in the calibration.

Size Parameters

The size parameters for the HBW trips were obtained from the Census Public Use Microdata Samples (PUMS) data by aggregating the number of individuals working by industry category for each of the market segments see Table 49. For other purposes, the size factors were obtained by estimating an attraction regression model with coefficients shown in Table 50.

Table 49 PUMS Workers Aggregated by Market Segment (household income)

Industry Category	Total individuals		Row Percent (Size Coefficients)	
	Low Income	High Income	Low Income	High Income
High Traffic Retail	861	597	0.591	0.409
Industrial	1030	1448	0.416	0.584
Office	345	550	0.385	0.615
Retail	728	672	0.520	0.480
Service	2264	3295	0.407	0.593
Other	8318	6896	0.547	0.453

Table 50 Attraction Regression Model Results

Trip Purpose	HBO Low income		HBO High income		HBS (low & high)		NHB	
	estimate	t-stat	estimate	t-stat	estimate	t-stat	estimate	t-stat
Constant	-0.4850	-1.1	-2.4200	-4.1	-0.6400	-1.6	-0.7500	-0.9
High traffic retail employees	0.0212	7.0	0.0348	8.8	0.0370	10.6	0.0622	11.3
Industrial employees	---	---	---	---	---	---	---	---
Office employees	0.0101	4.7	0.0118	4.1			0.0135	3.4
Retail employees	0.0138	4.9	0.0139	3.8	0.0400	11.8	0.0571	10.8
Service employees	0.0056	7.4	0.0070	6.9	---	---	0.0058	3.9
Total households	0.0068	7.1	0.0115	9.2	---	---	0.0109	6.1
University enrollment	0.0010	2.1	0.0010	1.5	---	---	---	---

The size factors used for each of the trip purposes are tabulated in Table 51. HBW12, HBO12, and HBS12 indicate that the corresponding rows contain the size factors used for the first market segment (low income). Similarly HBW34, HBO34, and HBS34 are the ones used for the high income market segment. NHB is not segmented, hence only one set of size factors for those two trip purposes.

Table 51 Size Factors by Trip Purpose

Trip Purpose	High traffic retail employees	Industrial employees	Office employees	Retail employees	Service employees	Total households	University enrollment
HBW12	0.591	0.416	0.385	0.520	0.407	0.000	0.000
HBW34	0.409	0.584	0.615	0.480	0.593	0.000	0.000
HBO12	0.021	0.000	0.010	0.014	0.006	0.007	0.001
HBO34	0.035	0.000	0.012	0.014	0.007	0.012	0.001
HBS12	0.037	0.000	0.000	0.040	0.000	0.000	0.000
HBS34	0.037	0.000	0.000	0.040	0.000	0.000	0.000
NHB	0.062	0.000	0.013	0.057	0.006	0.011	0.000

UTILITY COEFFICIENTS

The destination choice utility coefficients are specified by purpose and market segment and are tabulated in Tables 52 and 53.

Table 52 Utility Coefficients by Market Segment – Distance Factors

Purpose	Distance Factors							
	0-1 miles	1-2 miles	2-3 miles	3-4 miles	4-5 miles	5-6 miles	6-7 miles	7-8 miles
HBW12	0.44	-0.16	0.64	0.11	0.04	-0.29	-0.13	-0.04
HBW34	0.44	-0.16	0.64	0.11	0.04	-0.29	-0.13	-0.04
HBO12	2.45	1.68	1.22	0.72	0.24	0.3	0.05	0.12
HBO34	2.45	1.68	1.22	0.72	0.24	0.3	0.05	0.12
HBS12	1.49	1.18	0.74	0.64	-0.19	-0.04	0	-0.51
HBS34	1.49	1.18	0.74	0.64	-0.19	-0.04	0	-0.51
NHB	-0.24	-0.27	-0.19	-0.17	-0.19	-0.47	-0.33	-0.02

Table 53 Utility Coefficients by Market Segment

Purpose	Mode choice logsum	Distance terms				Intra-zonal const.
		Dist.	Dist. Squared	Dist. Cubed	Dist. log.	
HBW12	0.6	-0.14	0	0	0	1.48
HBW34	0.6	-0.139	0	0	0	1.48
HBO12	0.8	-0.18	0	0	0	0.22
HBO34	0.8	-0.18	0	0	0	0.22
HBS12	0.6	-0.26	0	0	0	0.2
HBS34	0.6	-0.26	0	0	0	0.2
NHB	0.8	-0.28	0.008	-0.0001	-0.518	0.66

MODEL CALIBRATION

The calibration of the destination choice model involves making small incremental adjustments to the distance coefficients in order to better match observed trip patterns. The models are first calibrated to match first-order calibration targets for trip length frequency and average trip lengths by trip purpose. Often segmented distance terms are needed to match the short distance portion of the observed trip length frequency curve. The distance cap is also often adjusted during model calibration to ensure that the model reproduces the tail (longer trips) of the trip length frequency distribution. In the case of the FBRMPO model, intrazonal coefficients for the destination choice equations were tested and added at the calibration step of destination choice.

The FBRMPO destination choice models were calibrated to reproduce observed trip patterns, including trip length frequency distributions, district to district flows, and intrazonal percentages from the 2013 FBRMPO Travel Survey.

CALIBRATION TARGETS

The following calibration targets were developed for this effort:

- Average trip lengths by trip purpose and market segmentation
- Trip length distributions by trip purpose and market segmentation
- Intrazonal percentage by trip purpose
- District to district flows

The calibration targets used model estimated travel times (skims) from the survey data.

Table 54 provides a summary of the destination choice model calibration by trip purpose. The coincidence ratio is a measure of the goodness of fit of the calibrated trip length distribution compared to the observed trip length distribution. Anything above 0.75 is usually considered a good fit given the lumpiness in the observed distribution. The close match between the calibrated trip length profile and the observed trip length profile can be observed in the figures that follow in the next section. The percentage of total trips that are attracted to the production zone (intrazonal trips) is also compared between the model and the observed data. They also match very closely. The model predicted average trip distance is within 5% of the observed distances for all the trip purposes.

Table 54 Goodness of Fit Measures

Purpose	Coincidence ratio	%Intra-zonal trips		Average trip length (miles)		Average trip length (min)	
		Survey	Survey	Model	Model	Survey	Model
HBW	.84	8.2%	8.4%	9.01	9.29	12.23	13.17
HBO	.81	8.1%	8.3%	6.50	6.51	9.09	9.64
HBS	.80	5.3%	5.3%	6.29	6.42	8.85	9.59
NHB	.89	12.0%	12.4%	5.84	6.14	8.04	8.97

The average trip distances for the HBW and HBO purposes also match well for each of the two income groups, see Table 55. In the survey data the low income and high income segments have an average HBW trip distance of 8.43 and 9.46 miles. The corresponding model numbers are 8.37 and 9.45. Similarly for the HBO trip the survey numbers are 6.09 and 6.90 for low income and high income households. The corresponding model values are 5.82 and 6.92.

Table 55 Average Trip Length by Income Category

Trip Purpose	Average trip length (miles)	
	Survey	Model
HBW – low income	8.43	8.81
HBW – high income	9.46	9.64
HBO – low income	6.09	5.98
HBO – high income	6.90	7.20

Trip Length Frequency Distribution Calibration

Household survey data was processed into trip length frequency distributions and prepared as targets against the destination choice output. The trip length frequency curves were visually observed as well as compared using a normalized coincidence index.

Figures 25 - 28 show the trip length frequency distribution for the model output and for the survey data.

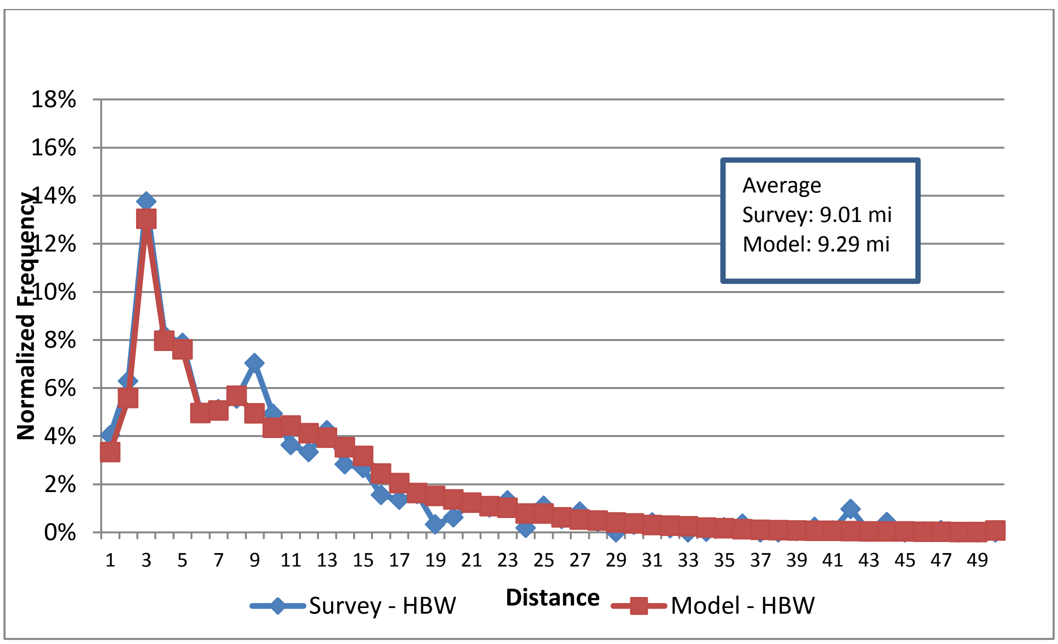


Figure 25 HBW Trip Length Frequency Distribution

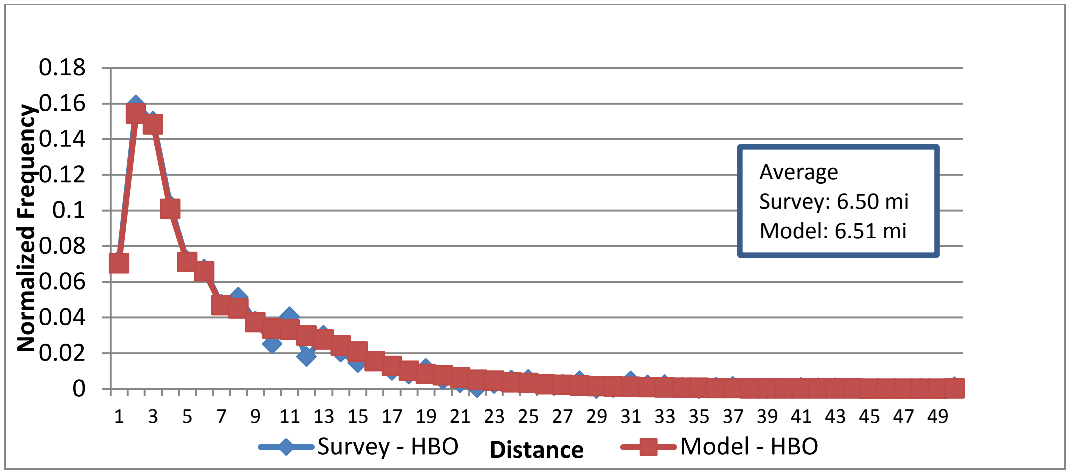


Figure 26 HBO Trip Length Frequency Distribution

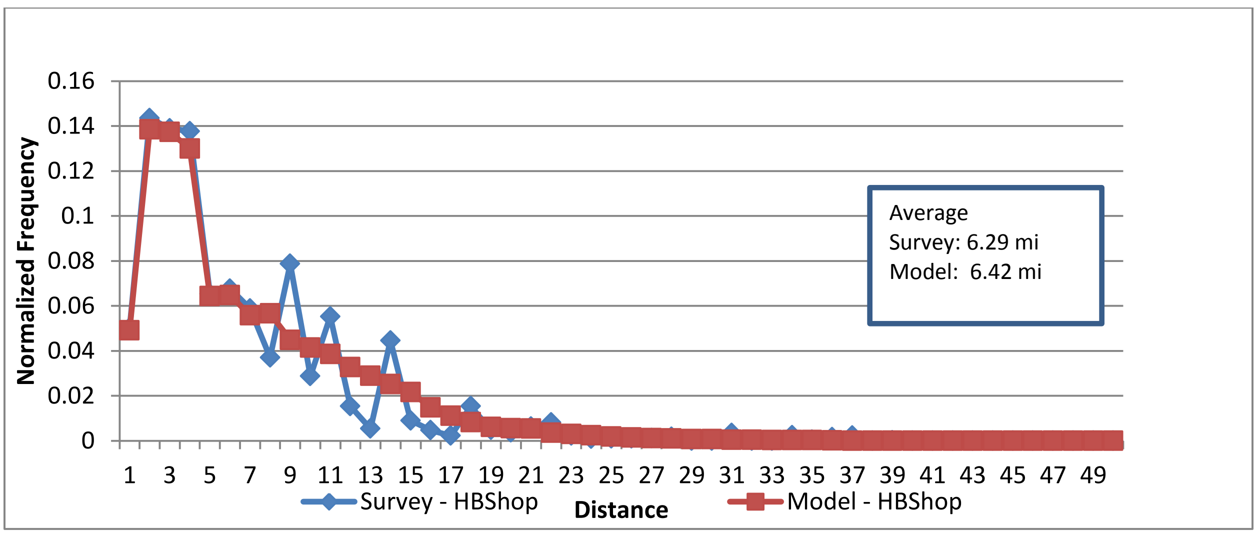


Figure 27 HBS Trip Length Frequency Distribution

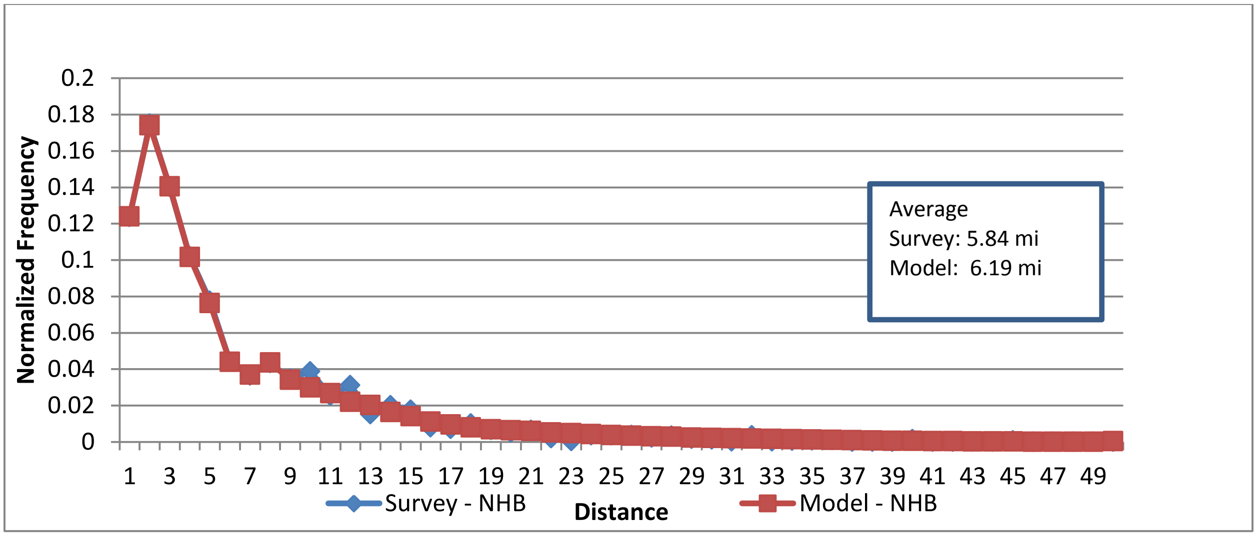


Figure 28 NHB Trip Length Frequency Distribution

District to District Calibration

District to district flows were also compared as part of the destination choice calibration. The goal of this exercise is to compare person movements between the study districts using the trip tables output from destination choice calibration. This is an iterative process with the findings from these comparisons used to refine the destination choice models. Given the sparseness of the survey observations between the original 32 FBRMPO districts, the districts were aggregated to 12 super districts shown in Figure 29. The first digit for each district corresponds to the county of reference as summarized in Table 56.

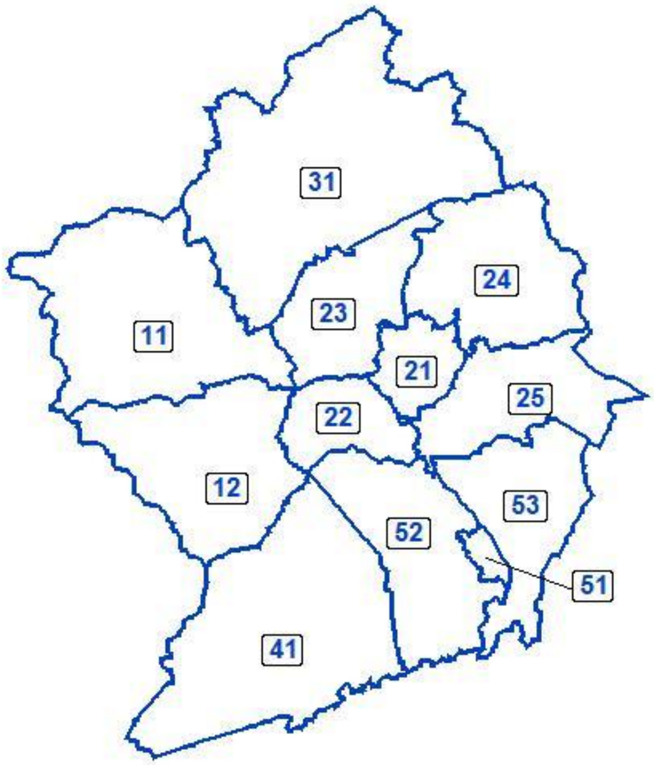


Figure 29 FBRMPO Super Districts

Table 56 Asheville Super Districts

Super District	County
21	Buncombe
22	Buncombe
23	Buncombe
24	Buncombe
25	Buncombe
11	Haywood
12	Haywood
51	Henderson
52	Henderson
53	Henderson
31	Madison
41	Transylvania

Worker flow comparison with CTPP

Tables 57 and 58 show the comparison between the worker flows obtained from the CTPP data and the same from the calibrated model.

Table 57 CTPP Work Flow by Super District (normalized by model row totals)

		Attraction District												Row Totals
		11	12	21	22	23	24	25	31	41	51	52	53	
Production District	11	2443	4738	913	240	171	94	146	12	0	9	81	38	8885
	12	2961	12340	1912	496	288	225	593	77	0	57	174	169	19292
	21	89	219	26478	1329	1832	2353	3107	353	355	286	324	538	37263
	22	44	313	5652	1936	955	606	1378	20	75	186	189	410	11764
	23	62	224	11919	1417	4027	1954	1956	551	0	149	204	326	22789
	24	60	48	9235	619	1695	5853	2730	319	0	170	86	186	21001
	25	26	239	10054	1046	772	2336	7097	62	102	675	609	1225	24243
	31	76	127	2763	443	947	1068	585	4317	0	65	66	28	10485
	41	0	28	528	131	125	75	428	0	12999	640	726	377	16057
	51	0	9	758	206	68	144	400	13	5	4736	1542	1867	9748
	52	10	56	2596	566	270	291	1660	25	1064	8125	5131	3467	23261
	53	0	129	3264	757	362	378	1648	0	271	5780	2785	5010	20384
Total		5771	18470	76072	9186	11512	15377	21728	5749	14871	20878	11917	13641	225172

Note: slight differences may exist due to rounding

Table 58 Model Work Flow by Super District

		Attraction District												Row Totals
		11	12	21	22	23	24	25	31	41	51	52	53	
Production District	11	2791	4984	1330	385	227	77	193	74	12	22	30	40	10165
	12	2110	14198	2760	814	440	155	397	21	82	40	62	79	21157
	21	31	129	30368	1236	1366	1668	2595	83	39	152	229	407	38301
	22	71	315	5949	2875	650	316	1543	19	59	169	280	318	12565
	23	101	418	14798	1434	3712	1798	1190	513	26	100	147	200	24435
	24	9	37	10125	317	1079	7237	1916	403	17	61	91	169	21462
	25	11	44	9854	845	306	1910	9405	20	114	527	684	1563	25284
	31	76	125	3827	160	1085	1185	260	4379	15	25	30	40	11209
	41	3	24	487	185	25	38	616	3	13452	751	1175	449	17207
	51	1	5	436	118	23	34	587	1	135	5995	1425	1290	10049
	52	6	26	2470	791	123	192	2965	6	1653	6839	5814	3293	24179
	53	5	20	2893	496	106	256	3504	5	215	5558	2401	6429	21889
Total		4813	5214	20324	85298	9656	9142	14866	25170	5528	15820	20238	12368	14278

Note: slight differences may exist due to rounding

The comparison of district interchanges focused on those where the absolute difference between estimated and observed was greater than 1,000. Overall the comparison between the estimated worker flows and the CTPP worker flows is favorable. Two district interchanges have been flagged in Table 59, highlighting district interchanges where the model is higher than 50% (though the overall magnitude of trips is small).

Table 59 Estimated vs. CTPP Work Trips – Flagged Super District Interchanges

HBW CTPP	11	12	21	22	23	24	25	31	41	51	52	53
11												
12												
21												
22												
23												
24												
25												
31												
41												
51												
52							High					
53							High					

Non-work flow comparisons with household survey

Tables 60 and 61 show the comparison between the non-work trip flows obtained from the household travel survey (HHS) and the same from the calibrated model. Due to the sparseness of the observed data for the individual trip purposes, non-work trip purposes from the destination choice model are grouped together.

Table 60 HHS Non-Work Flow by Super District (normalized by model row totals)

		Attraction District												
		11	12	21	22	23	24	25	31	41	51	52	53	Row Totals
Production District	11	7806	26850	1766	955	380	0	0	0	93	50	0	0	37899
	12	7008	77803	4696	835	310	1263	880	0	25	60	0	0	92878
	21	0	1706	191054	11595	6665	10760	17888	1523	348	1548	3511	1308	247907
	22	37	72	15877	18629	1929	877	7793	0	50	0	2190	826	48279
	23	0	504	42795	1913	22248	14645	2310	1487	0	0	0	124	86027
	24	0	0	23895	0	10250	42135	6908	1113	0	0	0	0	84301
	25	0	355	23549	3419	833	5258	59066	0	1354	2311	6706	8526	111376
	31	553	351	4205	0	3028	4837	453	26689	0	0	0	0	40115
	41	0	0	3608	308	0	423	1487	0	63240	1783	1245	550	72644
	51	48	80	2364	0	0	0	1454	0	1202	36183	11538	8920	61787
	52	0	386	4580	135	191	0	11003	0	3489	15692	42582	6481	84539
	53	0	62	3846	946	0	0	7081	0	431	25663	6600	37750	82379
Total		17405	15451	108168	322235	38735	45834	80197	116322	30812	70232	83290	74372	64485

Note: slight differences may exist due to rounding

Table 61 Model Non-Work Flow by Super District

		Attraction District												Row Totals
		11	12	21	22	23	24	25	31	41	51	52	53	
Production District	1	1389	1986	1796	737	760	96	271	323	11	35	44	60	37899
	1	8807	7648	3514	1508	1390	196	543	34	109	75	98	122	92878
	2	129	489	21433	5306	8903	5447	1039	212	144	550	713	1284	247907
	2	239	1077	17755	15412	4903	586	5855	44	132	463	878	934	48279
	2	325	1301	41030	5717	2482	8336	2230	1341	50	223	271	382	86027
	2	36	137	33025	738	7708	3265	7666	1451	42	192	233	416	84301
	2	51	193	35547	2667	1393	6967	5202	61	309	1815	2488	7865	111376
	3	496	436	8880	385	6010	4637	607	18435	18	54	65	91	40115
	4	11	99	939	262	94	65	1135	6	6302	1908	4171	928	72644
	5	5	18	812	165	88	66	1047	3	251	4662	6881	5827	61787
	5	17	67	3978	1305	368	254	6887	12	4208	2788	29594	9962	84539
	5	16	62	5372	782	341	363	1175	12	405	2294	7988	3233	82379
Total		2516	2403	10023	36698	3498	5677	5967	10041	2193	6870	10277	5342	60207

Note: slight differences may exist due to rounding

The comparison of district interchanges focused on those where the absolute difference between estimated and observed was greater than 2,500. This value is higher than the base value for the work trips given the magnitude of the total trips. There is a lot more noise in the non-work district to district flows than with the work trips. Part of this can be attributed to the lumpiness of the household survey data. Table 62 shows the district interchanges that have been flagged as either high, where the model estimate is higher than 50%; or low, where the model estimate is lower than 50%. There is a noticeable pattern in the plot with respect to district 21 (central Asheville), where the model is over estimating trip attractions into this district from neighboring districts, and under estimating trip productions into neighboring districts. The introduction of a Central Business District (CBD) bias constant improved these results somewhat over the original calibration work.

Table 62 Estimated vs. HHS Non-Work Trips – Flagged Super District Interchanges

NonWork	11	12	21	22	23	24	25	31	41	51	52	53
11	High											
12												
21				Low							Low	
22					High							
23				High								
24												
25			High								Low	
31			High		High							
41			Low								High	
51												
52										High		High
53							High					

Comparisons to AirSage Data

District to district flows were developed using the mobile phone location data collected by AirSage, Inc. AirSage uses algorithms to classify observed trips as HBW, HBO, or NHB. The AirSage data is reported in origin-destination (OD) format, rather than production-attraction (PA) format. The estimated trip tables from the destination choice model are in PA format. In order to compare the output from destination choice to the AirSage data, time of day and directional split factors were applied to the data to convert the PA data to OD data.

As with the HHS comparison, the focus was on district interchanges where the absolute difference between estimated and observed was greater than 1,000 for work trips and 2,500 for non-work trips. Tables 63 and 64 show the flagged district interchanges for work and non-work trips, respectively. The comparison of work trips against the AirSage data show four district interchanges that meet the flagging criteria of 50% over or under estimated. The districts are different than the two that were flagged using the CTPP data. Most importantly is that there are no readily discernable patterns. The comparison for the non-work trips is encouraging and may suggest that earlier comparisons against the HHS data were a result of the sparseness in the data. In all cases, these districts will be closely monitored during subsequent model calibration and validation steps to determine if further measures are needed to improve the overall performance of the model.

Table 63 Estimated vs. AirSage Work Trips – Flagged Super District Interchanges

HBW	11	12	21	22	23	24	25	31	41	51	52	53
11												
12	Low											
21												
22												
23												
24												
25												
31					Low			High				
41												
51												
52												
53												High

Table 64 Estimated vs. AirSage Non-Work Trips – Flagged Super District Interchanges

NonWork	11	12	21	22	23	24	25	31	41	51	52	53
11		High										
12	Low											
21								High				
22			High									
23			High									
24												
25												
31												
41												
51												High
52										High		
53										High		

HOME-BASED UNIVERSITY TRIPS

Because of the unique nature of home-based university trips, neither the gravity model nor the destination choice model does a very good job of modeling the underlying travel behavior and resulting trip patterns for this trip purpose. A better approach is to develop trip tables directly using a matrix of student home locations and university campus locations.

APPROACH

The standard approach for developing the university trip table requires as input student home locations by traffic analysis zone (TAZ) and university enrollment by TAZ. The FBRMPO staff were able to provide student home locations for Asheville-Buncombe Technical Community College (AB-Tech), but not for any of the remaining universities or colleges (universities). Rather than merge this trip purpose into the HBO trip purpose, losing the specificity of this unique travel market, and the ability for the MPO to evaluate future scenarios that capture changes in university enrollment, a procedure was developed to synthetically estimate student home locations for the remaining universities using student enrollment data and travel pattern data from the household survey. This approach only requires as input total university enrollment by TAZ and the percent of off-campus students in those TAZs.

The student home locations are synthesized through the implementation of a household location model. The household location model takes the form of a logit model:

$$Percent_i = \frac{exp^{utility_i}}{\sum_{i=1}^{n} exp^{utility_i}}$$

Where the utility is defined as:

$$u_i = \ln(Households) - \ beta_1 * [Travel\ Time] + \ beta_2 * [Travel\ Time]^2$$

For a given zone, this model estimates the utility (i.e. attractiveness) of all possible housing location zones considering the number of households in that zone and the travel time between that zone and the university zone. A probability is calculated for each candidate zone and off-campus students are assigned to each zone based on its calculated probability.

In lieu of a student travel survey, the initial beta parameters were borrowed from the Honolulu model, where the student household location model was originally estimated. The FBRMPO model was calibrated to match the observed trip length distribution for HBU trips in the FBRMPO household survey. Table 65 shows the final calibrated beta coefficients and a comparison of the estimated and observed average travel time. Figure 30 shows a plot of the estimated (model) and observed average travel time distribution.

Table 65 Household Location Model Calibration Statistics

Calibrated Coefficients	
	$beta_1$ = -0.27
	$beta_2$ = 0.0026
Average Travel Time (min)	
	Observed = 8.69
	Estimated = 8.65

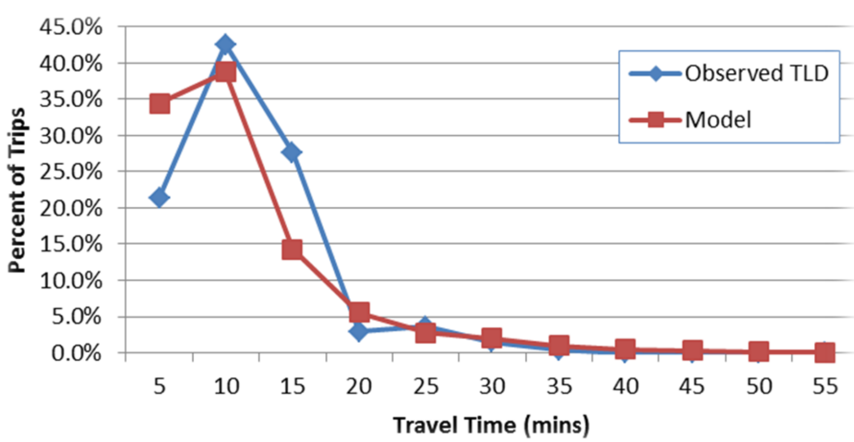


Figure 30 Household Location Model Travel Time Distribution

With the student home locations for off-campus students estimated, a HBU trip rate was applied to estimate trips between the student home locations and the universities in the region. The trip rate was estimated from the household survey at 1.07 HBU trips per student. This rate is low based on experience from elsewhere, and may be modified during the overall model calibration and validation if highway assignment results around the university campuses are found to be systematically low.

HOME-BASED K-12 SCHOOL TRIPS

Home-based K-12 school trips (SCH) are similar to the HBU trips in that the trip end locations are set by the location and enrollment of the schools in the region. However, unlike the HBU trips where only university student households are allowed to make HBU trips, SCH trips can come from any zone with households. For simplicity, SCH trips were modeled using the gravity model formulation:

$$T_{ij} = P_i\left(\frac{A_i F_{ij} K_{ij}}{\sum_{k=1}^{n} A_k F_{ik} K_{ik}}\right)$$

where:

T_{ij} = the number of trips from TAZ i to TAZ j
P_i = the number of trip produced in TAZ i
A_j = the number of trips attracted to TAZ j
F_{ij} = the friction factor between TAZ i and TAZ j
K_{ij} = optional adjustment factor between TAZ i and TAZ j
n = the total number of TAZs
i = the origin TAZ number
j = the destination TAZ number

The friction factor in the above equation is derived empirically from the travel time or travel impedance distribution. It is inversely related to the spatial separation of the TAZs. As the travel time between TAZs increases, the friction factor decreases. The gamma function was used to estimate friction factors for the SCH trip distribution model. The gamma function can be stated as follows:

$$F_{ij} = a * t_{ij}^{b} * e^{c * t_{ij}}$$

Where:

F_{ij}	=	friction factor from TAZ i to TAZ j
a, b, c	=	model coefficients
t_{ij}	=	travel time, or impedance from TAZ i to TAZ j
e	=	base of the natural logarithms

CALIBRATION TARGETS

The following calibration targets were developed for this effort:

- Average SCH trip length
- Intrazonal percentages
- SCH trip length distribution
- District to district flows

The calibration targets used model estimated travel times (skims) from the survey data. Table 66 provides a summary of the gravity model calibration results, and Table 67 summarizes the final gamma coefficients. The estimated average travel time and percent intrazonal trips match well with the observed values.

Table 66 Gravity Model Goodness of Fit Measures – SCH Trips

Purpose	%Intra-zonal trips		Average travel time (min)	
	Survey	Model	Survey	Model
SCH	12.3%	11.6%	7.1	7.1

Table 67 Final Gamma Coefficients – SCH Trips

a =	8581463
b =	2.5
c =	0.146

TRIP LENGTH FREQUENCY DISTRIBUTION CALIBRATION

Figure 31 shows the trip length frequency distribution (min) for the estimated and observed SCH trips, showing that visually the modeled results match well the observed data.

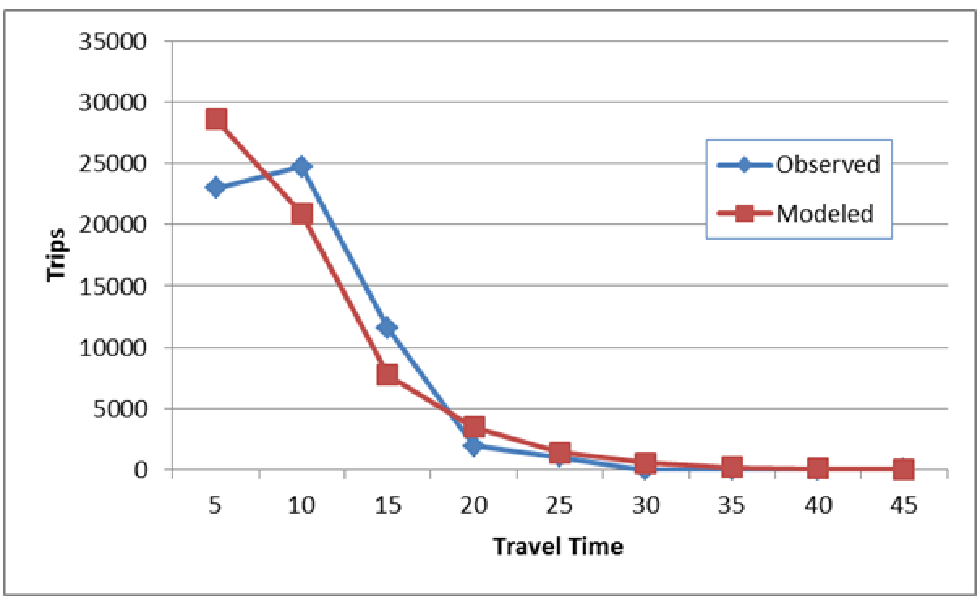


Figure 31 SCH Trip Length Frequency Distribution (min)

District to District Calibration

Tables 68 and 69 show the comparison between the school flows observed in the HHS and the same from the calibrated model. The results match well with no district interchange with a percent difference greater than +/- 10% for district interchanges where the absolute difference between estimated and observed is greater than 500.

Table 68 HHS School Flow by Super District (normalized by model row totals)

		Attraction District												
		11	12	21	22	23	24	25	31	41	51	52	53	Row Totals
Production District	11	294	1980	37	66	11	4	18	14	0	1	3	3	2431
	12	49	5296	21	39	6	2	10	0	0	0	1	1	5427
	21	0	32	7205	517	514	347	988	19	0	9	29	33	9692
	22	1	100	294	2385	76	20	399	2	1	10	51	31	3371
	23	2	133	2146	1008	2632	617	176	308	0	6	17	16	7060
	24	0	11	924	82	644	3954	302	121	0	3	9	11	6061
	25	0	7	513	171	25	842	4671	3	1	30	116	283	6660
	31	12	15	108	17	539	316	19	2143	0	1	2	2	3173
	41	0	2	12	17	2	1	57	0	3774	79	383	56	4383
	51	0	0	3	3	0	0	14	0	0	1735	417	438	2612
	52	0	4	52	99	6	5	331	1	85	1277	3698	699	6257
	53	0	2	55	56	4	8	661	0	1	513	700	3908	5910
Total		359	7584	11369	4460	4458	6117	7646	2612	3862	3664	5426	5481	63038

Note: slight differences may exist due to rounding

Table 69 Model School Flow by Super District

		Attraction District												Row Totals
		11	12	21	22	23	24	25	31	41	51	52	53	
Production District	11	249	2090	21	47	6	2	12	1	0	0	1	1	2,431
	12	36	5358	7	17	2	1	4	0	0	0	0	0	5,427
	21	0	11	7841	382	398	194	833	7	0	3	10	13	9,692
	22	0	66	178	2676	51	6	348	1	0	4	26	14	3,371
	23	1	93	2081	1042	2879	566	121	261	0	2	8	7	7,060
	24	0	5	803	55	612	4225	260	89	0	1	4	5	6,061
	25	0	2	317	106	9	849	5106	1	0	12	56	201	6,660
	31	9	11	81	12	511	284	14	2250	0	0	1	1	3,173
	41	0	2	7	14	1	1	54	0	3795	76	384	49	4,383
	51	0	0	1	1	0	0	5	0	0	1910	325	370	2,612
	52	0	1	26	77	3	2	273	0	47	1261	4007	559	6,257
	53	0	1	28	37	1	3	617	0	0	383	592	4249	5,910
Total		296	7640	11391	4466	4473	6130	7648	2611	3843	3655	5415	5470	63038

Note: slight differences may exist due to rounding

MODE CHOICE MODEL

The mode choice models were developed with information from the 2013 FBRMPO Household Travel Survey and the 2013 FBRMPO Transit On-Board Survey. The model formulation (nesting structure) reflects the outcome of the mode choice model design meeting held in Asheville, North Carolina on August 22, 2013. Based upon the proposed structure and asserted coefficient values, calibration target values were constructed from the observed data.

The mode choice models are calibrated using market-stratified person trip tables from the trip distribution model. Calibration includes the calibration of alternative specific constants while reviewing district level observed and estimated trip flows by purpose, market stratification, and access mode. Calibration is an iterative process that considers transit network assumptions, paths, and other inputs in addition to the choice of mode.

CALIBRATION TARGET PREPARATION

In order for the mode choice model to accurately reflect observed travel patterns, the model must be calibrated to observed conditions. These observed conditions typically come from the household travel survey, the transit on-board survey, or ideally a combination of the two. The calibration process consists of adjusting the terms in the mode choice utility equations to match observed data in the form of calibration targets. For the FBRMPO mode choice calibration process calibration targets were needed by trip purpose and market segment. The preparation of the calibration targets required combining the FBRMPO household travel survey and the transit on-board survey. Household travel surveys rarely include a representative capture of transit use, so the two surveys are combined into one master survey database that facilitates the development of targets for all travel modes. This process is described below.

The household survey captured weekday travel between April 29, 2013 and June 17, 2013 for a sample of 1,434 households and 14, 656 trips. The transit on-board survey captured weekday travel between May 20, 2013 and May 30, 2013 714 trip samples. These data sets combined provide insight into the travel markets in the FBRMPO region with respect to geography, trip purpose, demographics, mode, and mode access.

To begin creating mode choice targets, a count of trips was developed for each market from the expanded surveys. Table 70 shows the market segments used by the FBRMPO model.

Table 70 Transit Markets

Purpose	Description	Market
HBW12	Home-based Work Low Income Market	Income less than 50,000
HBW34	Home-based Work High Income Market	Income greater or equal to 50,000
HBO12	Home-based Other Low Income Market	Income less than 50,000
HBO34	Home-based Other High Income Market	Income greater or equal to 50,000
SCH	Home-based School K – 12	All
HBU	Home-based University	All
NHB	Non-Home-Based	All

As noted in the table, the HBW and HBO purposes are split into two sub-markets based on household income.

Combining the Surveys

The household survey contains trip records for transit trips, but the number of records is fairly small and not representative of the true transit trip patterns in the region. It is for this reason that on-board transit surveys are needed to gain a better understanding of transit travel in the region. In contrast to the household survey, the on-board survey contains 714 transit trip records. The total number of trip records in the household survey (for all modes) is 14,656. In practice, the total number of trips reported in the household survey is taken as the total number of trips for the region because of the comprehensive nature of the survey, the stratified sampling of households, and weighting and expansion factors designed to expand the survey to represent households in the region. However, the on-board survey is taken as the total number of transit trips for the region because of a sampling plan that is developed by route, direction, and time of day, and weighted and expanded to represent the universe of transit users in the region. To capitalize on the strengths of both surveys, the two surveys are combined and then total trips rebalanced by trip purpose and market such that the original distribution of trips observed in the household survey is respected.

Prior to merging the surveys, the school bus trips are removed from the household survey records as school bus trips are not modeled in the mode choice model. The household survey has a total of 1,411,453 expanded trips. Of those, 11,119 are school bus trips; removing these trips from the data targets results in a total of 1,400,334 trips that will be used for the mode choice targets.

Table 71 provides a summary of the expanded transit trips by survey type. In this case, the expanded household survey reports a greater number of expanded transit trips than those reported in the on-board survey. This is an artifact of the weighting and expansion of the household survey to the total households on the region. Because the on-board survey is expanded to the universe of transit riders, the transit target for the FBRMPO region is actually 4,676. The difference in the expanded transit trips between the two surveys is 4,808. Because the expanded trips from the household survey are used as the control for the overall trips in the region, these 4,808 trips identified as transit trips in the household survey must be reallocated to the overall target values by trip purpose, market, and non-transit mode as described below and in Tables 72 and 73.

Table 71 Transit Trips by Survey

Survey	Transit Trips
Household Survey	9,484
On-Board Survey	4,676

Table 72 shows the breakdown of transit trips by trip purpose and market from both the household survey and the on-board survey. The 4,808 trips are proportionally allocated first by trip purpose and market. For example, taking the market defined by high income (HBW34), the household survey shows 587 expanded transit trips, while the on-board survey shows 644 expanded transit trips. The 587 expanded household survey transit trips are removed from the targets and replaced by the 644 expanded transit trips from the on-board survey. In this case, the household survey has fewer transit trips than the on-board survey, so when replaced by the 644 trips from the on-board survey, there are now too many trips in the target file and this market must be reduced by 57 trips. This adjustment to the target values is done proportionate to the non-transit mode share observed in the household survey with the assumption that these records are distributed like the rest of the population, and Table 73 presents an example of this modification for HBW34. This adjustment results in a total of 127,907 non-transit trips for HBW34, including the 644 transit trips from the on-board survey, bringing the total to 128,551 total trips for HBW34.

Table 72 Transit Trips by Trip Purpose and Market

Purpose	Market	Household Survey Transit Trips	On-Board Survey Transit Trips	Difference
HBW12	Low Income	802	826	-24
HBW34	High Income	587	644	-57
HBO12	Low Income	2,512	1,485	1,027
HBO34	High Income	1,951	641	1,310
SCH	All	0	16	-16
HBU	All	0	198	-198
NHB	All	3,632	866	2,765
	Total	**9,484**	**4,676**	**4,808**

Table 73 Trip Adjustment by Mode of HBW34

Mode	Expanded Non-Transit Trips	Percent of Non-Transit Trips	Trip Adjustment	Final Expanded Non-Transit Trips
Bike	734	0.6%	-0.3	733.2
DA	114,505	89.5%	-50.8	114,454.4
SR2	6,416	5.0%	-2.8	6,413.5
SR3+	1,812	1.4%	-0.8	1,811.1
Walk	4,497	3.5%	-2.0	4,495.3
Total	127,964	100%	-57	127,907.5

Drive Alone (DA), Shared-Ride 2 (SR2), Shared-Ride 3+ (SR3+)

A final check of the target data by trip purpose and market to the original household survey data is made after merging the two data files to ensure a conservation of trips. The final comparison is shown in Table 74.

Table 74 Total Trips by Trip Purpose and Market (Household Survey vs. Targets)

Purpose	Market	Before Combining Surveys	After Combining Surveys
HBW12	Low Income	99,023	99,023
HBW34	High Income	128,551	128,551
HBO12	Low Income	307,525	307,525
HBO34	High Income	310,002	310,002
SCH	All	51,109	51,109
HBU	All	12,065	12,065
NHB	All	492,059	492,059
	Total	**1,400,334**	**1,400,334**

The resulting mode choice targets are provided in Tables 75 - 77.

Table 75 Auto – Mode Choice Targets

Purpose	Market	Mode	Access Mode	Final Expanded Trips
HBW12	Low Income	DA	All	82,488
HBW12	Low Income	SR2	All	8,311
HBW12	Low Income	SR3	All	2,198
HBW34	High Income	DA	All	114,454
HBW34	High Income	SR2	All	6,413
HBW34	High Income	SR3	All	1,811
HBO12	Low Income	DA	All	205,748
HBO12	Low Income	SR2	All	61,008
HBO12	Low Income	SR3	All	22,601
HBO34	High Income	DA	All	208,412
HBO34	High Income	SR2	All	63,188
HBO34	High Income	SR3	All	23,694
SCH	All	DA	All	18,572
SCH	All	SR2	All	13,872
SCH	All	SR3	All	16,621
HBU	All	DA	All	9,368
HBU	All	SR2	All	1,912
HBU	All	SR3	All	227
NHB	All	DA	All	259,615
NHB	All	SR2	All	147,656
NHB	All	SR3	All	54,508

Table 76 Transit – Mode Choice Targets

Purpose	Market	Mode	Access Mode	Final Expanded Trips
HBW12	Low Income	Local Bus	KNR	24
HBW12	Low Income	Local Bus	PNR	0
HBW12	Low Income	Local Bus	Walk	802
HBW34	High Income	Local Bus	KNR	24
HBW34	High Income	Local Bus	PNR	28
HBW34	High Income	Local Bus	Walk	591
HBO12	Low Income	Local Bus	KNR	56
HBO12	Low Income	Local Bus	PNR	0
HBO12	Low Income	Local Bus	Walk	1429
HBO34	High Income	Local Bus	KNR	15
HBO34	High Income	Local Bus	PNR	0
HBO34	High Income	Local Bus	Walk	625
SCH	All	Local Bus	KNR	0
SCH	All	Local Bus	PNR	0
SCH	All	Local Bus	Walk	16
HBU	All	Local Bus	KNR	27
HBU	All	Local Bus	PNR	0
HBU	All	Local Bus	Walk	171
NHB	All	Local Bus	KNR	9
NHB	All	Local Bus	PNR	0
NHB	All	Local Bus	Walk	858

Table 77 Non-Motorized – Mode Choice Targets

Purpose	Market	Mode	Access Mode	Final Expanded Trips
HBW12	Low Income	Bike	All	1,741
HBW12	Low Income	Walk	All	3,458
HBW34	High Income	Bike	All	733
HBW34	High Income	Walk	All	4,495
HBO12	Low Income	Bike	All	3,283
HBO12	Low Income	Walk	All	13,400
HBO34	High Income	Bike	All	1,049
HBO34	High Income	Walk	All	13,019
HBU	All	Bike	All	360
HBU	All	Walk	All	0
NHB	All	Bike	All	4,311
NHB	All	Walk	All	25,104
SCH	All	Bike	All	0
SCH	All	Walk	All	2,029

Mode Choice Model Description

Mode choice models are mathematical expressions which are used to estimate the modal shares of the travel market given the time and cost characteristics of the various competing modes, the demographic and socio-economic characteristics of the residents, and the un-included attributes of the modes represented in the model. Mode choice models are designed to be an integral link in the travel demand chain, with possible feedback mechanisms to a number of related model components such as auto ownership, trip generation, trip distribution, and (modal) trip assignment.

Basic Logit Model Mathematics

The mode choice model structure recommended for the FBRMPO mode choice model is a nested logit mode choice model, as opposed to a hierarchical or multinomial model. Figure 32 illustrates the differences between the various mode choice model structures.

The multinomial logit model assumes that there is equal competition among alternatives. This allows for the "shifting" of trips to and from other modes in proportion to the initial estimates of these modes. A common problem typically associated with the multinomial structure is the potential for violation of the Independence of Irrelevant Alternatives (IIA) axiom.

The hierarchical logit model is a variation of the multinomial model that allows for the subsequent splitting (or allocation) of trips to a set of sub-modes. In most structures of this type a LogSum variable (or the denominator of the lower level choice) is used in the upper level choice together with other (typically socio-economic) explanatory variables. In this manner, the lower level sub-modes are reflected in the upper level choice, but as if they were equally competing modes with the other primary mode(s) (i.e., with a LogSum coefficient of 1.0).

A nested logit model recognizes the potential for something other than equal competition among modes. This structure assumes that modes, sub-modes, and access modes are distinctly different types of alternatives that present distinct choices to travelers. Its most important departure from the multinomial structure is that the lower level choices are more elastic than they would be in the multinomial or hierarchical structures. Thus, an improvement in walk access to transit would alter the existing diversions between walk and drive access to transit the most. This same improvement in walk access would also shift travelers from auto to transit, but with elasticities that are equal to the elasticities found in the multinomial logit models; therefore, the elasticities for access choice are higher. This increased sensitivity is reasonable if the modes included in a single level of the nest are reasonably related. It seems intuitive that a person who has already decided to use transit would be more sensitive to a change in transit travel time or cost, than would be a person who is deciding to use transit or not.

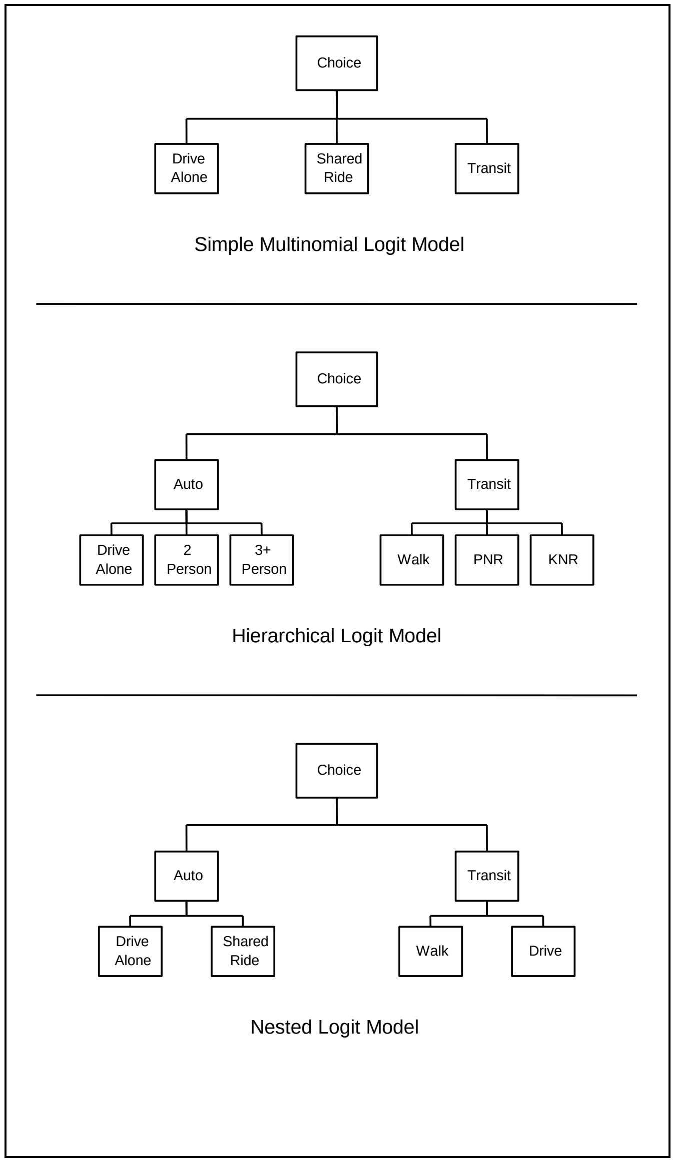


Figure 32 Three Types of Logit Models

Mathematical Formulation for Logit Models

The standard logit formulation can be expressed as:

$$P_i = \frac{e^{U_i}}{\sum_k e^{U_i}}$$

Where:

P_i	=	is the probability of a traveler choosing mode i
U_i	=	is a linear function of the attributes of mode i that describe its attractiveness
$\sum e^{Ui}$	=	is the summation of the linear functions of the attributes over all the i
k	=	alternatives (k) for which a choice is feasible

The utility expression for each available mode (i) is specified as a linear function which incorporates a range of variable types, including time, cost, locational measures, and the socio-economic characteristics of the traveler. For example:

$$U_i = \beta_1 * Time_i + \beta_2 * Cost_i + \beta_3 * Location_{Var} + \beta_4 * SE + \beta_0$$

Where:

U_i	is the utility for mode i
β_0	is a constant specific to mode i that captures the overall effect of any significant variables that are missing or unexplained in the expression (e.g., comfort, convenience, safety)
β_1	is a set of coefficients describing the level-of-service (in travel time) provided by mode i (e.g., in-vehicle time, wait time, walk time)
β_2	is a set of coefficients describing travel cost, (e.g., transit fare, automobile operating cost, parking costs)
β_3	is a set of coefficients describing the specific attributes of the trip interchange (e.g., Central Business District destination, park and ride lot use)
β_4	is a set of coefficients describing the influence of each socio-economic characteristic of the traveler (e.g., income group, auto ownership)

The travel time variables are typically disaggregated into in-vehicle and out-of-vehicle time at a minimum. Out-of-vehicle time is further stratified into walk time, initial wait, and transfer wait time – the latter two categories being applicable to the transit modes only. Similarly, travel cost is often disaggregated into the more general out-of-pocket cost (i.e., automobile operating cost and transit fare) and destination parking cost.

Locational variables in utility expressions are used to reflect a set of unique geographically based characteristics, such as a Central Business District (CBD). Alternatively, these geographic attributes may be represented in the form of land use variables such as employment and/or population density. A wide variety of variables are possible in the socio-economic category (SE) including variables that measure the relative wealth of the trip maker (income or auto sufficiency) or reflect other household characteristics (i.e., workers per household). Finally, an alternative specific constant reflects the unexplained behavior, or the un-included attributes of that mode. The individual coefficients associated with each variable reflect the relative importance of each attribute.

In the simple example nested model structure shown in Figure 32 the formulation employs three multinomial logit models, one for the primary choice of mode among auto and transit, a second level choice among auto sub-modes (drive-alone and shared-ride) and another second level choice among transit access modes (walk and drive access). In application, the model independently addresses auto sub-mode and transit access choice first. This is expressed as:

$$P_{DA} = \frac{e^{U_{DA}}}{e^{U_{DA}} + e^{U_{SR}}} \qquad P_w = \frac{e^{U_w}}{e^{U_w} + e^{U_D}}$$

A composite of the utilities of the auto sub-mode and transit access choices then represent auto and transit respectively in the upper tier of the model structure. This composite measure is the natural logarithm of the denominator of the logit model, often termed the "LogSum". The LogSum term is effectively the total utility provided by the sub-modes of a particular primary mode. A LogSum is calculated for each of the second level nests as:

$$LogSum_A = -\ln[\, e^{U_{DA}} + e^{U_{SR}} \,] \qquad LogSum_T = -\ln[\, e^{U_w} + e^{U_D} \,]$$

The LogSum terms for the auto sub-modes and transit access choice then appear in the utility expression for the primary mode level as:

$$P_T = \frac{e^{\beta_T * LogSum_T}}{e^{\beta_T * LogSum_T} + e^{\beta_A * LogSum_A}}$$

The value of the LogSum coefficients in the upper tier of the model (i.e., auto versus transit), is an indicator of the degree to which the lower level choices form a sub-choice that is distinct from the primary mode alternatives. A value of 1.0 indicates that the lower level modes are not a sub-choice but rather are full options equally competitive with the primary modes. In this instance, these lower level choices can be simplified or included directly in the upper level. A value of 0.0 would indicate that the lower level choices are perfect substitutes for each other. Values between 0.0 and 1.0 indicate the extent to which the lower level choices represent a sub-choice.

MARKET SEGMENTATION CONSIDERATIONS

Traditionally, a larger number of trip purposes are maintained in the trip generation and trip distribution models than in mode choice. Common practice has been to merge the subset of non-work purposes into a single purpose, resulting in three basic purposes for mode choice modeling - Home-Based Work, Home-Based Non-Work, and Non-Home Based. This simplification stems from the notion that household and individual travel behavior properties, as translated into elasticities, are relatively similar when considering the choice of mode.

In the FBRMPO model, this approach is used as a framework with the addition of two additional purposes: Home-Based K-12 School (SCH) and Home-Based University (HBU).

Another element often used for market segmentation is the stratification of alternative specific constants by an indicator of wealth or socio-economic status. Historically, either auto ownership or income has been used for this purpose. The initial design of the mode choice model called for stratification by auto sufficiency. Unfortunately this stratification had to be dropped early on in the model development process due to a lack of data to support this stratification. Instead, high and low income is used to stratify both the HBW and HBO trip purposes. Low income is used to capture households with income less than $50,000, and high income captures households with income of at least $50,000. The final mode choice model structure applied in the FBRMPO model is graphically displayed in Figure 33.

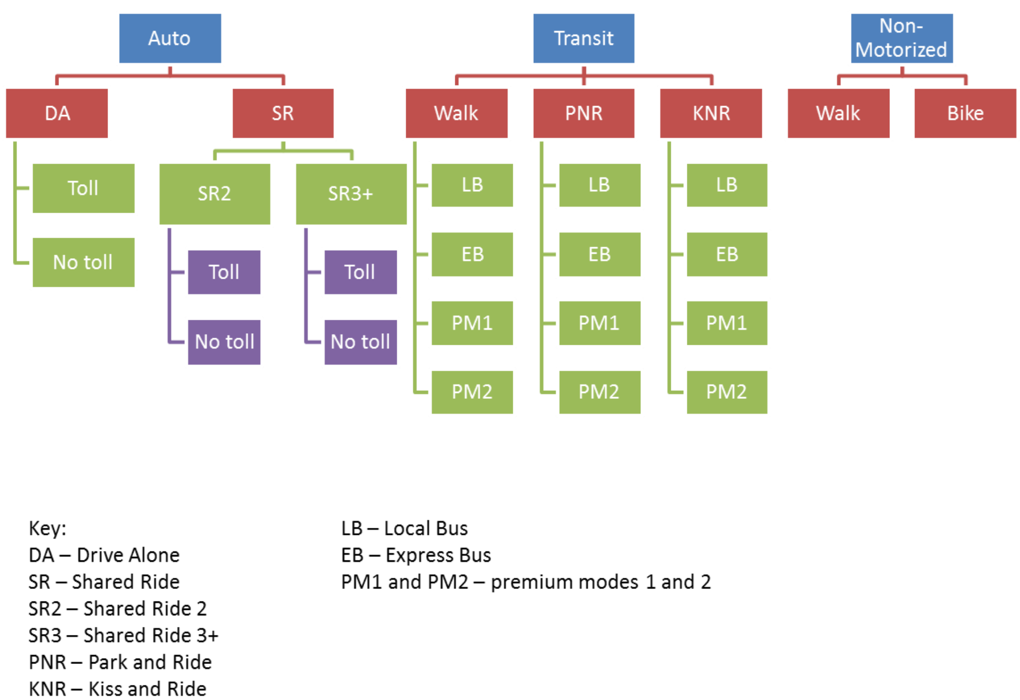


Figure 33 FBRMPO Nested Mode Choice Structure

At the upper level of the nesting structure are non-motorized modes, highway modes (auto) and transit. In the non-motorized nest, bicycle and direct walk are represented. The auto mode nest addresses the auto occupancy choice including drive alone, drive 2, and drive 3+ (3 person carpools).

Although the base year transit service in the FBRMPO only includes local bus, the model design includes the options for evaluating four primary transit modes at the upper level of the transit nest. Local bus is on the ground in the FBRMPO region and is represented in the FBRMPO transit on-board survey. Three potential transit modes, express bus, BRT and Light Rail are available for application in forecast testing. This extensive design recognizes that, in many instances, the various transit modes offer travelers a competitive choice. It also allows the model to reflect the important differences in un-included attributes offered by each of the primary transit modes. An access choice nest differentiates primarily between walk and drive access to each primary transit mode.

Asserted Model Coefficients

Table 78 presents the recommended set of mode choice coefficients for the five trip purposes in the FBRMPO model. Logical and consistent nesting coefficients are applied at each level of the nest.

Table 78 Mode Choice Model Coefficients

Variable Description	*Variable*	*HBW*	*HBO*	*SCH*	*HBU*	*NHB*
In-Vehicle Travel Time	CIVT	-0.025	-0.015	-0.015	-0.015	-0.015
Initial Transit Wait Time < 5.0 minutes	CWAIT1S	-0.05625	-0.03375	-0.03375	-0.03375	-0.03375
Initial Transit Wait Time >= 5.0 minutes	CWAIT1L	-0.025	-0.015	-0.015	-0.015	-0.015
Transit Transfer Wait Time	CXFERWAIT	-0.0625	-0.0375	-0.0375	-0.0375	-0.0375
Drive to transit in-vehicle time	CDRVACCIVT	-0.05625	-0.03375	-0.03375	-0.03375	-0.03375
Intrazonal shares for drive alone	INTDA	0.48512	0.13935	0.51127	0.2294	0.06587
Intrazonal shares for share ride 2	INT2P	0.14171	0.32366	0.39883	0.18877	0.17777
Intrazonal shares for share ride 3P	INT3P	0.00958	0.51719	0	0.04075	0.58972
Intrazonal shares for walk trips	INTWK	0.35957	0.0198	0.0899	0.50401	0.09732
Level 1: Nesting coefficient	CLS_LVL1	0.7	0.7	0.7	0.7	0.7
Level 2: Nesting coefficient	CLS_LVL2	0.7	0.7	0.7	0.7	0.7
Level 3: Nesting coefficient	CLS_LVL3	0.5	0.5	0.5	0.5	0.5

Auto operating costs were established at 14.8 cents per mile for all purposes. It was understood that income-stratified cost coefficients would contribute to a better understanding of how various travelers see the auto operating cost. These coefficients were also used to compute transit costs. Table 79 summarizes the income-based cost coefficients.

Table 79 Income-Based Auto Operating Cost Coefficients

Income Category	Coefficient Value				
	HBW	***HBO***	***SCH***	***HBU***	***NHB***
Low Income Market	-0.299	-0.448	-0.18	-0.29	-0.19
High Income Market	-0.071	-0.107	0	0	0

PRELIMINARY MODE CHOICE CALIBRATION

BASIC CALIBRATION OF COEFFICIENTS

In this section, the model calibration of the base year is discussed. Model calibration is the process of establishing proper values for the alternative specific constants. A critical part of this process is to verify that the calibrated constants tell a coherent and plausible story about travel behavior, and not just reproduce the base year modal shares. The identification of constants must follow from a good understanding of the expected effect of non-included attributes, and the calibrated values must be logical and consistent with best practices.

A self-calibrating mode choice program was identified for use in the FBRMPO mode choice estimation procedure. The two market stratifications were used to structure the results. Table 80 shows key calibrated values for the mode choice models. Note that the market stratifications are active for both HBW and HBO. The other purposes were estimated for all auto categories as one.

Table 80 Mode Split Constants by Trip Purpose and Market Segmentation

Constant for Transit					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	-0.9383	-2.23327	-4.92478	-1.59841	-3.24099
High Income	-1.18319	-2.37692			
Constant for Non-Motorized					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	0.6393	-0.60842	-0.3472	-1.85908	-0.16792
High Income	1.11562	-0.17525			
Constant for Shared Ride 2					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	-1.69489	-0.92284	-0.07966	-1.18279	-0.35915
High Income	-1.99928	-0.76851			
Constant for Drive to Transit					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	-2.7484	-2.44901	0	-1.55748	-3.40104
High Income	-2.00459	-2.79063			
Constant for Bicycle					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	-2.39399	-2.35415	-12.25	0	-2.52603
High Income	-3.54575	-3.31887			
Constant for Shared Ride 3+					
Market Stratification	Constants				
	HBW	HBO	SCH	HBU	NHB
Low Income	-0.68673	-0.52235	0.07871	-1.0683	-0.53525
High Income	-0.6278	-0.48064			
Other					
All Categories	Constants				
	HBW	HBO	SCH	HBU	NHB
Constant on transit intrazonal drive access	*Not currently used*				
Constant on low income households					
CBD constant					

The constant for transit is generally negative, as expected.

Mode Choice Calibration & Results

Each travel mode, including access modes to transit, was calibrated addressing issues as they were identified. The main focus of the calibration was the transit system. As Table 76 shows, daily transit travel in the region is well under 1% of all travel. Calibrating mode choice thus required extensive calibration, review and re-calibration. In this section, we will begin with a small set of calibration challenges and how they were resolved. The investigation generally began with the HBW purpose and then those lessons were used as a starting point for the other trip purposes. This section concludes with the results of mode choice calibration effort: aggregate trip level comparisons, detailed access mode trip level comparisons, and district to district comparisons.

Calibration

The first step in mode choice calibration is the review of the aggregate totals coming out of the mode choice model, not in isolation, but in combination with the resulting constants. Calibration of the mode choice model involves adjusting the constants to match the aggregate totals so one would expect these to match closely, so the question to be answered at this level is whether or not the constants make sense.

After confirming the reasonableness of the constants and the aggregation totals of trip by mode and purpose, the next step is to review the district to district trips. In this case, the review focuses on available person trips, implied mode shares, and the difference between the observed transit trips from the survey and the estimated transit trips from the model. Available person trips are the district to district trips out of the destination choice model that have access to transit, as not all district interchanges have access. The implied mode share is the observed transit trips by district divided by the available person trips by district from the destination choice model. The calculated mode share is what the model would have to achieve from the available person trips in order to match the survey data. This review often highlights underlying issues with the code, the person trip table, or the input data. It also provides insight into the important transit markets in the region and whether or not the model is getting these markets right. The mode choice model is an excellent diagnostic tool as it will often highlight errors in the upper level models that are missed when reviewing the upper level models.

The district system used for this review is shown in Figure 34. Since the majority of the transit trips occur within the Asheville district, this district was further divided into sub-districts as shown in Figure 35.

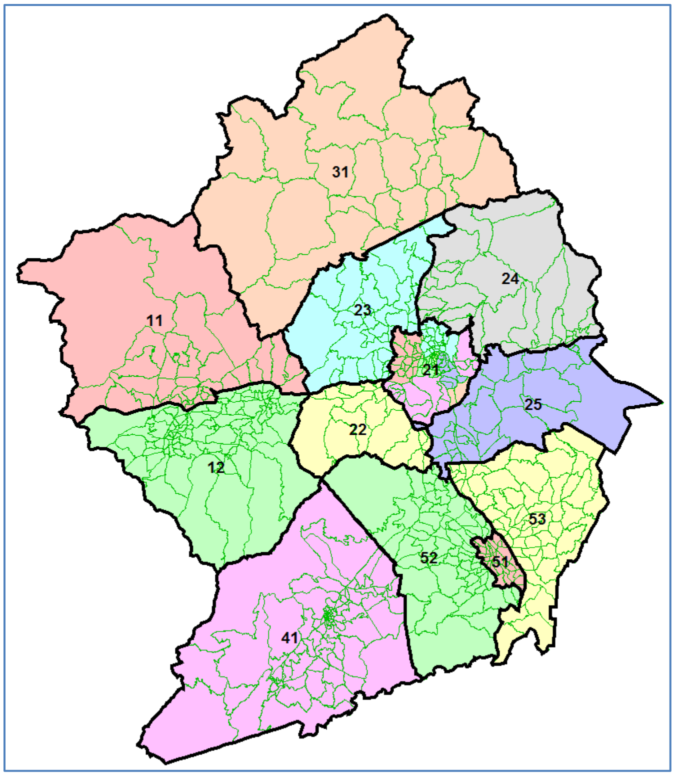


Figure 34 FBRMPO Districts

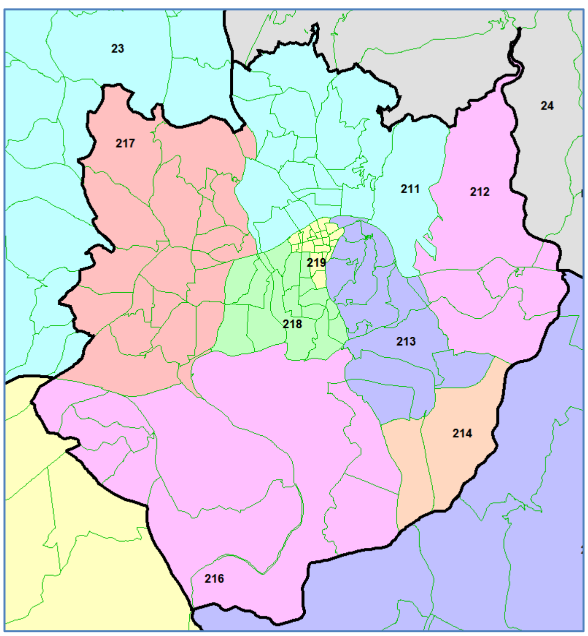


Figure 35 FBRMPO Sub-Districts

The final step in this process is to assign the estimated transit trips to the coded route system and to compare the estimated ridership to the observed ridership. This final step also provides insight into any underlying issues with the input data or the coding of the route system.

The calibration of the FBRMPO model involved 3 major iterations plus the initial run of the model. This section discusses the iterations of the mode choice calibration, including a summary of model results, investigations, and the findings and modifications that lead to the next iteration of the model.

Iteration 0

The aggregate summaries for the initial run of the mode choice model are shown in Table 81, and as expected, the aggregate estimated trips are a good match against the observed data. Note that the observed targets in this table vary slightly from the ones presented earlier that were derived directly from the survey data. This variance exists because the mode choice targets are always normalized to the output from trip production prior to running the calibration routines.

Table 81 Top Level Mode Choice Validation – Iteration 0

Mode		Trips	% of Total
Auto	*Observed*	1,360,956	94.5%
	Estimated	1,360,893	94.5%
Bike	*Observed*	11,587	0.8%
	Estimated	11,542	0.8%
Walk	*Observed*	62,969	4.4%
	Estimated	63,073	4.4%
Local Bus	*Observed*	4,676	0.3%
	Estimated	4,680	0.3%
Total	*Observed*	1,440,188	
	Estimated	1,440,189	

A review of the constants shows that all constants have the correct sign and are within the expected range.

Surveyed transit trips by district for the FBRMPO region are shown in Table 82. The Asheville district interchanges are shaded for ease of reference. The majority of transit trips are within the Asheville district, as noted previously, this district was further subdivided as shown in Figure 35, and the surveyed transit trips for these sub-districts are shown in Table 83.

Table 82 Surveyed Transit Trips by District – FBRMPO Region

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0	0		0	0	0	0	0	0	0	0	0	0
12 S Haywood	0	0		0	0	0	0	0	0	0	0	0	0
21 Asheville			3,574	9	4	61	143			38		7	3,837
22 SW Buncombe	0	0	26	0	0	0	0	0	0	0	0	0	26
23 NW Buncombe	0	0	150	0	0	0	0	0	0	0	0	0	150
24 NE Buncombe	0	0	117	0	0	0	0	0	0	0	0	0	117
25 SE Buncombe	0	0	235	0	0	0	23	0	0	0	0	0	258
31 Madison	0	0		0	0	0	0	0	0	0	0	0	0
41 Transylvania	0	0		0	0	0	0	0	0	0	0	0	0
51 Hendersonville	0	0	6	0	3	0	0	0	0	105	0	47	161
52 W Henderson	0	0	12	0	0	0	7	0	0	32	0	7	59
53 E Henderson	0	0	7	0	0	0	0	0	0	49	3	9	69
	0	0	4,126	9	7	61	173	0	0	225	3	71	4,676

Table 83 Surveyed Transit Trips by Sub-District – Asheville District

	211	212	213	214	216	217	218	219	
211 N Asheville	138	109	141	13	23	101	200	241	*965*
212 E Asheville	14	29	39	0	0	19	4	106	*211*
213 S Asheville	70	59	94	16	0	38	78	139	*494*
214 Biltmore Forest	9	27	16	0	0	11	14	31	*107*
216 W Asheville	0	0	3	7	0	4	4	12	*30*
217 N Downtown	101	46	112	3	22	89	107	207	*687*
218 E Downtown	86	74	105	12	32	104	67	180	*659*
219 Asheville CBD	85	97	87	7	4	42	84	15	*421*
	501	*441*	*597*	*58*	*81*	*408*	*557*	*931*	***3,574***

The available person trips for the initial iteration are shown in Tables 84 and 85. Interchanges with no transit access are removed.

Table 84 Available Person Trips by District – FBRMPO Region

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0	0		0	0	0	0	0	0	0	0	0	0
12 S Haywood	0	0		0	0	0	0	0	0	0	0	0	0
21 Asheville			183,241		3,961	2,718	2,297			311	158	584	193,271
22 SW Buncombe	0	0		0	0	0	0	0	0	0	0	0	0
23 NW Buncombe	0	0	15,961	0	2,018	267	156	0	0	37	16	50	18,505
24 NE Buncombe	0	0	19,049	0	256	10,768	1,935	0	0	40	17	74	32,141
25 SE Buncombe	0	0	7,976	0	71	2,208	5,622	0	0	339	164	1,385	17,765
31 Madison	0	0		0	0	0	0	0	0	0	0	0	0
41 Transylvania	0	0		0	0	0	0	0	0	0	0	0	0
51 Hendersonville	0	0	661	0	19	29	497	0	0	40,941	2,332	3,098	47,576
52 W Henderson	0	0	1,528	0	35	49	1,538	0	0	15,090	4,763	4,157	27,160
53 E Henderson	0	0	2,850	0	45	77	5,754	0	0	19,563	2,366	15,025	45,679
	0	0	231,266	0	6,405	16,117	17,798	0	0	76,322	9,816	24,374	382,098

Table 85 Available Person Trips by Sub-District – Asheville District

	211	212	213	214	216	217	218	219	
211 N Asheville	18,109	690	6,399	161	261	2,369	1,968	17,318	*47,276*
212 E Asheville	2,967	4,575	7,560	276	187	872	798	4,386	*21,622*
213 S Asheville	1,927	1,411	9,334	878	355	639	1,966	6,120	*22,629*
214 Biltmore Forest	760	887	4,394	825	739	311	499	1,680	*10,096*
216 W Asheville	383	129	1,145	575	536	355	286	1,005	*4,413*
217 N Downtown	6,010	749	5,370	253	1,302	19,692	3,013	12,541	*48,929*
218 E Downtown	3,224	650	3,803	359	329	3,811	4,448	8,228	*24,852*
219 Asheville CBD	397	24	573	7	13	111	252	2,049	*3,426*
	33,777	*9,115*	*38,577*	*3,334*	*3,721*	*28,160*	*13,230*	*53,328*	183,241

The implied mode shares for iteration 0 are shown in Tables 86 and 87. While the regional transit mode share of one percent transit seems reasonable, there are several district interchanges with implied mode shares that are much too high. After confirming that the survey data was coded correctly, an investigation of the person trips by trip purpose was undertaken for the districts with the highest error. These investigations lead to the identification of a bug in the destination choice model. It was discovered that the NHB trip productions were not being properly scaled to the estimated trips by destination zone, and two of the size term coefficients had been transposed. Fixing the bug in the destination choice model script required recalibration of the destination choice models and recalibration of the mode choice models. The results are discussed under the next section.

Table 86 Implied Transit Mode Shares by District – Iteration 0

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
12 S Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
21 Asheville			2.0%			2.3%	6.2%			12.1%		1.3%	2%
22 SW Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
23 NW Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
24 NE Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
25 SE Buncombe	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
31 Madison	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
41 Transylvania	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
51 Hendersonville	0.0%	0.0%		0.0%	17.2%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	1.5%	0%
52 W Henderson	0.0%	0.0%		0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.2%	0.0%	0.2%	0%
53 E Henderson	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.1%	0.1%	0%
	0%	0%	2%	0%	0%	0%	1%	0%	0%	0%	0%	0%	1%

Table 87 Implied Transit Mode Shares by Sub-District – Iteration 0

	211	212	213	214	216	217	218	219	
211 N Asheville	0.8%	15.7%	2.2%	8.1%	8.8%	4.2%	10.2%	1.4%	2.0%
212 E Asheville	0.5%	0.6%	0.5%	0.0%	0.0%	2.2%	0.5%	2.4%	1.0%
213 S Asheville	3.6%	4.2%	1.0%	1.8%	0.0%	5.9%	3.9%	2.3%	2.2%
214 Biltmore Forest	1.1%	3.0%	0.4%	0.0%	0.0%	3.6%	2.7%	1.9%	1.1%
216 W Asheville	0.0%	0.0%	0.3%	1.2%	0.0%	1.1%	1.3%	1.2%	0.7%
217 N Downtown	1.7%	6.1%	2.1%	1.2%	1.7%	0.5%	3.5%	1.6%	1.4%
218 E Downtown	2.7%	11.3%	2.8%	3.3%	9.8%	2.7%	1.5%	2.2%	2.7%
219 Asheville CBD	21.3%	405.9%	15.1%	93.3%	31.5%	38.3%	33.4%	0.7%	12.3%
	1.5%	4.8%	1.5%	1.7%	2.2%	1.4%	4.2%	1.7%	2.0%

Iteration 1

After recalibrating the destination choice and mode choice models, the aggregate summaries and estimated constants were again reviewed for reasonableness. Finding no issues or concerns, district level implied mode shares were reviewed. Tables 88 and 89 report the implied mode shares for the updated mode choice model. The implied shares are much more reasonable, but there were still some problematic districts that required further investigation, especially within the Asheville district.

Table 88 Implied Transit Mode Shares by District – Iteration 1

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
12 S Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
21 Asheville			2.1%			2.4%	7.6%			16.6%		1.7%	2%
22 SW Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
23 NW Buncombe	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
24 NE Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
25 SE Buncombe	0.0%	0.0%	3.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
31 Madison	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
41 Transylvania	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
51 Hendersonville	0.0%	0.0%		0.0%	13.8%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	1.5%	0%
52 W Henderson	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.2%	0.0%	0.2%	0%
53 E Henderson	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.2%	0.1%	0%
	0%	0%	2%	0%	0%	0%	1%	0%	0%	0%	0%	0%	1%

Table 89 Implied Transit Mode Shares by Sub-District – Iteration 1

	211	212	213	214	216	217	218	219	
211 N Asheville	0.8%	15.8%	2.4%	9.0%	11.6%	4.6%	11.2%	1.5%	2.2%
212 E Asheville	0.6%	0.8%	0.6%	0.0%	0.0%	3.1%	0.7%	2.9%	1.2%
213 S Asheville	3.9%	4.6%	1.1%	2.0%	0.0%	6.5%	4.3%	2.5%	2.4%
214 Biltmore Forest	1.4%	3.8%	0.4%	0.0%	0.0%	5.2%	3.7%	2.2%	1.3%
216 W Asheville	0.0%	0.0%	0.3%	1.3%	0.0%	0.8%	1.1%	1.1%	0.6%
217 N Downtown	1.8%	6.5%	2.3%	1.4%	2.1%	0.5%	4.0%	1.8%	1.5%
218 E Downtown	2.5%	9.0%	2.2%	3.0%	10.0%	2.7%	1.5%	2.2%	2.5%
219 Asheville CBD	10.2%	81.8%	5.9%	23.6%	10.2%	14.3%	17.0%	0.5%	6.8%
	1.6%	5.3%	1.6%	1.9%	2.5%	1.6%	4.5%	1.8%	2.1%

During this investigation we noticed a systematic issue with the low income markets for the HBW and HBO trip purposes, which highly correlate with zero auto households. An investigation of the auto ownership model showed that results were not as robust in areas with mixed density. The investigation also confirmed that earlier issues with the group quarter population were impacting the auto ownership estimates. The auto ownership model was re-estimated and calibrated with the addition of a mixed density variable. This required recalibration of trip productions, destination choice, and mode choice, leading to the iteration 2 results reported in the next section.

Iteration 2

The iteration 2 aggregate summaries and estimated constants were reviewed for reasonableness. Finding no issues or concerns, district level implied mode shares were reviewed. Tables 90 and 91 report the implied mode shares for the iteration 2 model run. The implied shares for shares for iteration 2 are now consistent with the level of transit service provided in the FBRMPO region.

Table 90 Implied Transit Mode Shares by District – Iteration 2

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
12 S Haywood	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
21 Asheville			1.7%			1.5%	4.2%			7.0%			2%
22 SW Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
23 NW Buncombe	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
24 NE Buncombe	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
25 SE Buncombe	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1%
31 Madison	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
41 Transylvania	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
51 Hendersonville	0.0%	0.0%		0.0%	8.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.8%	0%
52 W Henderson	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.3%	0.0%	0.2%	0%
53 E Henderson	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.1%	0.1%	0%
	0%	0%	2%	0%	0%	0%	1%	0%	0%	0%	0%	0%	1%

Table 91 Implied Transit Mode Shares by Sub-District – Iteration 2

	211	212	213	214	216	217	218	219	
211 N Asheville	0.8%	6.4%	1.7%	3.8%	5.1%	2.5%	6.9%	2.0%	2.0%
212 E Asheville	0.5%	0.6%	0.5%	0.0%	0.0%	1.5%	0.4%	4.1%	1.0%
213 S Asheville	1.4%	1.4%	0.6%	1.1%	0.0%	1.9%	2.6%	2.0%	1.3%
214 Biltmore Forest	1.2%	2.6%	0.4%	0.0%	0.0%	2.7%	2.7%	3.8%	1.2%
216 W Asheville	0.0%	0.0%	0.2%	1.4%	0.0%	0.3%	0.6%	1.2%	0.4%
217 N Downtown	1.8%	3.7%	2.2%	0.8%	1.6%	0.5%	2.6%	2.8%	1.6%
218 E Downtown	2.4%	8.2%	2.4%	2.6%	8.0%	2.5%	1.4%	3.8%	2.8%
219 Asheville CBD	2.1%	18.2%	2.4%	6.4%	2.5%	2.7%	5.9%	0.1%	1.9%
	1.2%	3.0%	1.2%	1.3%	1.5%	1.2%	3.1%	2.0%	1.7%

Having reasonable confidence with the person trip tables, the focus shifted to investigating the actual transit trips. It is most helpful to look at the difference between estimated and observed transit trips, rather than just looking at the estimated transit trips. Table 92 shows estimated minus observed transit trips by district. This comparison shows that transit trips are under-estimated to the Asheville district, but over-estimated to the Hendersonville district, with the highest over-estimation within the Hendersonville district. Windowing in on the Asheville district, Table 93shows that the biggest problem with under-estimation is for trips originating in north Asheville and east downtown, and for trips with destinations in east Asheville and east downtown.

Table 92 Estimated minus Observed Transit Trips by District – Iteration 2

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0	0	0	0	0	0	0	0	0	0	0	0	0
12 S Haywood	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Asheville	0	0	-842	-9	2	-55	-135	0	0	-38	0	-6	-1,083
22 SW Buncombe	0	0	-26	0	0	0	0	0	0	0	0	0	-26
23 NW Buncombe	0	0	-110	0	0	0	0	0	0	0	0	0	-110
24 NE Buncombe	0	0	-28	0	0	84	9	0	0	0	0	0	66
25 SE Buncombe	0	0	-184	0	0	11	-1	0	0	2	1	13	-158
31 Madison	0	0	0	0	0	0	0	0	0	0	0	0	0
41 Transylvania	0	0	0	0	0	0	0	0	0	0	0	0	0
51 Hendersonville	0	0	-5	0	-3	0	2	0	0	419	13	-20	406
52 W Henderson	0	0	-12	0	0	0	2	0	0	26	14	8	39
53 E Henderson	0	0	-1	0	0	0	32	0	0	32	3	89	155
	0	0	-1,207	-9	-1	41	-91	0	0	441	31	84	-711

Table 93 Estimated minus Observed Transit Trips by Sub-District – Iteration 2

	211	212	213	214	216	217	218	219	
211 N Asheville	127	-101	-45	-12	-22	-69	-168	52	*-238*
212 E Asheville	8	11	26	1	0	-12	3	-57	*-20*
213 S Asheville	-33	-37	33	-6	3	-26	-49	-11	*-127*
214 Biltmore Forest	-4	-24	17	2	4	-9	-8	-15	*-36*
216 W Asheville	3	1	6	-3	3	2	0	-2	*11*
217 N Downtown	-50	-36	-48	-1	-15	188	-42	-29	*-33*
218 E Downtown	-31	-66	-34	-10	-30	-25	14	-41	*-223*
219 Asheville CBD	-45	-95	-55	-7	-4	-31	-72	133	*-176*
	-25	*-347*	*-100*	*-35*	*-59*	*16*	*-322*	*31*	***-842***

Calibration efforts focused on trying to reduce the over-estimation of trips in Hendersonville, as this would increase the share of transit trips in Asheville. Further investigation into the Hendersonville routes showed that the Green Line was the biggest contributor to the over-estimated trips. Additional research showed that this route operates as a deviated fixed-route line, and not a true fixed-route, explaining why the ridership was over-estimated. This route was removed from the route system. The other discovery during this investigation was a discrepancy between the fares for the two systems that resulted in higher fares for the Asheville system due to a generous subsidy program for the Hendersonville system. The average fares were adjusted to create more equity between the two systems. Following both of these changes, the mode choice model was recalibrated and the results are reported in the section for Iteration 3.

Iteration 3

The results for iteration 3 are reported in Tables 94 and 95. The removal of the Green Line improved the overall assignment of trips by route in Hendersonville, but had very little impact on the overall transit trips within the district. The changes to the transit fare did however improve transit trip results for the Asheville district.

Table 94 Estimated minus Observed Transit Trips by District – Iteration 3

	11	12	21	22	23	24	25	31	41	51	52	53	
11 N Haywood	0	0	0	0	0	0	0	0	0	0	0	0	0
12 S Haywood	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Asheville	0	0	-307	-9	3	-32	-121	0	0	-37	0	-3	-507
22 SW Buncombe	0	0	-26	0	0	0	0	0	0	0	0	0	-26
23 NW Buncombe	0	0	-107	0	0	0	0	0	0	0	0	0	-107
24 NE Buncombe	0	0	64	0	0	46	4	0	0	0	0	0	115
25 SE Buncombe	0	0	-134	0	0	4	1	0	0	10	3	15	-101
31 Madison	0	0	0	0	0	0	0	0	0	0	0	0	0
41 Transylvania	0	0	0	0	0	0	0	0	0	0	0	0	0
51 Hendersonville	0	0	-4	0	-3	0	12	0	0	418	17	-7	432
52 W Henderson	0	0	-11	0	0	0	6	0	0	38	13	11	57
53 E Henderson	0	0	7	0	0	0	36	0	0	42	7	51	142
	0	0	-519	-9	0	18	-62	0	0	471	40	67	6

Table 95 Estimated minus Observed Transit Trips by Sub-District – Iteration 3

	211	212	213	214	216	217	218	219	
211 N Asheville	165	-94	-6	-10	-21	-53	-149	32	*-137*
212 E Asheville	13	12	61	1	1	-5	8	-52	*39*
213 S Asheville	-10	-20	115	-1	3	-10	-31	15	*62*
214 Biltmore Forest	4	-22	36	4	3	-5	-3	0	*16*
216 W Asheville	4	1	6	-4	1	1	0	-3	*5*
217 N Downtown	-39	-22	2	2	-16	166	-31	-31	*30*
218 E Downtown	-21	-61	-11	-8	-30	-19	33	-28	*-144*
219 Asheville CBD	-44	-94	-48	-6	-4	-29	-68	116	*-177*
	72	*-301*	*155*	*-22*	*-62*	*46*	*-242*	*48*	***-307***

CALIBRATION RESULTS

AGGREGATE TRIP LEVEL COMPARISONS

A set of tables were prepared to show the performance of the mode choice models. The first, Table 96, provides an overview. This table shows an excellent fit of observed trips to the calibrated mode choice estimated trips. 63.9% of daily trips are conducted using the drive alone mode. Non-motorized travel makes up 5.2% of the region's average weekday travel. Transit is represented by linked trips, not boardings, and represents less than one percent of the region's average weekday travel.

Table 96 Top Level Mode Choice Validation

Mode		Trips	% of Total
Drive Alone	*Observed*	873,909	63.98%
	Estimated	873,882	63.97%
Shared Ride 2	*Observed*	295,132	21.61%
	Estimated	295,134	21.61%
Shared Ride 3+	*Observed*	121,356	8.88%
	Estimated	121,357	8.88%
Bike	*Observed*	11,197	0.82%
	Estimated	11,166	0.82%
Walk	*Observed*	59,650	4.37%
	Estimated	59,760	4.37%
Local Bus	*Observed*	4,676	0.34%
	Estimated	4,678	0.34%
Total	*Observed*	1,365,921	
	Estimated	1,365,976	

Table 97 shows the same information by trip purpose. In this table it can be seen that HBO (which includes shopping, recreational, personal business, and related travel from a residence) makes up 40% of daily travel. The other very large contributor to daily trips is the NHB purpose. Transit trips are most highly associated with the HBO purpose although travelers also use transit for other purposes, most notable are HBW and NHB. This table also shows that the percentages of observed trips by trip purpose are replicated by the mode choice model.

Table 97 Top Level Mode Choice Validation by Purpose

Mode		HBW	HBO	SCH	HBU	NHB
Drive Alone	*Observed*	206,115	367,664	22,950	14,494	262,731
	Estimated	206,042	367,664	22,951	14,495	262,730
Shared Ride 2	*Observed*	15,287	110,324	17,143	2,958	149,428
	Estimated	15,281	110,324	17,143	2,958	149,428
Shared Ride 3+	*Observed*	4,166	41,138	20,540	352	55,162
	Estimated	4,165	41,138	20,540	352	55,162
Bike	*Observed*	2,549	3,729	0	558	4,363
	Estimated	2,561	3,729	0	513	4,362
Walk	*Observed*	8,316	23,424	2,507	0	25,405
	Estimated	8,382	23,424	2,505	45	25,404
Local Bus	*Observed*	1,470	2,125	16	198	866
	Estimated	1,472	2,125	16	198	866
Total	*Observed*	237,902	548,405	63,155	18,559	497,954
	Estimated	237,903	548,405	63,155	18,560	497,954
% of Total	*Observed*	17.42%	40.15%	4.62%	1.36%	36.45%
	Estimated	17.42%	40.15%	4.62%	1.36%	36.45%

The detailed versions of the same mode choice output by trip purpose and income group are shown in the following tables. HBW and HBO are displayed with the two income groups tabulated. The other purposes were not stratified by income and are displayed as a single stratification.

- Table 98: Home-Based Work Mode Choice Validation
- Table 99: Home-Based Other Mode Choice Validation
- Table 100: All Other Purposes Mode Choice Validation

Table 98 shows the mode choice results for the Home-Based Work trips.

- **Overall:** The mode choice model performs well for the HBW mode choice with a 0% error over all modes.
- **Drive**: As expected, the Drive Alone mode dominates drive nest, with high income showing the highest share of Drive Alone trips.
- **Transit**: Local bus is currently the only transit market within the FBRMPO region. The share of bus trips is higher for low income households.
- **Non-Motorized**: The share of non-motorized trips for the region is much higher than the share of transit trips. The bike trips are dominated by low income households, while the reverse is true for the walk trips, with a higher share of walk trips for high income households.

Table 98 HBW Mode Choice Validation

Mode		Low Income	High Income
Drive Alone	*Observed*	83,560	122,554
	Estimated	83,531	122,511
Shared Ride 2	*Observed*	8,419	6,867
	Estimated	8,416	6,865
Shared Ride 3+	*Observed*	2,227	1,939
	Estimated	2,226	1,939
Bike	*Observed*	1,764	785
	Estimated	1,772	789
Walk	*Observed*	3,503	4,813
	Estimated	3,528	4,854
Local Bus	*Observed*	826	644
	Estimated	827	645
Total	*Observed*	100,299	137,603
	Estimated	100,299	137,603

Table 99 shows the mode choice results for the Home-Based Other trips.

- **Overall:** The mode choice model performs well for the HBO mode choice with a 0% error over all modes.
- **Drive**: Drive Alone trips are slightly higher for high income households.
- **Transit**: As with the work trips, the share of bus trips is higher for low income households.
- **Non-Motorized**: Bike trips are higher for low income households. Unlike the work trip, the walk trips for the HBO purpose are similar for both low and high income households.

Table 99 HBO Mode Choice Validation

Mode		Low Income	High Income
Drive Alone	*Observed*	172,035	195,629
	Estimated	172,033	195,631
Shared Ride 2	*Observed*	51,011	59,312
	Estimated	51,011	59,313
Shared Ride 3+	*Observed*	18,898	22,241
	Estimated	18,898	22,241
Bike	*Observed*	2,745	984
	Estimated	2,745	985
Walk	*Observed*	11,204	12,220
	Estimated	11,206	12,217
Local Bus	*Observed*	1,485	641
	Estimated	1,485	641
Total	*Observed*	257,378	291,027
	Estimated	257,378	291,027

Table 100 summarizes all other trips purposes. No income categories were established for these purposes. Each purpose has its own profile of modal use.

- **Overall:** The mode choice model performs well for all other trip purposes with a 0% error over all modes for all purposes.
- **Home-Based School**: Not surprisingly, Shared Ride 2 and Shared Ride 3-plus dominate with the vast majority of the mode share replicated faithfully by the mode choice model.
- **Home-Based University –** Drive Alone dominates in this purpose with the mode shares replicated well.
- **Non-Home-Based** – This purpose has a high number of walking trips.

Table 100 All Other Purposes Mode Choice Validation

Mode		SCH	HBU	NHB
Drive Alone	*Observed*	22,950	14,494	262,731
	Estimated	22,951	14,495	262,730
Shared Ride 2	*Observed*	17,143	2,958	149,428
	Estimated	17,143	2,958	149,428
Shared Ride 3+	*Observed*	20,540	352	55,162
	Estimated	20,540	352	55,162
Bike	*Observed*	0	558	4,363
	Estimated	0	513	4,362
Walk	*Observed*	2,507	0	25,405
	Estimated	2,505	45	25,404
Local Bus	*Observed*	16	198	866
	Estimated	16	198	866
Total	*Observed*	63,155	18,559	497,954
	Estimated	63,155	18,560	497,954

District Level Comparisons

A comparison of district level flows was prepared to test the fidelity of the mode choice output to observed trip flows. This analysis focused on transit trips.

Table 101 shows the observed Home-Based Work transit trips from the FBRMPO onboard survey. Table 102 shows the same information as estimated by the mode choice model. Finally, Table 103 shows the difference between the observed and estimated transit trips by district. The following can be noted:

- Each district to district table for HBW (observed and estimated) contains about 1,500 transit trips.
- The transit trips are concentrated in the Asheville districts (211 through 219)
- The highest concentration of estimated trip attractions is to 219, the CBD district. District 213 also has a high number of estimated trip attractions. The model slightly over-estimates trips to both of these districts.
- The highest concentration of estimated trip productions is from 217. The highest concentration of observed trip productions is from 211. The model under-estimates the trips from this district by 156 trips.
- Most of the cell values representing district to district transit trips are measured in one or two digits; the total over-estimation for this purpose is 6 transit trips out of a total of approximately 1,500 trips.

Table 101 District to District Transit Trips (HBW Observed)

	11	12	22	23	24	25	31	41	51	52	53	211	212	213	214	216	217	218	219	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	4	9	0	**30**
24	0	0	0	0	0	0	0	0	0	0	0	12	3	13	0	5	9	4	0	**46**
25	0	0	0	0	0	9	0	0	0	0	0	30	5	26	19	3	0	0	16	**108**
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
51	0	0	0	0	0	0	0	0	36	0	0	2	3	0	0	0	0	0	0	**41**
52	0	0	0	0	0	3	0	0	5	0	7	0	0	0	0	0	0	0	0	**16**
53	0	0	0	0	0	0	0	0	11	0	4	0	0	0	0	0	0	0	0	**15**
211	0	0	0	0	13	39	0	0	2	0	5	35	32	76	13	16	34	48	65	**379**
212	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	8	0	6	**34**
213	0	0	0	0	0	0	0	0	0	0	0	49	11	19	9	0	19	28	17	**152**
214	0	0	0	0	0	10	0	0	0	0	0	5	17	7	0	0	2	14	13	**67**
216	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0	**7**
217	0	0	0	0	0	6	0	0	0	0	0	40	5	48	0	5	47	15	119	**286**
218	0	0	0	0	3	4	0	0	0	0	3	17	28	28	0	15	18	11	59	**186**
219	0	0	0	0	10	0	0	0	0	0	0	26	29	20	7	0	0	11	0	**103**
	0	**0**	**0**	**0**	**26**	**72**	**0**	**0**	**54**	**0**	**18**	**216**	**133**	**277**	**48**	**43**	**146**	**141**	**296**	**1,470**

Table 102 District to District Transit Trips (HBW Estimated)

	11	12	22	23	24	25	31	41	51	52	53	211	212	213	214	216	217	218	219	Total
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0	4	1	5	**15**
24	0	0	0	0	20	2	0	0	0	0	0	7	5	16	0	0	1	3	16	**71**
25	0	0	0	0	2	7	0	0	2	1	4	2	1	10	1	1	1	3	8	**42**
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
51	0	0	0	0	0	4	0	0	172	7	12	0	0	0	0	0	0	0	0	**195**
52	0	0	0	0	0	4	0	0	32	4	8	0	0	0	0	0	0	0	0	**48**
53	0	0	0	0	0	17	0	0	24	2	14	0	0	3	0	0	0	1	1	**63**
211	0	0	0	1	1	0	0	0	0	0	0	58	3	70	0	1	12	23	109	**279**
212	0	0	0	0	1	1	0	0	0	0	0	8	9	34	0	1	2	5	25	**86**
213	0	0	0	0	1	0	0	0	0	0	0	11	5	61	3	3	5	19	57	**164**
214	0	0	0	0	0	2	0	0	0	0	0	2	1	25	1	1	1	5	11	**49**
216	0	0	0	0	0	1	0	0	0	0	0	1	0	3	1	0	1	1	3	**10**
217	0	0	0	0	1	0	0	0	0	0	0	19	4	56	1	3	60	31	90	**264**
218	0	0	0	0	0	0	0	0	0	0	0	16	1	41	0	1	15	19	63	**158**
219	0	0	0	0	0	0	0	0	0	0	0	3	0	8	0	0	1	3	11	**27**
Total	**0**	**0**	**0**	**1**	**27**	**38**	**0**	**0**	**229**	**14**	**38**	**129**	**31**	**330**	**8**	**11**	**102**	**113**	**400**	**1,472**

Table 103 District to District Transit Trips (HBW Estimated minus HBW Observed)

	11	12	22	23	24	25	31	41	51	52	53	211	212	213	214	216	217	218	219	Total
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23	0	0	0	0	0	0	0	0	0	0	0	2	0	-14	0	0	-1	-8	5	**-15**
24	0	0	0	0	20	2	0	0	0	0	0	-5	2	3	0	-5	-8	-1	16	**25**
25	0	0	0	0	2	-2	0	0	2	1	4	-28	-4	-15	-18	-3	1	3	-8	**-66**
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
51	0	0	0	0	0	4	0	0	136	7	12	-2	-3	0	0	0	0	0	0	**154**
52	0	0	0	0	0	1	0	0	27	4	0	0	0	0	0	0	0	0	0	**33**
53	0	0	0	0	0	17	0	0	13	2	11	0	0	3	0	0	0	1	1	**49**
211	0	0	0	1	-12	-39	0	0	-2	0	-5	23	-29	-6	-13	-15	-22	-25	43	**-100**
212	0	0	0	0	1	1	0	0	0	0	0	8	9	14	0	1	-6	5	20	**52**
213	0	0	0	0	1	0	0	0	0	0	0	-38	-6	42	-6	3	-14	-9	40	**12**
214	0	0	0	0	0	-8	0	0	0	0	0	-3	-16	18	1	1	-1	-9	-2	**-18**
216	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	-3	1	3	**3**
217	0	0	0	0	1	-6	0	0	0	0	0	-22	-1	7	1	-2	12	16	-29	**-22**
218	0	0	0	0	-3	-4	0	0	0	0	-3	-1	-27	13	0	-14	-3	8	4	**-28**
219	0	0	0	0	-10	0	0	0	0	0	0	-23	-28	-12	-7	0	1	-9	11	**-76**
Total	**0**	**0**	**0**	**1**	**1**	**-33**	**0**	**0**	**176**	**14**	**20**	**-87**	**-102**	**53**	**-40**	**-32**	**-44**	**-28**	**104**	**2**

SUMMARY OF MODE CHOICE

Following the calibration of the destination choice models, the mode choice model was calibrated based upon the observed market-stratified person trip matrices from the FBRMPO household survey and the FBRMPO on-board transit survey. Comparison of district level observed and estimated trip flows by purpose and access mode were prepared and analyzed and showed a very good fit to observed trips. The calibration process revealed the need to repair and modify various components of the model chain as documented.

Recreational Vehicle Model

The RV trip model for the FBRMPO region follows the traditional 3-step process for trip generation, trip distribution, and highway assignment, see Figure 36. All trips from RV parks are vehicle trips assigned to the highway network. These trips are split by time of day and added to the single occupancy vehicle (SOV) trips prior to final highway assignment.

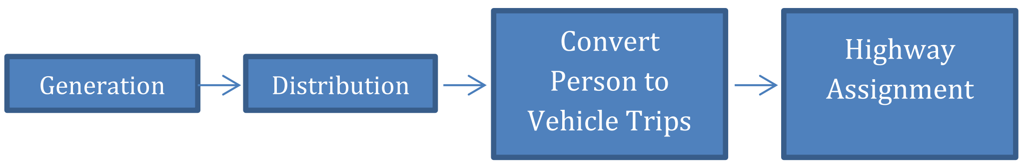


Figure 36 RV Model Process

Survey Processing

Development of the RV trip model was based on the 2013 FBRMPO RV Survey. The survey collected travel and demographic information from 70 RVs in July 2013. Each RV was treated as a household, and the respondents made a total of 182 trips. When accounting for party size, that equated to 338 person trips. Surveys were collected from six RV parks in Haywood County. Table 104 provides a breakdown of the RV survey responses for each of these parks.

Table 104 Breakdown of RV Survey Responses by Park

Campground	Responses
Butch Teague	11
Creekwood Farm	5
Cross Creek	10
Pride Resorts	13
Stone Bridge	12
Windgray	19
Total	**70**

The survey records were not originally geocoded, but contained excellent address information allowing for efficient geocoding of each place visited by a party. The statistical software package R was used to process the geocoded place file into a trip file with the following fields:

Origin traffic analysis zone (TAZ)

- Destination TAZ
- Trip Purpose
    - Home-based shopping (HBS)

- Home-based other (HBO)
- Non-home-based (NHB)

- Number of People in the Travel Party

TRIP GENERATION

The survey trip records were separated by trip purpose and an average trip production rate was calculated for each purpose. Table 105 summarizes the final trip production rate by trip purpose for RV households. The rate provided in Table 105 is the person trip rate per RV. For example, each RV produces 1.6 person trips for the HBS trip purpose.

Table 105 RV Trip Production Rates by Purpose

Trip Purpose	Person Trips per Occupied RV
HBS	1.6
HBO	1.4
NHB	1.7

Using trip end data from the RV survey, average trip attraction rates were computed based on employment in each TAZ. Table 106 summarizes the final trip attraction rates by trip purpose for RV households.

Table 106 RV Trip Attraction Rates by Purpose

Trip Purpose	Office	Service	High Traffic Retail
HBS	-	-	0.318
HBO	0.264	0.264	-
NHB	0.157	0.157	0.157

TRIP DISTRIBUTION

Trip distribution for the RV households is estimated using an intervening opportunities model. This model is preferred over the standard gravity model based on the assumption that, unlike permanent residents, RV households are more likely to satisfy their demand for travel at the nearest available destination. The TransCAD default value of -0.225 was used as the initial starting point for probability parameter, λ, for each trip purpose and then the average trip length from the model compared to that from the survey. Table 107 provides a summary of the model average trip length compared to the survey average trip length. Figures 37-39 show the model versus survey trip length distribution curves for each trip purpose. The NHB trip model performs very well in comparison to the survey data, but the HBS and HBO modeled average trip length trip is much longer than the survey value.

Table 107 RV Average Trip Lengths (min) by Trip Purpose

Trip Purpose	Survey	Model
HBS	15.29	30.88
HBO	15.92	29.64
NHB	6.64	5.36

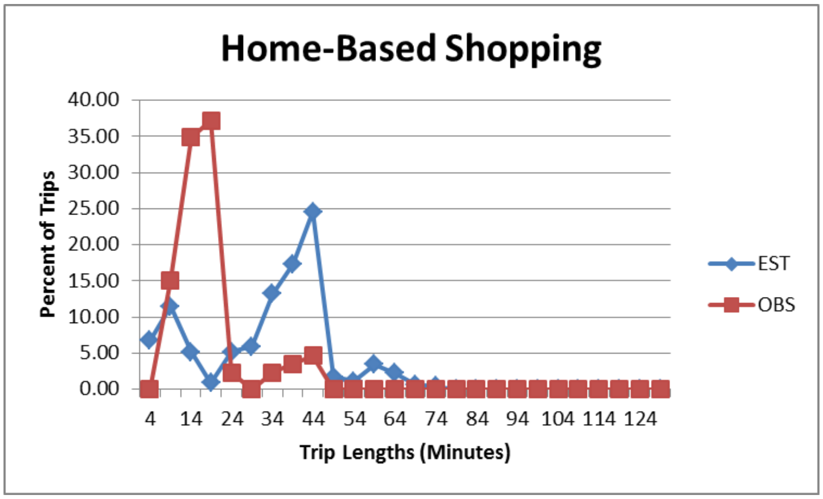


Figure 37 HBS Estimated vs. Observed Trip Length Distribution

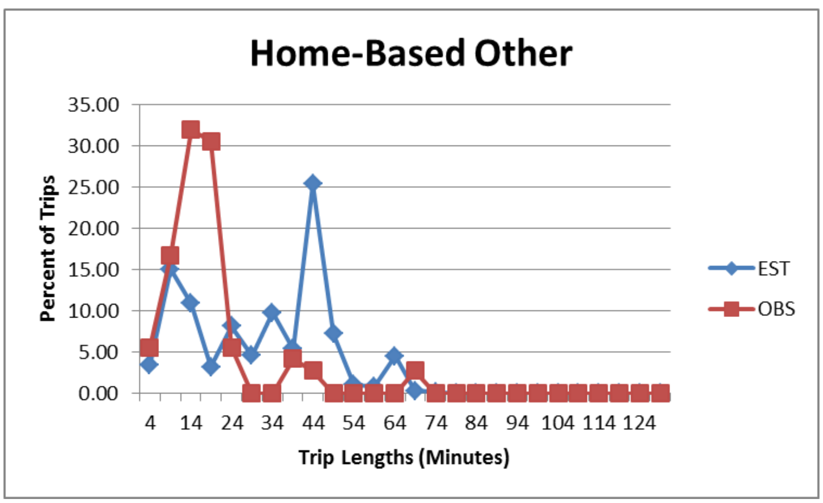


Figure 38 HBO Estimated vs. Observed Trip Length Distribution

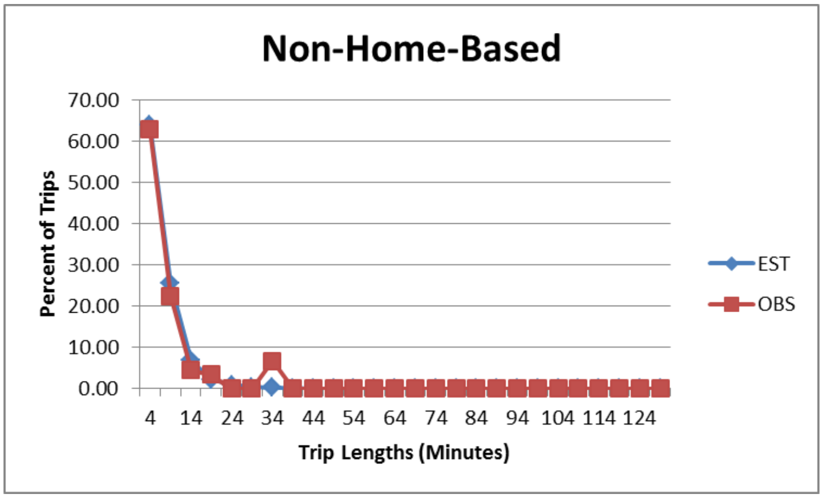


Figure 39 NHB Estimated vs. Observed Trip Length Distribution

Multiple model iterations were performed with a range of values on the probability parameter, λ, in an effort to improve model fit. The resulting change in the model average trip length was negligible. This pointed to a couple of possible theories that required testing, either the intervening opportunities model was not a good model for these two trip purposes, or the distribution of available activities at a regional level did not support the shorter trip lengths reported by survey participants.

A gravity model was applied and calibrated for the HBS and HBO trip purposes, but the modeled average trip length did not improve over that observed with the application of the intervening opportunities model. This test showed that it was not the model form that was at issue.

The investigation into the locations of the RV parks, both surveyed and non-surveyed, in comparison to the location and magnitude of available activities provided a clear explanation of the discrepancy between the survey and the model application. Figure 40 shows a plot of the modeled HBS RV productions (blue) and modeled HBO RV productions (green) as compared to available modeled RV attractions by trip purpose which are directly related to available activities demonstrated by the magnitude and type of employment. Figure 41 shows a plot of the TAZs where RV parks were surveyed in addition to RV parks not included in the survey. The surveyed parks are located much closer to potential activities than are many of the RV parks not surveyed, but included in the model. It is therefore logical that longer travel times would be required to participate in HBS and HBO activities from many of these more remote parks. Based on this analysis, we feel confident moving forward with the modeled trip length distributions for HBS and HBO.

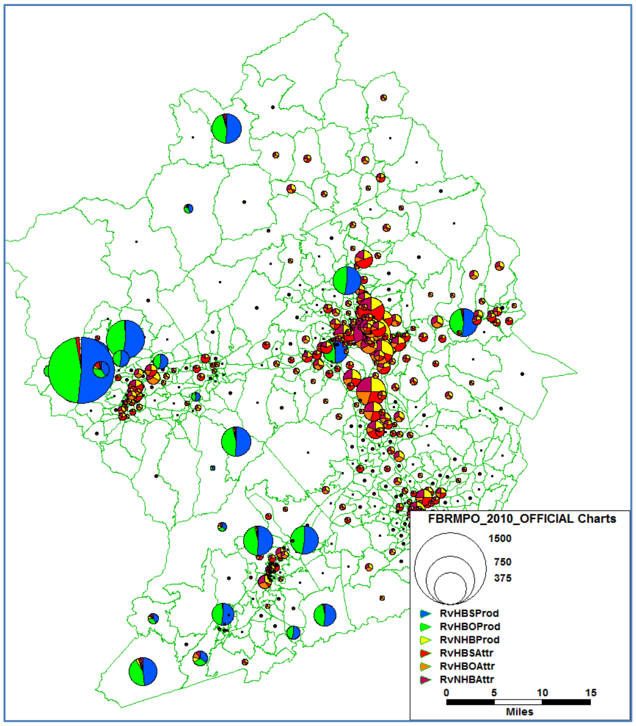


Figure 40 Modeled RV Productions and Attractions

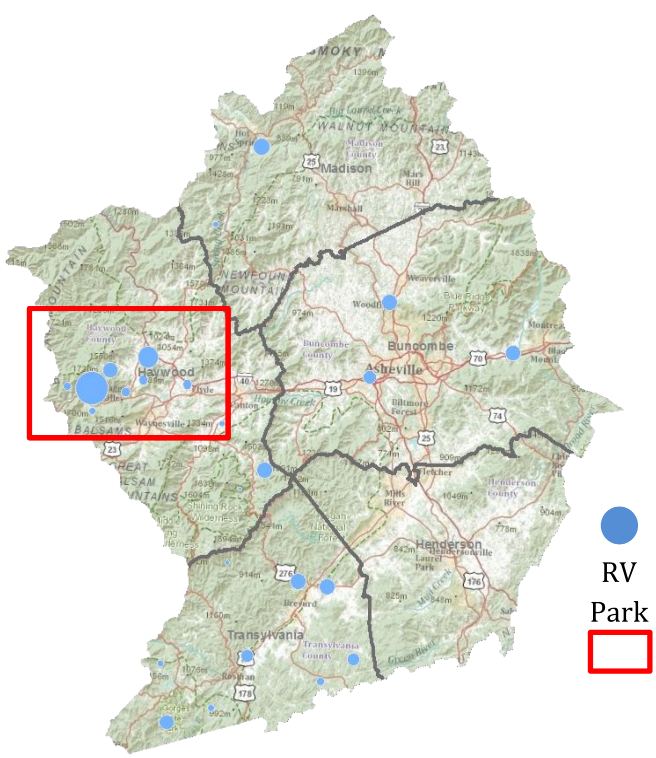


Figure 41 Surveyed RV Park Locations

TIME OF DAY

The RV Survey was used to develop a directional split by time of day and the average persons per RV trip. Applying these factors converts the daily Production-Attraction person trip table to an origin-destination vehicle trip table by time of day. According to the survey, the average persons per RV trip are 1.875 persons per trip. The directional split by time of day is provided in Table 108.

Table 108 RV Time of Day Directional Split Factors

Purpose	Direction	AM	MD	PM	NT	Total
HBS	From Home	0.00	0.42	0.06	0.02	0.50
HBS	To Home	0.00	0.21	0.24	0.06	0.50
HBO	From Home	0.10	0.32	0.05	0.03	0.50
HBO	To Home	0.02	0.30	0.09	0.09	0.50
NHB	From Home	0.00	0.78	0.19	0.03	1.00

MODEL APPLICATION

In addition to the rates and parameters discussed in previous sections, the RV model requires as input the number of RV park hookups and campsites by TAZ and a seasonal occupancy factor for spring, summer, fall, and winter. The base year model was applied using the spring occupancy factor, which was determined to be 0.59 from the survey data collection effort. This occupancy factor reflects the percent of the sites that are occupied during the specified time of year. Changing this value will have the effect of either increasing or decreasing the number of trips produced by the RV trip model as only occupied sites generate trips. The current model setup uses the 0.59 factor for all seasons, but this value can be easily modified by the user to test the impact of different seasonal factors.

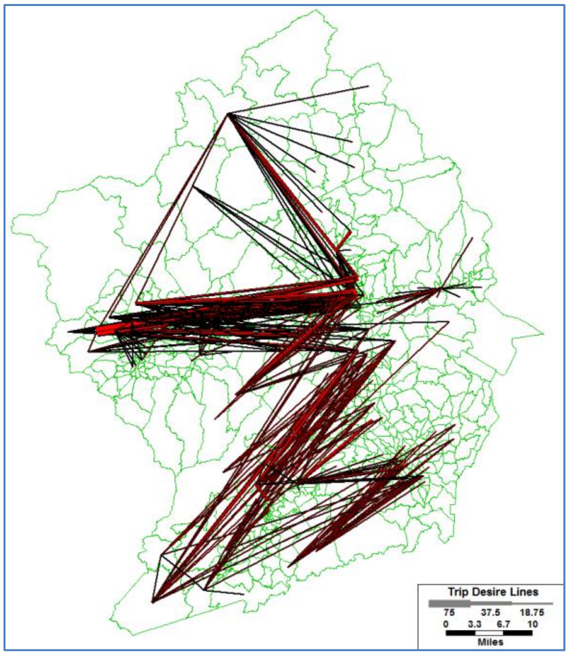
MODEL VALIDATION

The following comparison of model versus observed trips shows that the trip production model is reasonably calibrated to the survey observed trip productions as shown in Table 109.

Table 109 Comparison of Model versus Survey RV Trip Productions

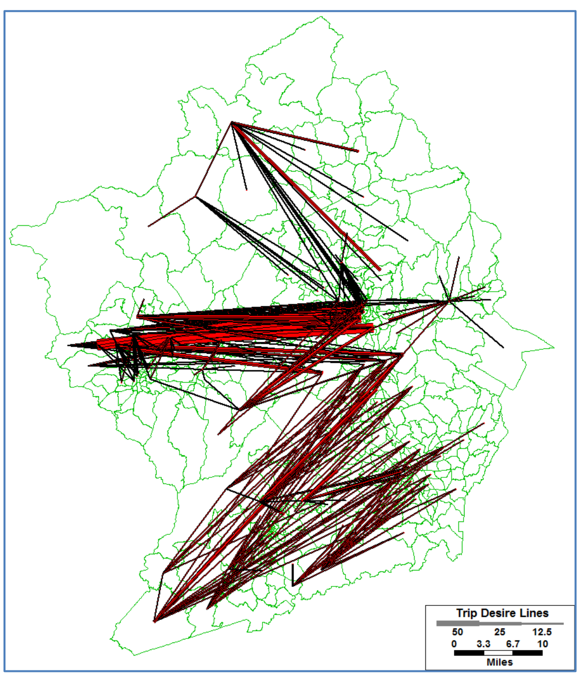
Trip Purpose	Observed Trip Productions (Survey)	Predicted Trip Productions (Model)	Percent Difference (Survey versus Model)
HBS	2785.45	2785	-0.02%
HBO	2465.00	2466	0.04%
NHB	2958.00	2958	0.00%
Total	8208.45	8209	0.01%

The survey was too sparse for a comparison of modeled versus survey trips by district, but Figures 42-44 show the modeled trip distribution for the RV trips by trip purpose.



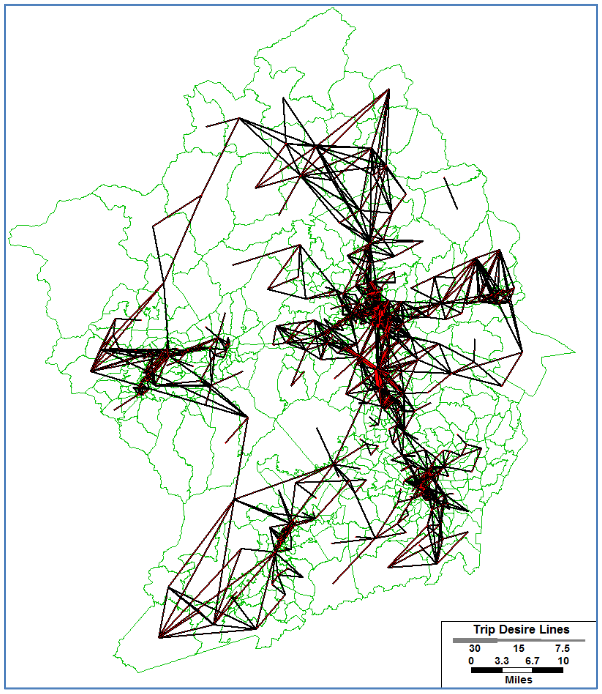
Only interchanges > .5 trips shown

Figure 42 HBS Daily Trip Distribution (Origin-Destination Format)



Only interchanges > .5 trips shown

Figure 43 HBO Daily Trip Distribution (Origin-Destination Format)



Only interchanges > .5 trips shown

Figure 44 NHB Daily Trip Distribution (Origin-Destination Format)

VISITOR MODEL

The French Broad River Metropolitan Planning Organization (FBRMPO) region enjoys the benefits of being a major attraction for visitors outside the region. While benefiting the region's economy, visitor travel can also impact the transportation system. To better understand and evaluate the role of visitor travel in the region, Parsons Brinckerhoff implemented a trip-based visitor model that can be used to forecast travel by business and vacation travelers staying at hotels and motels (hotels) in the region. The model includes trip generation, trip distribution, a motorized/non-motorized mode split, time of day, and trip assignment as shown in Figure 45 below.

In total, the model predicts approximately 24,000 auto trips per day made by visitors staying in the region. While this is a relatively small value compared to the total number of trips per day made by residents, including these trips in the model provides a better representation of traffic flows around key areas in the region that are heavily impacted by tourism related travel, like Biltmore Estate. Additionally, this model enhancement provides the MPO with the capability of evaluating the impacts of visitor related travel during various times of the year.

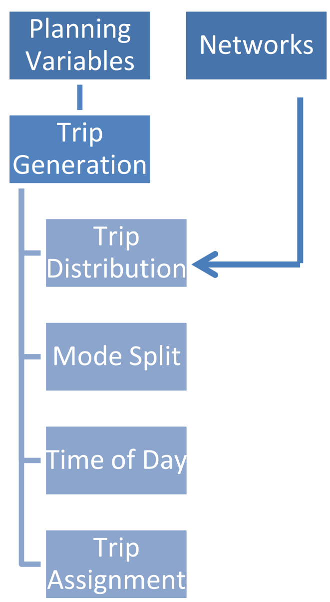


Figure 45 FBRMPO Visitor Model Structure

APPROACH

In lieu of a visitor survey for the region, the basic model structure along with the initial rates and parameters were borrowed from another region. A scan of visitor models recently completed by Parsons Brinckerhoff was performed in order to identify the best fit. Most of the recent models developed were either specific to one particular venue, like an airport visitor model in Nashville, Tennessee, or were advanced tour based models as was the case in Oahu, Hawaii. Reno, Nevada was ultimately selected as the best fit based on the trip based structure and a current (within the last 5 years) visitor survey. Recognizing that gaming plays a big role in visitor travel to Reno, Nevada, all model data related to the gaming industry was excluded from the analysis for the FBRMPO model. It is also important to note that the transferred rates and parameters only served as the starting point, after application they were adjusted to better reflect data local to the FBRMPO region.

TRIP PURPOSES

Six trip purposes were specified for the FBRMPO visitor model. These trip purposes capture travel specific to the business traveler, specific to the vacation traveler, and common to both. Table 110 provides a summary of the trip purposes and their description.

Table 110 Trip Purposes

Trip Purpose	Description
HBW	Hotel-Based Work/Business
HBSR	Hotel-Based Social/Recreation
HBDE	Hotel-Based Dining/Entertainment
HBSHP	Hotel-Based Shopping
NHBW	Non-Hotel-Based Work
NHBO	Non-Hotel-Based Other

TRIP GENERATION MODEL

Trip generation models predict the number of *person* trips that are generated by and attracted to each defined zone in the FBRMPO region. This estimate of the number of person trip ends is stratified by trip purpose and based on the characteristics of the trip-maker (business traveler or vacation traveler) and the geographic location (downtown or other). Trip "productions" and "attractions" are output by the trip generation model and serve as the input to the trip distribution model.

TRIP PRODUCTION MODEL

The analysis or basic unit of visitor trip-making in the production model is the room. Intuitively, it stands to reason that business travelers have different trip making characteristics than do vacation travelers, and the data support this. In regions with active downtowns, visitor survey data also support the theory that trip making varies for travelers staying in downtown hotels versus hotels outside of the downtown area. For this reason, trip rates are stratified by purpose of the visit and the geographic location of the hotel, with different rates for hotels in the downtown area.

A summary of the initial set of trip rates *per person* borrowed from the Reno model are presented in Table 111. Trip rates are in trips per person, but as noted previously, the unit of analysis is the hotel room. To apply the rates to the number of hotel rooms by TAZ tabulated in the socioeconomic data (SE) input file, the average party size by purpose of visit is used. These values, shown below, were borrowed from the Reno visitor model and applied to the FBRMPO visitor model. These values can be easily modified if more local data is available from the MPO.

- Business Related: 1.20
- Recreation/Vacation: 2.58

Table 111 Visitor Model Trip Production Rates (Per Person)

Trip Purpose	Purpose of Visit	Downtown	Other
Hotel-Based Work/Business	Business	0.599	0.248
	Vacation	NA	NA
Hotel-Based Social/Recreation	Business	0.013	0.032
	Vacation	0.143	0.143
Hotel-Based Dining/Entertainment	Business	0.058	0.143
	Vacation	0.141	0.094
Hotel-Based Shopping	Business	0.013	0.032
	Vacation	0.016	0.087
Non Hotel-Based Work/Business	Business	0.040	0.032
	Vacation	NA	NA
Non Hotel-Based Other	Business	0.088	0.121
	Vacation	0.075	0.101

Trip rates are per person

Trip Attraction Model

Trip attraction models predict the number of trips attracted to each zone by trip purpose. For the business traveler, service and office employment is a strong indicator of trip attractions. For the vacation traveler, retail and special venues are strong indicators of trip attractions. Table 112 presents the initial trip attraction rates by trip purpose borrowed from the Reno model.

Table 112 Trip Attraction Model Rates (per Employee)

Trip Purpose	Retail	Service & Office	Hotel Room	Special Venue
Hotel-Based Work/Business		3.99		
Hotel-Based Social/Rec.				Used annual visitors[1]
Hotel-Based Dining/Entertainment	0.615			
Hotel-Based Shopping	0.445			
Non-Hotel-Based Work		0.171	0.070	
Non-Hotel-Based Other	0.253			

[1]*Determination of rate described below*

HBSR Visitor Calculation

One trip attraction rate thought to be very specific to the FBRMPO region was the rate for social and recreational trips to special venues in the region. Fortunately, the FBRMPO staff was able to collect and provide annual visitor numbers for key sites in the region. These values formed the basis for estimating average weekday visitors for special venues using the process and assumptions described below.

The annual visitors were factored to daily visitors by first assuming 50 weeks of operation per year and 7 days per week. Because the model is a weekday model, not a daily model, the number had to be further adjusted to factor out weekend visitors, using the assumption that weekends are more active than weekdays, the daily number was lowered by 20%. Similarly, a seasonal adjustment factor was applied to slightly boost spring, summer, and fall months relative to winter months. Finally, the visitor model only captures visitors from hotels in the modeled region, and some of the observed visitors likely come from outside of the region. The assumption applied is that 75% of the visitors to special venues within the FBRMPO actually come from hotels within the region. All of the values cited above are best estimates based on our knowledge of the region. These values may require revision during the model validation step, or likewise, can be modified using information provided by the MPO. In application, this process is applied for each TAZ in the SE data input file with annual visitor data. Once converted to daily visitors by TAZ, this number is used as attractions to distribute the hotel-based social/recreational (HBSR) trip purpose. The example below shows how the calculations are applied using the annual visitor data provided by the MPO.

6,846,196	Annual Visitors to the Study Area
/ 50	Operational Weeks per Year
/ 7	Operational Days per Week
* 1	Seasonal Factor for Spring
* .8	Weekday vs Weekend-day Factor
* .75	Percent of Visitors from Local Hotels
11,736	Daily Weekday Visitors in the Study Area

Seasonal Factors

1	spring
1.15	summer
1.2	fall
0.65	winter

Model Validation

The transferred production and attraction models were applied using hotel rooms by TAZ for the productions, and employment by type for the attractions for all but the HBSR trip purpose where estimated average daily visitor data was used for the attractions. The results of the initial estimation are shown in Table 113. Best practice modeling suggests that the production to attraction ratio (P/A) should be between 0.9 and 1.1. Clearly the initial application of the FBRMPO production and attraction models violates this rule. Having more faith in the trip production rates for all but the HBSR trip purpose, the initial attraction rates were reduced to bring the estimated productions and attractions more into range. For the HBSR trip purpose, the trip production rate was adjusted since the trip attractions for this trip purpose are based on locally collected data. The final trip production rates are provided in Table 114, and the final trip attraction rates are provided in Table 115.

Table 113 Estimated Productions and Attractions

Trip Purpose	Productions	Attractions	P/A Ratio
HBW	515	42908	0.012
HBSR	1248	12909	0.097
HBDE	1079	30444	0.035
HBSHP	623	22028	0.028
NHBW	52	18707	0.003
NHBO	968	12524	0.077

Table 114 Visitor Model Final Trip Production Rates (Per Person)

Trip Purpose	Purpose of Visit	Downtown	Other
Hotel-Based Work/Business	Business	0.599	0.248
	Vacation		
Hotel-Based Social/Rec	Business	0.135	0.331
	Vacation	1.480	1.480
Hotel-Based Dining/Entr	Business	0.058	0.143
	Vacation	0.141	0.094
Hotel-Based Shopping	Business	0.013	0.032
	Vacation	0.016	0.087
Non Hotel-Based Work/Bus	Business	0.040	0.032
	Vacation		
Non Hotel-Based Other	Business	0.088	0.121
	Vacation	0.075	0.101

Trip rates are per person

Table 115 Visitor Model Final Trip Attraction Rates (Per Person)

Trip Purpose	Retail	Service & Office	Hotel Room	Special Venue
Hotel-Based Work/Business		0.005		
Hotel-Based Social/Rec.	1.998*	1.998*		Average daily visitors
Hotel-Based Dining/Entertainment	0.022			
Hotel-Based Shopping	0.013			
Non-Hotel-Based Work		0.001		
Non-Hotel-Based Other	0.02			

* applied to specific TAZs only

TRIP DISTRIBUTION MODEL

The trip distribution model "connects" the independent productions and attractions estimated by the trip generation model based upon a quantitative description of the relative difficulty in reaching each potential destination zone from an origin zone and an understanding of the underlying functional relationship between these variables (i.e., productions, attractions, and impedance).

In other words, visitors are influenced by the attractiveness of the destination (as measured by the estimated quantity of trip attractions), but also tend toward selecting the first destination which satisfies the purpose of the trip. Due to this behavior, the gravity model tends to over-estimate visitor trip lengths given the intrinsic limits associated with the functional form of the F_{ij} factors (friction factors between zone i and zone j). The intervening opportunities model, however, possesses this very attribute in its functional form. The premise governing the intervening opportunities model states that total impedance is minimized subject to the condition that every destination has a finite probability of being accepted, subject to the desire that each trip be as short as possible. The intervening opportunities model generally has a steeper decay slope to its distribution function, which leads to shorter trips. The mathematical form of the model is as follows:

$$T_{ij} = T_i * [\, e^{L*R_{j-1}} - e^{L*R_j} \,]$$

where:

T_{ij}	=	number of trips from zone i to zone j
T_i	=	number of trips produced in zone i
R_j	=	rank of destination zone j
R_{j-1}	=	rank minus 1 of destination zone j
L	=	probability of accepting a destination if it is considered.

Experience has shown that this model form is an excellent choice for the distribution of visitor trips. This model was applied to the estimated visitor productions and attractions and the resulting trip length distributions and average travel times by trip purpose were reviewed for reasonableness. Table 116 provides a summary of the average trip length by trip purpose, and Figure 46 shows the trip length distributions by trip purpose. The trip length distributions look reasonable, particularly the marked difference in the HBSR trip purpose. Destinations for that purpose are limited, which spreads out the distribution.

Table 116 Trip Distribution Probability Parameters

Trip Purpose	Average Trip Length (min.)
Hotel-Based Work/Business	8.2
Hotel-Based Social/Rec.	24.31
Hotel-Based Dining/Entertainment	11.96
Hotel-Based Shopping	13.38
Non-Hotel-Based Work	8.64
Non-Hotel-Based Other	8.93

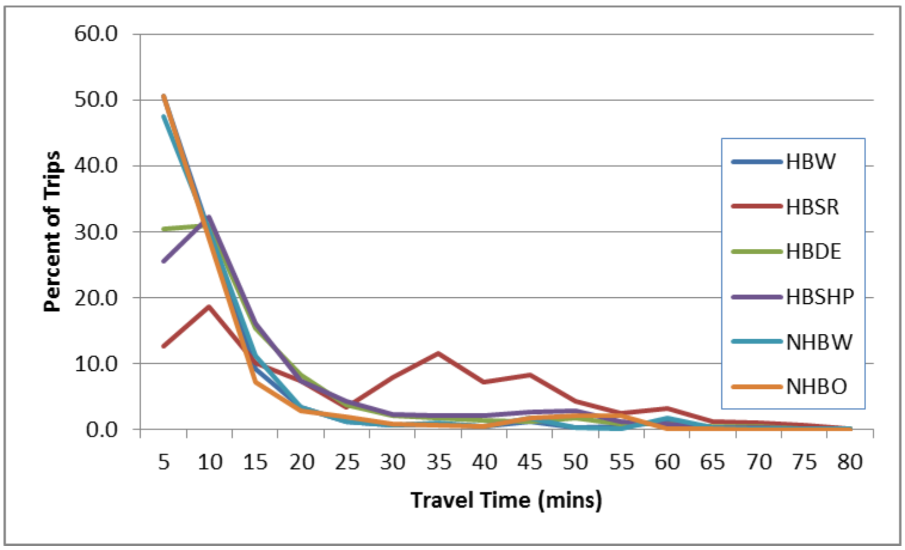


Figure 46 Trip Length Distributions by Trip Purpose

A summary of the calibrated L-Value for each trip purpose is shown in Table 117.

Table 117 Trip Distribution Probability Parameters

Trip Purpose	Probability Factor
Hotel-Based Work/Business	0.15000
Hotel-Based Social/Rec.	0.06000
Hotel-Based Dining/Entertainment	
Hotel-Based Shopping	
Non-Hotel-Based Work	0.20000
Non-Hotel-Based Other	

MODE SPLIT

While there is no formal mode choice model for the FBRMPO visitor model, it seems reasonable to apply a mode split factor to specific trip purposes for visitors staying at hotels within the downtown region given the density, mixed use, and walkability of the downtown area. A mode split factor was also applied to hotel-based dining and entertainment trips for visitors outside of the downtown region. Often these hotels are located in mixed use centers with many restaurants within close walking distance of the hotel. The mode split factor in the FBRMPO visitor model considers walk trips and auto trips, where the auto mode includes taxi, rental cars, and private auto. Walk trips are restricted to zone interchanges less than or equal to 0.5 miles.

Table 118 summarizes the mode split factors by trip purpose, area type and mode.

Table 118 Mode Split Factor Trip Purpose and Area Type

Trip Purpose	Downtown		Other	
	Auto	Walk	Auto	Walk
Hotel-Based Work	1.0		1.0	
Hotel-Based Social/Rec	1.0		1.0	
Hotel-Based Dining/Entr.	0.6	0.4	0.85	0.15
Hotel-Based Shopping	0.75	0.25	1.0	
Hotel-Based Other	0.75	0.25	1.0	
Non-Hotel Based Work	1.0		1.0	
Non-Hotel-Based Other	0.85	0.15	1.0	

TIME OF DAY AND DIRECTIONAL SPLIT

The time of day and directional split factors from the resident trip model were applied to the visitor trip model to convert the production/attraction (PA) trip table to an origin/destination (OD) trip table. Table 119 provides a mapping between the resident trip purposes and the visitor trip purposes.

Table 119 Trip Purpose Mapping between Resident Model and Visitor Model

Visitor Model Trip Purpose	Resident Model Trip Purpose
Hotel-Based Work/Business (HBW)	HB-Work
Hotel-Based Social/Rec. (HBSR)	HB-Other
Hotel-Based Dining/Entertainment (HBDE)	HB-Other
Hotel-Based Shopping (HBSHP)	HB-Shopping
Non-Hotel-Based Work (NHBW)	NHBW
Non-Hotel-Based Other (NHBO)	NHBO

The time of day factors by trip purpose are shown in Table 120.

Table 120 Visitor Model Time of Day Factors

Purpose	From Home/To Home	AM	MD	PM	NT	Total
HBW	From Hotel	0.286	0.129	0.026	0.059	**0.500**
	To Hotel	0.008	0.067	0.271	0.154	**0.500**
HBSR and HBDE	From Hotel	0.118	0.256	0.065	0.061	**0.500**
	To Hotel	0.008	0.111	0.102	0.280	**0.500**
HBSHP	From Hotel	0.047	0.271	0.110	0.072	**0.500**
	To Hotel	0.002	0.196	0.153	0.150	**0.500**
NHBW	From	0.076	0.243	0.137	0.044	**0.500**
	To	0.076	0.243	0.137	0.044	**0.500**
NHBO	From	0.029	0.289	0.131	0.050	**0.500**
	To	0.029	0.289	0.131	0.050	**0.500**

** See technical memorandum on Time of Day for more details on the development of these factors*

During the time of day and directional split factoring, the person auto trips are converted to vehicle auto trips through the application of a vehicle occupancy factor (VOR). The initial factors were derived from the visitor survey conducted in Reno, Nevada, see Table 121.

Table 121 Vehicle Occupancy Factors

Trip Purpose	VOR
HBW	1.56
HBSR	2.54
HBDE	2.54
HBSHP	2.54
NHBW	1.56
NHBO	2.20

Reasonableness Checking

Even without a locally collected visitor survey for model calibration and validation, it is still important to perform reasonableness checks on the model results. In addition to checking the rates and parameters for reasonableness throughout model development, an additional step was taken once the development of the model was complete. The resulting visitor trip tables were assigned to the highway network and the resulting traffic flows were compared against the known locations of key visitor sites to ensure that the flow patterns looked reasonable. See Figure 47 for a graphical representation of this analysis. In this figure, the blue circles represent hotels, which produce trips. Likewise, the red circles represent special venues like the Biltmore Estate, and green circles represent employment, both of which attract trips. The map shows that visitors are traveling as expected between hotels and visitor destinations. Figure 47 provides a good representation of the trips that would be missed without a separate visitor model as these travel patterns are very unique between the locations of hotel rooms, and the location of sites that attract visitor trips. The inclusion of this model should improve the modeling and forecasting of travel within the FBRMPO region, and in particular, around areas with a high concentration of visitor travel.

Highway Assignment

Prior to the final highway assignment step in the overall FBRMPO model, the visitor trips by time period will be combined with the resident trips in the appropriate time period. During highway assignment traffic counts near significant tourist attractions were used to gain further insight into visitor travel and adjustments to rates and parameters were made where necessary.

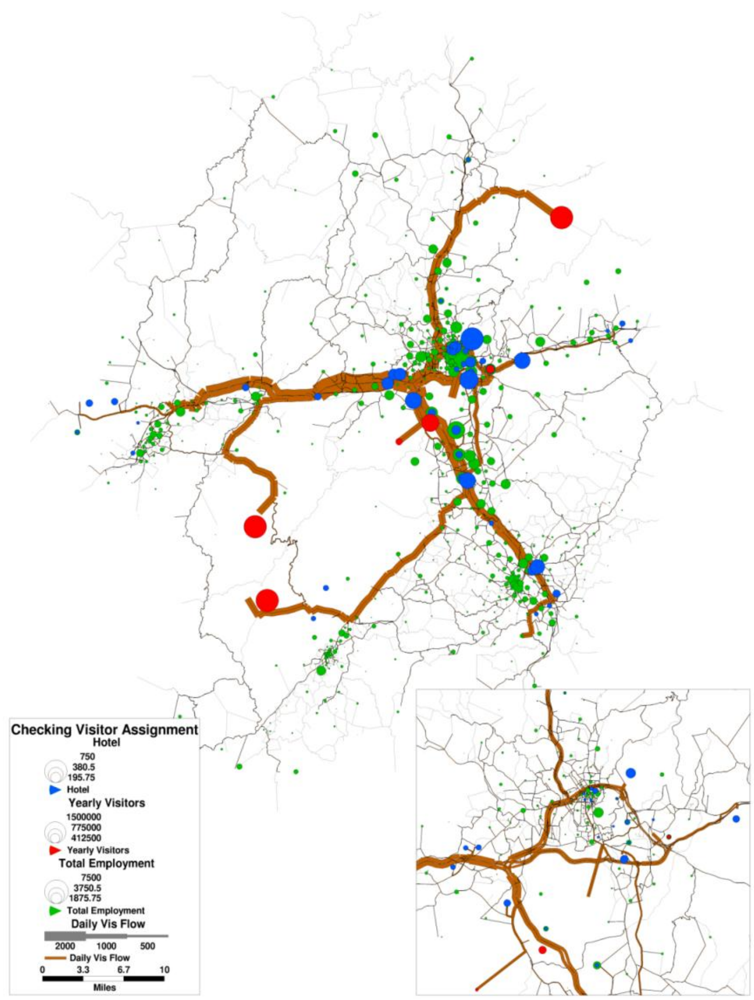


Figure 47 Visitor Model Trip Flows Compared to Key Visitor Sites

COMMERCIAL VEHICLES

This section describes the implementation of the commercial vehicle model for the FBRMPO. In an urban area commercial vehicles can account for increased congestion on major facilities. In most instances the travel behavior of commercial vehicles is much different from person trip behavior, including differences in trip rates and trip distribution. In an effort to better capture the commercial vehicle element of traffic in the FBRMPO model, a separate commercial vehicle model was developed. The model includes commercial vehicle trip estimation for three commercial vehicle types: commercial autos and vans (CV1), commercial pickups (CV2), and commercial trucks (CV3).

TRIP GENERATION

In the absence of field collected commercial vehicle data, the trip generation approach follows that outlined in the Federal Highways 2007 Quick Response Freight Manual II[1] (QRFM). In this case, the method assumes that productions equal attractions and one set of rates is provided. The employment rates implemented for the FBRMPO model were adapted from the Triad, North Carolina Regional Model. The household rates are from the Triangle Cordon Survey. The applied rates for CV1, CV2, and CV3 are summarized in Table 122. With the exception of office and service employment, the CV3 rates are much lower than truck rates reported in the QRFM. This finding follows experience from other modeled regions regarding the direct application of the QRFM rates and validation of the resulting truck trip assignment to truck counts. Experience has shown that the direct application of the QRFM truck trip rates leads to very high truck trip assignments as compared to truck counts in the highway network. The truck trip rates reported in the QRFM were derived from a single survey conducted in Phoenix, Arizona. The truck trip rates applied for the FBRMPO model were validated by comparing the final model assigned truck trips to the observed truck traffic counts.

Table 122 Commercial Vehicle Trip Rates

Vehicle Type	HH	Industry	Retail	High Traffic Retail	Service	Office
Autos/Vans (CV1)	.023	0.014	0.035	0.004	0.020	0.044
Pickups (CV2)	.047	0.013	0.056	0.016	0.033	0.031
Trucks (CV3)	.008	0.089	0.185	0.006	0.065	0.078
QRFM Trucks – 4 tire	0.25	0.94	0.89	0.89	0.44	0.44
QRFM Single Unit Trucks	0.10	0.24	0.25	0.25	0.07	0.07

The trip generation model was applied using the rates summarized in Table 122 and the socio-economic data provided by the MPO. The results from this application are shown in Table 123. Estimated truck trips make up approximately 42% of the internally generated commercial vehicle trips, for a total of 18,382 estimated truck trips. This number compares favorably to the internally generated truck trips in the North Carolina Statewide Transportation Model.

[1] Publication No. FHWA-HOP-08-010

Table 123 Estimated Commercial Vehicle Trips

Vehicle Type	Trips
Autos/Vans (CV1)	10,145
Pickups (CV2)	14,896
Trucks (CV3)	18,385
Total	43,426

TRIP DISTRIBUTION

The trip distribution model for the commercial vehicle trip purpose uses the NHB gamma coefficients documented in the NCDOT Small Area Travel Demand Model Procedures Manual as documented in Table 124 below.

Table 124 Default Gamma Coefficients

Vehicle Type	a	b	c
CV1	4.6750	0.2916	0.1390
CV2			
CV3			

The trip distribution model was applied using the default coefficients summarized in Table 124 and the results are shown in Table 125. The average travel time for each CV purpose is within a reasonable range of the average travel time observed in the Triad survey; however, several iterations were performed to better match those average travel times, especially for CV3 where the initial travel time for the FBRMPO model is a couple of minutes lower than the observed Triad data. In general, trip lengths for trucks are longer than those reported for autos, pickups, and vans.

Table 125 Initial Commercial Vehicle Trip Distribution Statistics

Vehicle Type	FBRMPO Estimated Average Travel Time	FBRMPO % Intra-zonal	Triad Observed Average Travel Time
CV1	13.32	8.1	12.82
CV2	13.86	7.3	13.81
CV3	12.02	7.4	14.56

The final gamma coefficients are summarized in Table 126, and the final trip distribution statistics are shown in Table 127. The final trip length distributions for each commercial vehicle type are shown in Figure 48.

Table 126 Final Gamma Coefficients

Vehicle Type	a	b	c
CV1	4.675	-0.115	0.139
CV2	4.675	-0.22	0.139
CV3	4.675	-0.665	0.139

Table 127 Final Commercial Vehicle Trip Distribution Statistics

Vehicle Type	FBRMPO Estimated Average Travel Time	FBRMPO % Intra-zonal
CV1	12.85	5.2
CV2	13.81	5.5
CV3	14.57	5.1

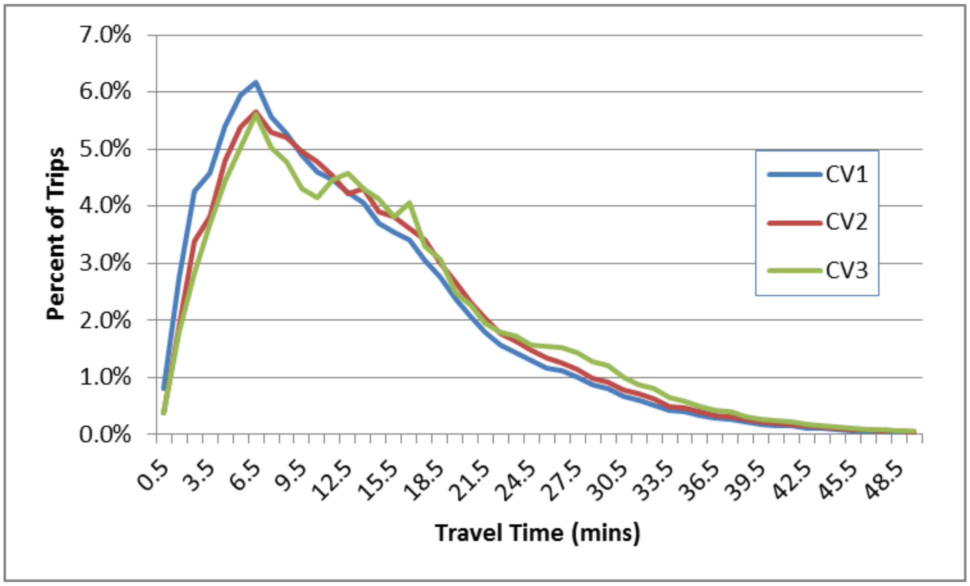


Figure 48 FBRMPO Commercial Vehicle Trip Length Distributions (min)

Reasonableness Checking

Reasonableness checks were performed on the model results by assigning the commercial vehicle trips from the commercial vehicle model and the commercial vehicle trips from the external trip model to the highway network. Comparisons of the truck flows were made against truck counts provided by the North Carolina Department of Transportation Traffic Survey Group. This comparison showed that the truck flows are slightly low, but still within an acceptable range.

EXTERNAL TRIPS

External trips are defined as trips in the FBRMPO region that have at least one endpoint outside the model boundary. Trips are stratified as external-external (EE), internal-external (IE), and external-internal (EI). All travel demand at the external stations is expressed as vehicle trips, so no mode choice estimation or application is needed for this model. The three stratifications used in the FBRMPO model are defined below:

1. External-External (EE) – trips with both ends outside the FBRMPO region, passing through the region
2. External-Internal (EI) – trips with the home end of the trip outside the FBRMPO region and destinations inside the region
3. Internal-External (IE) – trips with the home end of the trip inside the FBRMPO region and destinations outside the region

The external trip model for the FBRMPO region is estimated and developed from the AirSage mobile phone location data collected for the region. The AirSage data collection, processing, and analysis are described in more detail under a separate technical memorandum available upon request from NCDOT. The external trip models include trip generation, trip distribution, and time of day. The trip generation stage uses collected or forecast traffic volumes at the external stations along with traffic analysis zone (TAZ) level data on households and employment. Prior to highway assignment the external trips are combined with other trip purposes for the final traffic assignment.

DATA

AIRSAGE DATA

Cellular phone location data collected by AirSage, Inc. for observed weekday travel patterns during the month of May 2013 forms the basis for the FBRMPO external trip model. The data were collected at a sub-district level, but disaggregated to model TAZs and external stations following the procedure described in the "FBRMPO AirSage Data Analysis" technical memorandum dated February 19, 2014.

EXTERNAL STATIONS

There are 29 external stations in the FBRMPO model. Table 128 provides a summary of the external stations along with the average weekday traffic count (AWDT) for the external station.

Table 128 FBRMPO External Stations

Node ID	Road On	Description	AWDT
644	US 19	East of Blue Ridge Pkwy	3,924
645	US 23	Between SR 1157 and SR 1156	20,264
646	US 64	At Henderson Co. Line	2,822
647	I-40	At Buncombe Co. Line (E of SR 1407)	31,078
648	SR 1407	N of I-40	216
649	Old US 64	At Buncombe Co. Line	847
650	SR 2793	At Buncombe Co. Line	206
651	US 19	At Madison Co. Line	7,608
652	SR 1510	Ad Madison Co. Line	102
653	SR 1530	At Madison Co. Line	278
654	NC 197	At Buncombe Co. Line	70
655	Blue Ridge Parkway	West of NC 128	803
656	Blue Ridge Parkway	West of NC 215	271
657	NC 281	At Transylvania Co. Line E of SR 1763	170
658	US 64	At Transylvania Co. Line W of SR 1152	3,143
659	NC 281	At State Line	599
660	US 178	At State Line	542
661	US 276	At State Line	1,022
662	US 25	At State Line	13,358
663	US 176	At State Line	2,967
664	I-26	At State Line	38,842
665	SR 1602	W OF SR 1706	567
666	SR 2788	At Buncombe Co. Line	403
667	I-40	FROM TN LINE TO EXIT 7	20,144
668	US 25	At Madison Co. Line, W of SR 130	745
669	NC 208	At Madison Co. line	1,191
670	NC 212	At Madison Co. Line	320
671	I-26	At Madison Co. Line	7,660
672	Flag Pond Rd	At I-26 N	Missing

EE Trips

Also discussed at length in the technical memorandum on the analysis of the AirSage data is the development of the through trip tables for the FBRMPO region. AirSage data was used to directly develop a through trip table for the region, starting with the external sub-district flows obtained directly from AirSage and applying a disaggregate procedure to allocate flows to specific external stations. Readers should refer to the above referenced memo available by request from NCDOT for technical details.

IE/EI Trip Model

This section describes the development of the IE/EI trip model.

Trip Generation

The simplifying assumption of the IE/EI model is that all productions are made at the external stations. Trip attractions are based on employment by employment type and total households by TAZ. Including households in the attraction equation recognizes that some external trips are the results of trips produced by households in the region, not just employment attractions for households outside of the region.

The AirSage data provides the trip end data necessary for estimating an IE/EI trip attraction model. Given the large number of observed trip ends in the AirSage data, the trip attraction model could be estimated at the sub-district level. In total, there are 139 internal sub-districts, see Figure 49.

For each sub-district, the underlying socio-economic data was aggregated and a simple linear regression model was estimated using the statistical package R. The general form of the regression equation is shown below:

$$Attractions = 0 + \beta_1 HH + \beta_2 Ind + \beta_3 Ret + \beta_4 Off + \beta_5 Ser + \beta_6 HTRet$$

Multiple linear regression attempts to determine the relationship between a response variable, like trip attractions, and the independent variables related to it, like employment by type. In addition, each coefficient measures the effect of its independent variable after accounting for the effects of all other independent variables.

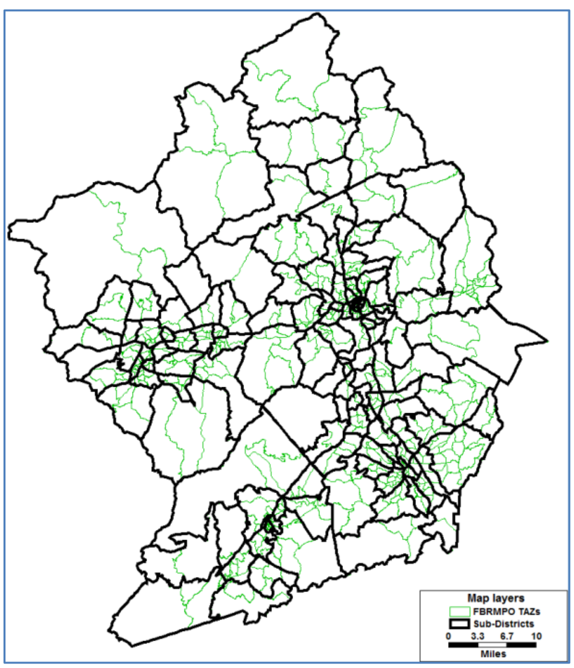


Figure 49 FBRMPO Sub-Districts

The results of the initial model estimation are shown in Figure 50.

```
Call:
lm(formula = TotExtTrips ~ 0 + HH + Ind + Off + Ser + Ret + HTRet,
    data = tbl)

Residuals:
    Min      1Q  Median      3Q     Max
-1127.8  -374.4  -191.8   177.6  4894.9

Coefficients:
      Estimate Std. Error t value Pr(>|t|)
HH     0.24299    0.05410   4.492 1.58e-05 ***
Ind    0.31546    0.16235   1.943   0.0542 .
Off    0.53922    0.24366   2.213   0.0287 *
Ser    0.03453    0.09333   0.370   0.7120
Ret    0.48422    0.33461   1.447   0.1503
HTRet  0.03938    0.37695   0.104   0.9170
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 779.8 on 126 degrees of freedom
Multiple R-squared:  0.545,     Adjusted R-squared:  0.5233
F-statistic: 25.15 on 6 and 126 DF,  p-value: < 2.2e-16
```

Figure 50 IE/EI Attraction Model – Initial Results

In this first model, some of the individual employment types had small coefficients with large standard error. This suggested combining them. After testing various combinations of employment groupings in the model estimation, the final model selected was:

$$Attractions = 0 + \beta_1 HH + \beta_2 Ind + \beta_3 NonInd$$

The final model results are provided in Figure 51. All estimated coefficients are of the correct sign and were found to be statistically significant at high confidence levels. The final estimated coefficient values are summarized in Table 129, along with a comparison of estimated coefficients from the 1997 Triangle Regional Model (TRM) and from the North Carolina Small Area Model (NCSAM). All of the rates compare favorably with the exception of the attraction rate on industry from the 1997 TRM survey. This finding is not surprising given the lesser influence of industrial employment on external trips in the Triangle region as compared to the FBRMPO region.

```
Call:
lm(formula = TotExtTrips ~ 0 + HH + Ind + NonInd, data = tbl)

Residuals:
    Min      1Q  Median      3Q     Max
-1203.2  -394.6  -147.0   181.3  5041.6

Coefficients:
       Estimate Std. Error t value Pr(>|t|)
HH      0.23455    0.05321   4.408 2.17e-05 ***
Ind     0.37392    0.15704   2.381  0.01873 *
NonInd  0.18186    0.05940   3.062  0.00268 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 785.9 on 129 degrees of freedom
Multiple R-squared:  0.5267,    Adjusted R-squared:  0.5157
F-statistic: 47.85 on 3 and 129 DF,  p-value: < 2.2e-16
```

Figure 51 IE/EI Attraction Model – Final Results

Table 129 Comparison of IE/EI Attraction Coefficients

Variable	FBRMPO AirSage Estimated Coefficient	1997 TRM OD Survey Estimated Coefficient	NCSAM Default Rates
Industry	0.37	0.06	0.34
Non-Industry	0.18	0.27	NA
Households	0.24	0.25	0.33

The FBRMPO AirSage estimated coefficients in Table 129 were applied to the TAZ level data and compared against the observed trip ends. The direct application resulted in a slight over-estimation in the number of IE/EI trips. Since traffic counts are used as the overall control for trips at the external stations, the original rates were scaled such that the estimated trip ends matched the observed traffic counts (IE/EI trips only). The final FBRMPO IE/EI attraction coefficients are provided in Table 130.

Table 130 Final FBRMPO IE/EI Attraction Coefficients

Variable	AirSage Original Estimated Coefficient	AirSage Final Calibrated Coefficient
Industry	0.37	0.36
Non-Industry	0.18	0.17
Households	0.24	0.22

TRIP DISTRIBUTION

The trip distribution model for the IE/EI trips takes the form of the gravity model. The gravity model links the trip productions from the trip generation step with the trip attractions from the trip generation step using the off peak travel time from the highway network. The mathematical form of the gravity model is as follows:

$$T_{ij} = P_i * \frac{A_j * F_{ij} * K_{ij}}{\sum_{k=1}^{zones}(A_k * F_{ik} * K_{ik})}$$

where:

T_{ij} = the number of trips from zone i to zone j
P_i = the number of trip productions in zone i
A_j = the number of trip attractions in zone j
F_{ij} = the friction factor between zone i and zone j (associated with the travel impedance from zone i to zone j)
K_{ij} = the socioeconomic or physically related factor for all movements between zone i and zone j

The friction factors are inversely related to the spatial separation of the TAZs. As the travel time between TAZs increases, the friction factor decreases. The gamma function was used to estimate the friction factors for the IE/EI gravity model. The mathematical form of the gamma function can be stated as follows:

$$F_{ij} = a * t_{ij}^{b} * e^{c * t_{ij}}$$

Where:

F_{ij}	=	friction factor from TAZ i to TAZ j
a, b, c	=	model coefficients
t_{ij}	=	travel time, or impedance from TAZ i to TAZ j
e	=	base of the natural logarithms

The gamma function is applied by factoring the current iteration friction factors for each time interval in the trip length frequency distribution by the ratio of the observed number of trips in the time divided by the current number of estimated trips in the time interval. The revised friction factors are used as independent variables in a linear regression to estimate the revised gamma function model coefficients for the next iteration. The key to the last step is the transformation of the gamma function to a log-linear function. Rather than applying this process manually, the TransCAD auto-calibration routine was iteratively run to adjust the parameters of the gamma function (a, b, and c) in order to closely match the observed trip length distribution, shown in Figure 52. The goal is to achieve average travel time results from the model that are within +/- 5% of the observed data. The shape of the estimated trip length frequency curve is also compared to the observed distribution for best fit. Following the automated TransCAD procedure, several manual adjustments were made to the coefficients to refine the calibration results. The final coefficients along with the estimated and observed average travel time are presented in Table 131. The final estimated trip length distribution as compared to observed trip length distribution is shown in Figure 53.

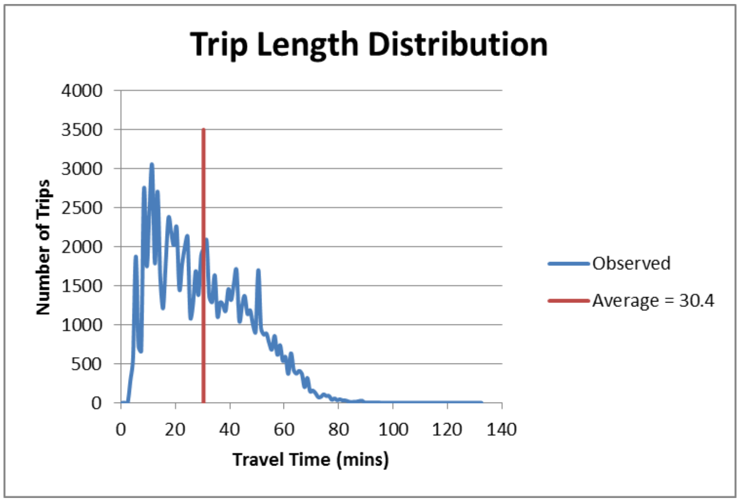


Figure 52 Observed Trip Length Frequency Distribution – IE/EI Trips

Table 131 Final Gamma Coefficients and Average Travel Time

Coefficients	**Observed**
a	1.0689
b	-0.4000
c	0.0666
Average Travel Time	
Observed	30.4
Estimated	30.0
% difference	-1.23%

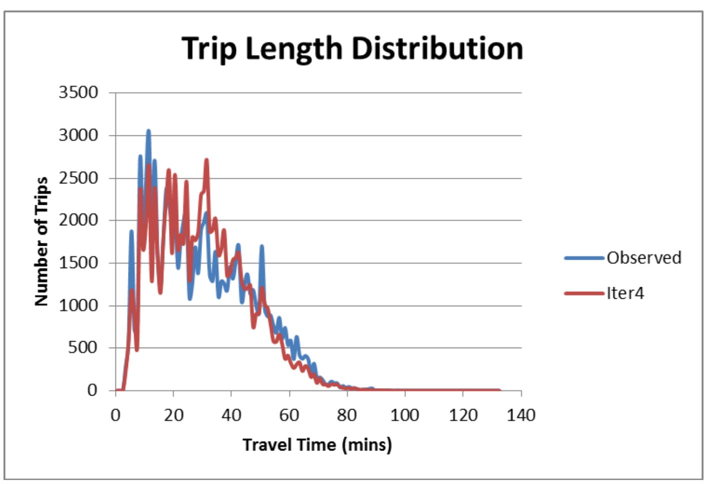


Figure 53 Estimated vs. Observed Trip Length Frequency Distribution – IE/EI Trips

TIME OF DAY MODEL

The output of trip distribution is a daily trip table in production/attraction (PA) format. Prior to highway assignment, these PA trip tables must be converted to origin/destination (OD) trip tables by time of day. The FBRMPO model uses four periods: AM (6AM – 9AM), Midday (9AM-3PM), PM (3PM-6PM), and Night (6PM-6AM). Because the AirSage survey data is in OD format, not PA format, this data cannot be used to directly develop directional factors by time of day as these factors are used to convert the PA trip tables to an OD trip table. Instead, the directional factors by time of day for the IE/EI trips are borrowed from the Triad region and summarized in Table 132. Factors for the EE trips are derived directly from the AirSage data since the EE trips are already in OD format and balanced directionality by time of day is assumed.

Table 132 Directional Split Factors by Time of Day

	AM	PM	MD	NT	Daily
EI	0.16	0.20	0.03	0.11	0.50
IE	0.03	0.28	0.08	0.11	0.50
EE	0.14	0.46	0.15	0.25	1.00

NON-RESIDENT NON-HOME-BASED TRIPS

Additional trips made within the study area by non-residents are called non-home based non-resident trips (NHBNR). These trips are not reflected in the household travel survey because they are non-resident trips. They may be quantified from an external survey if the survey includes questions about additional trips made by travelers to the region. Advances in the collection of AirSage data also support data processing that can help determine the number of additional trips made by non-residents of a region. This enhancement is not an element of the base data collection, but can be added for an additional fee. This enhancement was not purchased for the FBRMPO data due to budget constraints. Instead, the trips were estimated as a percentage of the EI trips. In this case it is assumed that the non-residents make NHB trips at a similar rate as residents.

For the FBRMPO region, the percentage of NHB resident trips within the study area is 35% of the total trips in the study area. Non-residents were assumed to make NHB trips at a slightly lower rate than residents, 30% instead of 35%. The NHBNR trips were then calculated by multiplying 0.30 times the number of EI trips. The AirSage data was used to determine the number of EI trips (45,763). This value was multiplied by 0.30 to estimate the number of NHBNR trips, for a total of 13,729. These trips were allocated to each TAZ based on the relative distribution of the IE/EI trip attractions. These NHBNR trips are then added to the resident NHB trip productions and distributed as resident trips using the destination choice model.

FINAL EXTERNAL STATION DATA

Table 133 provides a summary of the final external station data including the number and percent of EE trips and IE/EI trips for each external station.

Table 133 Final FBRMPO External Stations and Supporting Data

Node ID	Road On	Description	AWDT	EE Trips	% EE	IE/EI Trips	% IE/EI
644	US 19	East of Blue Ridge Pkwy	3,924	1,087	27.7	2,837	72.3
645	US 23	Between SR 1157 and SR 1156	20,264	5,612	27.7	14,652	72.3
646	US 64	At Henderson Co. Line	2,822	1,335	47.3	1,487	52.7
647	I-40	At Buncombe Co. Line (E of SR 1407)	31,078	6,924	22.3	24,154	77.7
648	SR 1407	N of I-40	216	48	22.3	168	77.7
649	Old US 64	At Buncombe Co. Line	847	189	22.3	658	77.7
650	SR 2793	At Buncombe Co. Line	206	97	47.3	109	52.7
651	US 19	At Madison Co. Line	7,608	2,818	37	4,790	63
652	SR 1510	Ad Madison Co. Line	102	38	37	64	63
653	SR 1530	At Madison Co. Line	278	103	37	175	63
654	NC 197	At Buncombe Co. Line	70	26	37	44	63
655	Blue Ridge Pkwy	West of NC 128	803	297	37	506	63
656	Blue Ridge Pkwy	West of NC 215	271	75	27.7	196	72.3
657	NC 281	At Transylvania Co. Line E of SR 1763	170	28	16.5	142	83.5
658	US 64	At Transylvania Co. Line W of SR 1152	3,143	519	16.5	2,624	83.5
659	NC 281	At State Line	599	321	53.6	278	46.4
660	US 178	At State Line	542	290	53.6	252	46.4
661	US 276	At State Line	1,022	547	53.6	475	46.4
662	US 25	At State Line	13,358	10,020	75	3,338	25
663	US 176	At State Line	2,967	936	31.5	2,031	68.5
664	I-26	At State Line	38,842	12,251	31.5	26,591	68.5
665	SR 1602	W OF SR 1706	567	179	31.5	388	68.5
666	SR 2788	At Buncombe Co. Line	403	90	22.3	313	77.7
667	I-40	From TN Line to Exit 7	20,144	12,548	62.3	7,596	37.7
668	US 25	At Madison Co. Line, W of SR 130	745	464	62.3	281	37.7
669	NC 208	At Madison Co. line	1,191	846	71	345	29
670	NC 212	At Madison Co. Line	320	104	32.4	216	67.6
671	I-26	At Madison Co. Line	7,660	2,481	32.4	5,179	67.6
672	Flag Pond Rd	At I-26 N	No Count	-	-	-	-

TIME OF DAY

The time of day model estimates the hourly and time period distribution of daily travel. Using diurnal factors, the time of day model transfers the 24-hour mode choice trip tables in production-attraction (PA) format into hourly trip tables in origin-destination (OD) format. The trip assignment model uses these tables to make time period trip assignments.

The diurnal factors consist of each period's share of the daily travel, and are based upon the FBRMPO Household Travel Survey. These diurnal factors are segmented by trip purpose. The time of day model also uses separate diurnal factors and directional split factors for commercial vehicles and external trips. The factors for commercial vehicles were borrowed from the Triad region of North Carolina, while the external trip factors were informed by both the AirSage survey data and the Triad data.

METHODOLOGY

The calculation of diurnal factors for trip purposes uses individual trips taken from the household survey data. These individual trips are segmented by trip purpose and whether or not the trip is a Production-to-Attraction (PA) or Attraction-to-Production (AP).

DIURNAL FACTORS BY TRIP PURPOSE

The diurnal factors for each trip purpose were estimated using the 2013 FBRMPO Household Travel Survey. Each individual trip record was segmented into one of the following trip purposes using origin and destination responses:

- Home-Based Work (HBW)
- Home-Based Shop (HBS)
- Home-Based School (SCH)
- Home-Based Other (HBO)
- Home-Based University (HBU)
- Non-Home-Based (NHB)

Each trip record was assigned one of two directions: PA or AP. Home-based trips with home as destination were designated as AP trips, home-based trips with other destinations were assigned as PA trips. All non-home-based trips were nominally designated as PA trips, and the PA/AP split was set at 0.5/0.5 for each hour.

Figures 54 - 59 show the diurnal distribution for each trip purpose. Note that the AP direction does not apply for non-home-based trips.

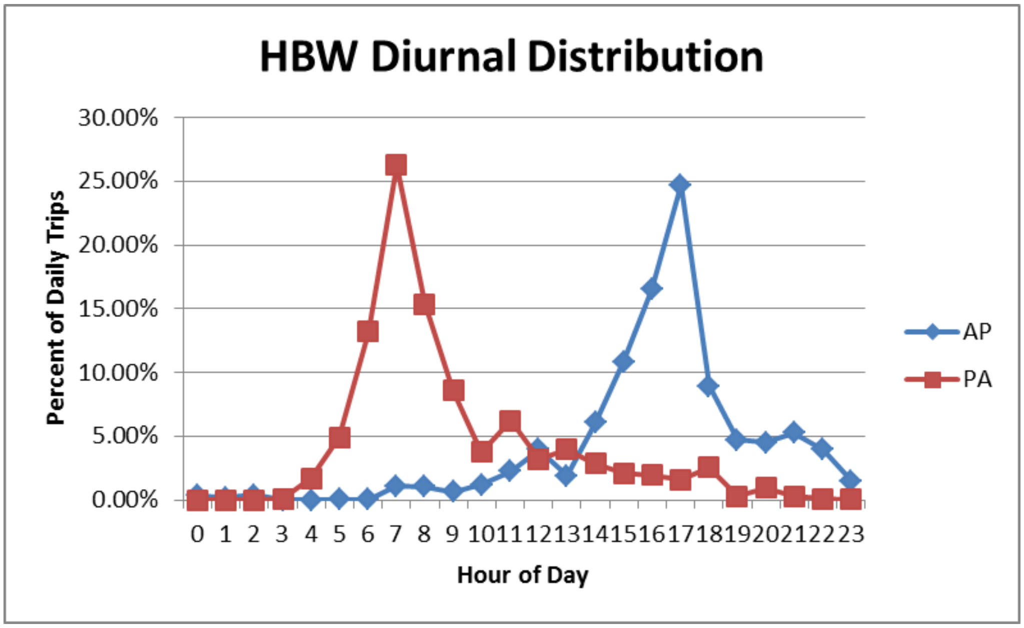


Figure 54 Diurnal Distribution of HBW Trips

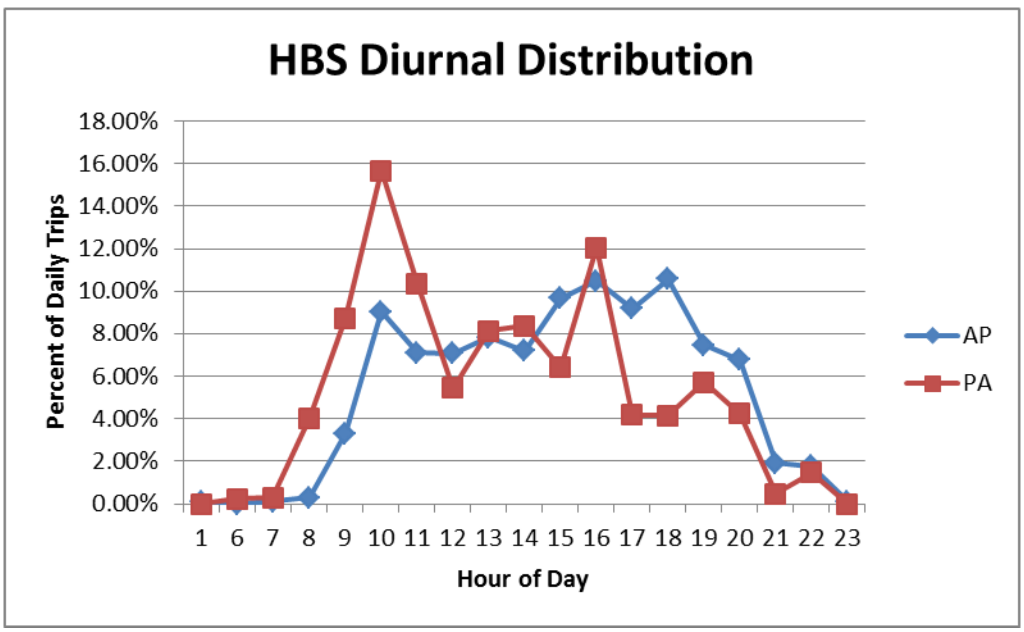


Figure 55 Diurnal Distribution of HBS Trips

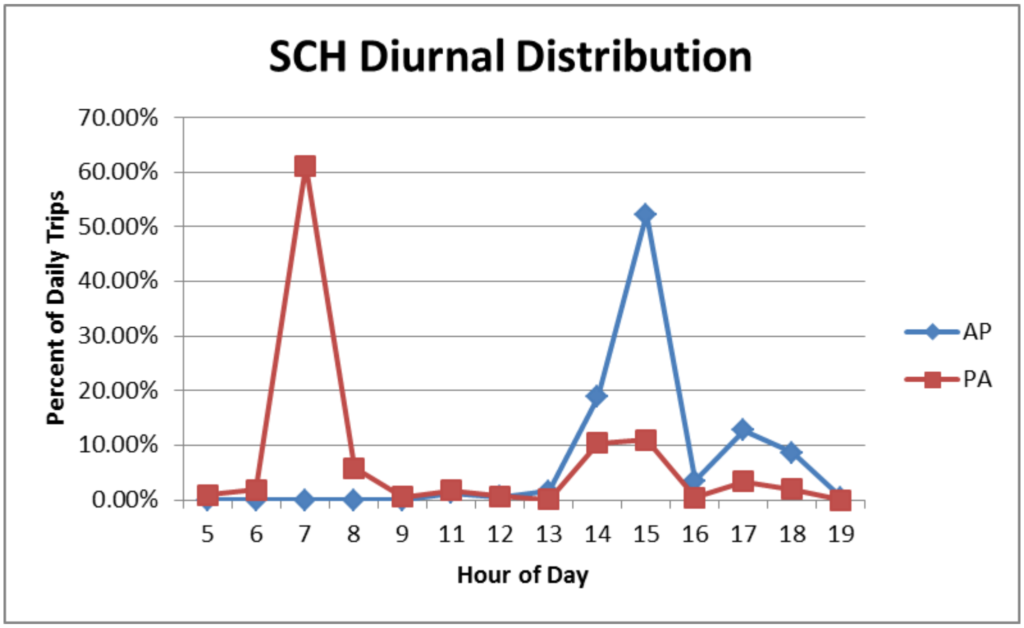


Figure 56 Diurnal Distribution of SCH Trips

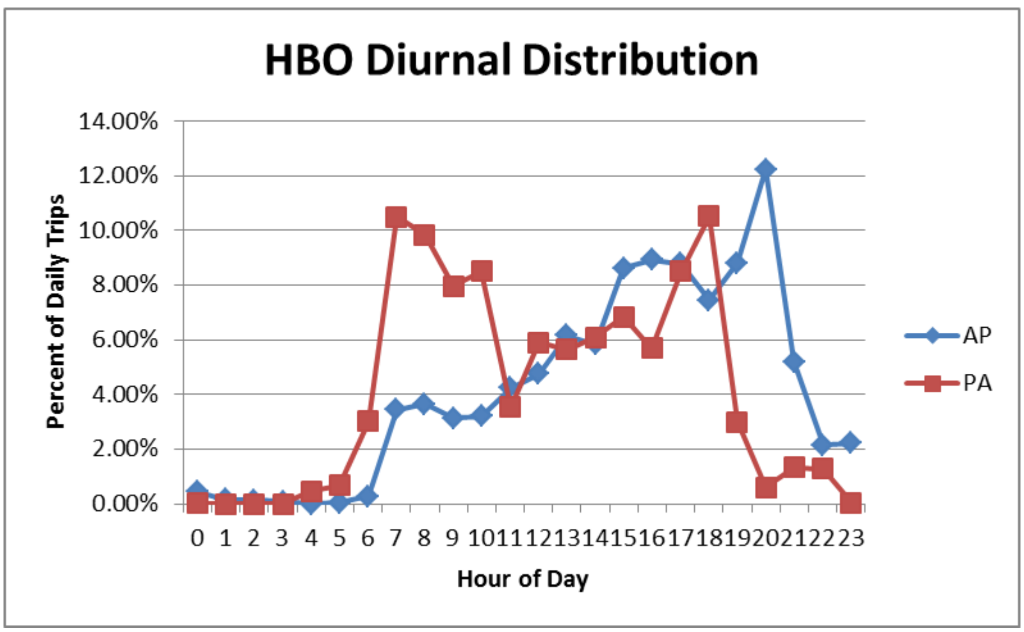


Figure 57 Diurnal Distribution of HBO Trips

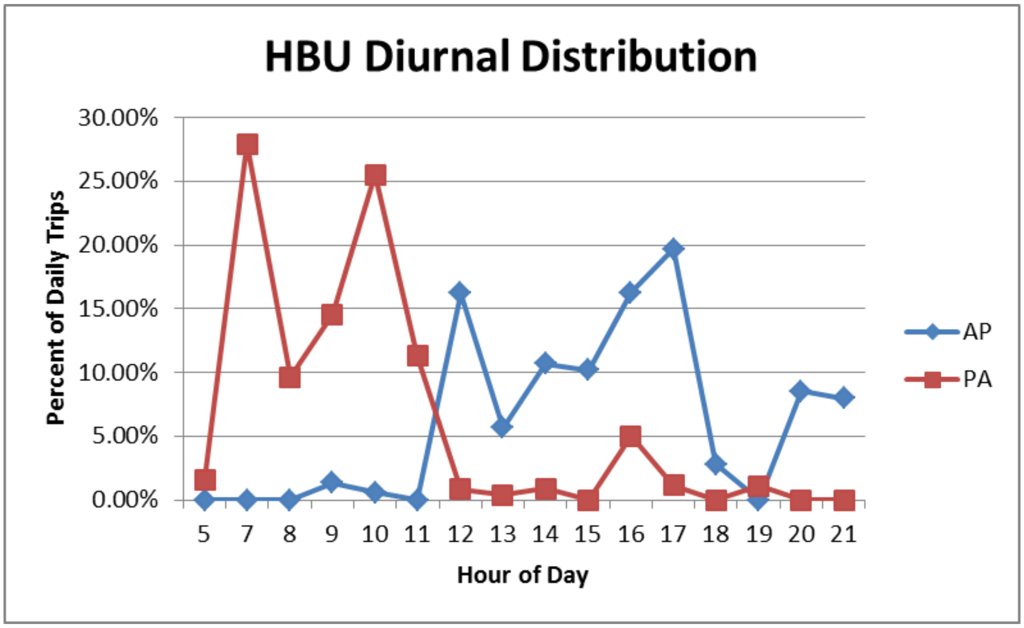


Figure 58 Diurnal Distribution of HBU Trips

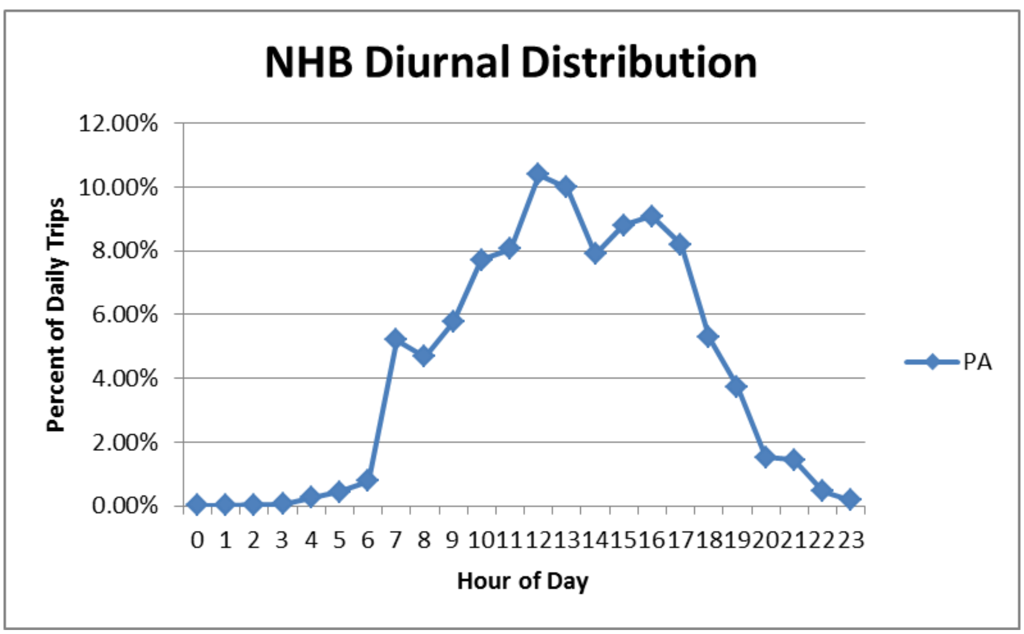


Figure 59 Diurnal Distribution of NHB Trips

Determination of the Peak Periods

The peak periods for the model were determined based on the peaking characteristics observed in the household survey data. The following guidelines were considered in selecting the peak periods:

- Three percent or more of the total daily trips should occur in the time period
- Home-based work trips should account for the majority of the trips

Based on a review of the distribution of trips by trip purpose across the data, the time periods summarized in Table 134 were selected.

Table 134 Time Period Summary

Time Period	Time Range	Period Length (hours)
AM	6:00am – 8:59am	3
Midday (MD)	9:00am – 2:59pm	6
PM	3:00pm – 5:59pm	3
Night (NT)	6:00pm – 5:59am	12

Time of Day and Directional Split Factors for Resident Trips

Time of day and directional split factors were developed from the diurnal distributions by trip purpose using the time period definitions given in the previous section. Table 135 shows the final time of day and directional split factors used for the FBRMPO model.

Table 135 Time of Day and Directional Split Factors

Purpose	Direction	AM	MD	PM	NT	Daily
HBW	From Home	28.6%	12.9%	5.9%	2.6%	50.0%
	To Home	0.8%	6.7%	15.4%	27.1%	50.0%
SCH	From Home	35.4%	2.0%	0.0%	12.6%	50.0%
	To Home	0.0%	10.6%	6.0%	33.4%	50.0%
HBS	From Home	4.7%	27.1%	7.2%	11.0%	50.0%
	To Home	0.2%	19.6%	14.9%	15.3%	50.0%
HBU	From Home	11.6%	32.2%	2.0%	4.2%	50.0%
	To Home	0.0%	13.2%	12.1%	24.8%	50.0%
HBO	From Home	12.1%	24.8%	5.8%	7.4%	50.0%
	To Home	2.4%	11.7%	22.8%	13.1%	50.0%
NHB	From Home	5.3%	27.0%	4.1%	13.6%	50.0%
	To Home	5.3%	27.0%	4.1%	13.6%	50.0%

Totals may not match exactly due to rounding

TIME OF DAY AND DIRECTIONAL SPLIT FACTORS FOR COMMERCIAL VEHICLES

Diurnal factors for commercial vehicles were borrowed from work completed in the Triad region using Commercial Vehicle survey data. In a trip based model, commercial vehicle trips behave much like NHB trips so the direction split factors are equal for all time periods. Table 136 summarizes the time of day and directional split factors applied to the commercial vehicle trip tables.

Table 136 Time of Day and Directional Split Factors for Commercial Vehicles

Purpose	Direction	AM	MD	PM	NT	Daily
Commercial Vehicles	From	4.58%	16.52%	16.34%	12.56%	50.0%
	To	4.58%	16.52%	16.34%	12.56%	50.0%

TIME OF DAY AND DIRECTIONAL SPLIT FACTORS FOR EXTERNAL TRIPS

Factors for the internal-external/external-internal (IE/EI) trips were also borrowed from previous work completed in the Triad. These factors could not be derived from the AirSage data because this data is already in origin-destination format, not production-attraction format. The AirSage data was used as the starting point in the development of the external-external time of day factors. The AirSage data was available for AM, PM, and OP. The Triad data was used to inform the breakdown of the OP trips into MD and NT. The final factors for the external trips are summarized in Table 137.

Table 137 Time of Day and Directional Split Factors for Commercial Vehicles

Purpose	Direction	AM	MD	PM	NT	Daily
IE/EI	IE	3%	28%	8%	11%	50.0%
	EI	16%	20%	3%	11%	50.0%
EE	NA	14.1%	45.8%	15.4%	24.7%	100%

Highway and Transit Assignment

The final step in the travel demand model is trip assignment. This is the process of assigning the zone to zone trips to the individual links in the highway network and the transit route system. This step is performed iteratively with overall model calibration and validation. When overall model calibration and validation is achieved, as measured by established performance measures, the trip assignment step provides the data needed for: 1) testing alternative transportation plans; 2) establishing priorities between different transportation investment strategies; 3) analyzing alternative locations for roadway improvements; and 4) forecasting design volumes needed to adequately design and construct new roadway facilities. The reliability of the output from this step is dependent upon the reliability of all the proceeding steps.

Highway Assignment

The algorithms used in traffic assignment attempt to replicate the process of choosing the best path between a given origin and destination. For the FBRMPO model, the algorithm used for assignment is an equilibrium assignment. This is a widely accepted, best practice approach that produces link loadings by optimally seeking user-equilibrium path loadings reflecting user path choices as influenced by congestion on the network. During the assignment process, the trip table is assigned to the highway network over multiple iterations. At the end of the iteration, link travel times are recalculated using the total link demand and compared to the link travel times of the previous iteration. The aggregate change of link travel times between the current iteration and the previous is compared against the convergence criteria. Thus, the number of iterations is determined by a user defined closure parameter (set to 0.0001 for the FBRMPO model) or for a maximum number of iterations (set to 500 for the FBRMPO model). The final assignment represents an optimum combination of previous assignments using the Frank-Wolfe algorithm.

For a given iteration, the volume-delay function is used to update the link speeds based on the previous iteration's vehicle demand and the link capacity. The Bureau of Public Roads (BPR) function was used for the FBRMPO model. The formulation of this function is shown below. The corresponding alpha and beta parameters by facility type used for the FBRMPO model are shown in Table 138.

$$T_c = T_0 * (1 + \alpha(\frac{V}{C})^{\beta})$$

Where:

T_c = congested link travel time
T_0 = initial link (free flow) travel time
V = assigned traffic volume
C = link capacity
α, β = calibration parameters

Table 138 FBRMPO Model Alpha and Beta Parameters

Facility Type	Alpha	Beta
Freeway	0.83	5
Expressway	0.83	5.5
Boulevard	0.15	4.5
Major Thoroughfare	0.15	4.5
Minor Thoroughfare	0.9	5
Rural Highway	0.9	5
Centroid Connector	N/A	N/A

Highway trip assignment is performed separately for the AM peak period (6:00 AM – 9:00 AM), Midday period (9:00 AM – 3:00 PM), the PM peak period (3:00 PM – 6:00 PM), and the Night period (6:00 PM – 6:00 AM). At the end of the assignment procedure, the time period assignments are summed to produce a daily traffic assignment.

INITIAL TRIP ASSIGNMENT RESULTS

There are three basic comparisons made when comparing actual traffic counts to estimated trip assignment results: 1) global measures of vehicle miles traveled (VMT) and average speed by facility type; 2) comparisons by screenline, volume group, and facility type, and 3) link level comparisons.

As expected, the initial highway assignment was out of range, and modifications and adjustments were necessary to improve the overall model calibration and validation. The major modifications and adjustments implemented are summarized below:

1. Initial assignment was low overall. Trip rates were increased slightly using guidance from recent literature documenting under reporting of trips from GPS surveys. After several iterations, the overall assignment measures were within an acceptable range.
2. Assignment measures by facility type were out of range. Iterative modifications were made to the volume delay function parameters by facility type to improve results.
3. Assignment results were low for all of the downtown districts, where travel demand is heavily influenced by visitor travel. The visitor model was modified to include Social-Recreational (HBSocRec) trip attractions to the downtown districts and other special districts within the region. The initial attraction rate was transferred, then iteratively adjusted to better reflect travel in these special districts. The visitor model was also modified to include visitor trip productions for bed and breakfast, cabins, and resorts, in addition to hotels/models.
4. The traffic flow around the Biltmore Estate was under represented. Modifications were made to the centroid connectors for the Biltmore Estate and Biltmore Village to better represent the true traffic loading onto the modeled roadway system.
5. Systemwide review of traffic counts, centroid connectors, and posted speeds was performed for all locations where the assignment measures were outside of the reasonable range. Following this review, numerous modifications were made to edit centroid connectors, remove illogical traffic counts, and update posted speed.

6. Recalibration of the mode choice model after introducing an intrazonal constant and a downtown constant to improve transit assignment.
7. Several recalibration runs for trip productions, destination choice, and mode choice were required depending upon the changes made to the upper level models.

FINAL HIGHWAY TRIP ASSIGNMENT RESULTS

Following an iterative calibration and validation process as discussed above, acceptable performance measures were achieved. This section describes the final highway trip assignment results.

Vehicle Miles Traveled (VMT)

At the regional level, comparisons of VMT provide useful information on how well the model understands the magnitude and geographic distribution of travel. Typically, estimated study area VMT should be within 5% of observed VMT. Table 139 summarizes calibrated base year VMT results for the FBRMPO Model. Regional VMT is within 5% and VMT by all facility types is within an acceptable range.

Table 139 Vehicle Miles Traveled by Facility Type

Facility Type	Estimated VMT	Observed VMT	% Deviation
Freeway/Expressway	3,959,010	3,763,551	5%
Arterials (Boulevards, Major Thoroughfares)	1,324,466	1,389,204	-5%
Collectors (Minor Thoroughfares, 2-lane roads)	671,877	638,675	5%
All Facilities	5,955,352	5,791,430	3%

Average Speed by Facility Type

Study area average speeds and speeds by facility type can be generated by dividing the VMT by vehicle hours traveled (VHT) for each time period assignment. In lieu of observed data from a speed survey, this data is reviewed to determine if the observed patterns are logical. Average speed data by time period and facility type are summarized in Table 140.

Table 140 Average Speeds by Time Period and Facility Type

Facility Type	Free Speed	AM	MD	PM	NT	Daily
Freeway/Expressway	63	59	59	57	62	59
Arterials (Boulevards, Major Thoroughfares)	42	40	39	38	40	39
Collectors (Minor Thoroughfares, 2-lane roads)	39	35	35	34	36	35

Screenline and Cutline Comparisons

The FBRMPO model utilizes one screenline and six cutlines:

1. Screenline 1 generally separates the northern and southern counties, running the length of the model region and capturing the north-south flow between the two parts of the region.

2. Cutline 2 runs between Haywood County to the west and Madison and Buncombe counties to the east, capturing the east-west flow of traffic between these regions.
3. Cutline 3 runs between Transylvania and Henderson counties, capturing the east-west flow of traffic between these two counties. Together, cutlines 2 and 3 form a north-south screenline for the region, capturing flow between the eastern and western counties in the region.
4. Cutline 4 runs between Madison and Buncombe counties, capturing the north-south flow of traffic between these two counties.
5. Cutline 5 runs in a north-south direction capturing the major east-west flow of traffic between Asheville and points west.
6. Cutline 6 is located north of Asheville and captures the major north-south flow of traffic between Asheville and points north.
7. Cutline 7 runs in a north-south direction capturing the major east-west flow of traffic between Asheville and Black Mountain.

The screenlines are shown in Figure 60 below.

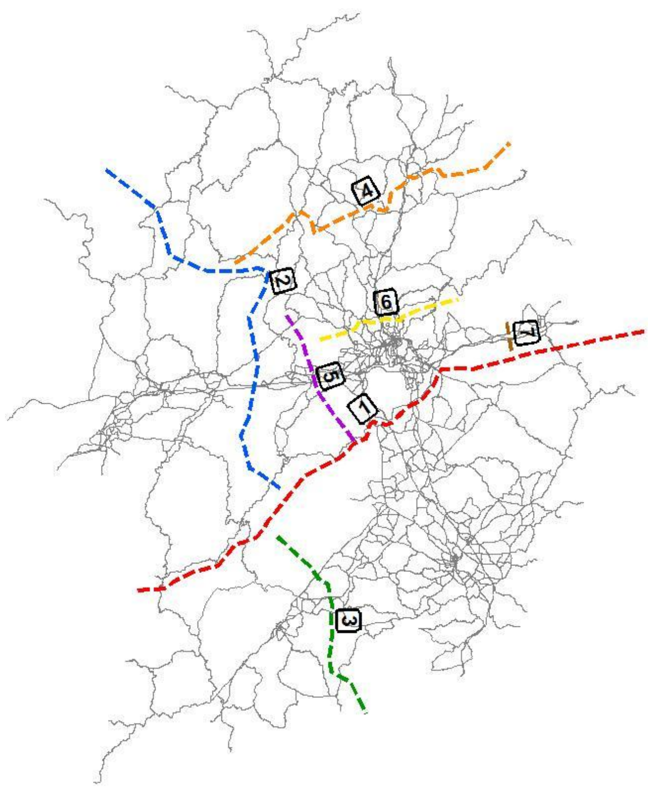


Figure 60 Screenline and Cutline Locations

When properly developed, screenline and cutline comparisons provide a good check on the need for possible adjustments to the trip distribution in the region through adjustments to the destination choice models. If all screenlines are either high or low this may indicate a need to make global adjustments to daily activity patterns. If some screenlines are high while others are low then this may be an indication that changes are needed in the destination choice model, or perhaps point to issues in the underlying transportation network. The screenline results from the initial assignment highlighted problems with traffic flow between Buncombe and Henderson counties, and into central Asheville. Modifications to the visitor's model along with the recalibration of the destination choice improved the screenline results. For the final assignment, all screenlines and cutlines are within an acceptable range. Final results are reported in Table 141.

Table 141 Screenline Results

Name	Total Estimated Flow	Total Observed Flow	% Deviation
1	166,346	174,414	-4.6%
2	68,606	62,051	10.6%
3	29,063	27,139	7.1%
4	45,524	42,827	6.3%
5	99,073	90,541	9.4%
6	146,841	134,225	9.4%
7	53,735	58,623	-8.3%
Total	609,188	589,820	3.3%

Volume Group and Facility Type Comparisons

At the link level, several comparisons were made including link assignment summaries by volume group and difference between estimated and observed through the calculation of the percent root mean square error (%RMSE) by facility type and volume group. The %RMSE is a measure of the variance between the observed and modeled volumes (numerator), normalized by the average of the observed data (denominator) and is expressed as a percent. The formula is as follows:

$$\%RMSE = \frac{(\Sigma_j (\, Model_j - Count_j \,)^2 \,/\, (Number\ of\ Counts - 1)\,)^{0.5}}{(\Sigma_j\, Count_j \;\;/\; Number\ of\ Counts)} * 100$$

Since the differences between estimated and observed are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the %RMSE is most useful when large errors are particularly undesirable. Targets for the %RMSE are in the ranges of 30-40%, depending upon the number of low-volume roadway segments included in the count sample. The %RMSE should decrease as volumes increase – thus for facility types with high volumes such as freeways, the %RMSE is expected to be lower (estimated should better match observed) than %RMSE measured on facility types with low volumes such as collectors. The %RMSE by facility type and volume group is summarized in Tables 142 and 143. By facility type, all facilities are well within the target range, and the overall %RMSE is between 30-40%. The volume group comparison also shows that all targets have been met, though the lower volume facilities do show more error as expected.

Table 142 Percent Root Mean Square Error by Facility Type

Classification	Observations	%RMSE	Target
Freeway/Expressway	109	14.7%	25%
Arterials (Boulevards, Major Thoroughfares)	352	40.9%	50%
Collectors (Minor Thoroughfares, 2-lane roads)	15	34.3%	65%
All Facilities	865	38.6%	30-40%

Table 143 Percent Root Mean Square Error by Volume Group

Volume Group	Observations	%RMSE	Target
0 to 4,999	425	81.6%	120%
5,000 to 9,999	176	43.0%	45%
10,000 to 19,999	153	31.7%	40%
20,000 to 39,999	107	20.8%	35%
40,000 and greater	4	9.7%	20%
Total	865	38.6%	30-40%

Count to Flow Comparisons

Table 144 provides a summary of the assignment results by comparing the daily count to the daily flow by volume group. The percent difference is calculated and compared to recommended target values. As the volume increases the calculated percent difference should decrease as recommended by the target values. The only performance measure not met is for facilities less than or equal to 1,000 vehicles per day. This is generally acceptable as the level of effort to calibrate a model to this level is generally not worth the return on the investment.

Table 144 Assignment Summary by Volume Group

Volume Group	Modeled Daily Flow	Count Daily Flow	Model % Error	Target % Error
Less than or equal 1,000	138,207	66,252	108.6%	60%
1,001 to 2,500	315,539	275,153	14.7%	47%
2,501 to 5,000	546,543	548,098	-0.3%	36%
5,001 to 10,000	1,049,661	1,278,406	-17.9%	29%
10,001 to 25,000	3,113,733	3,259,062	-4.5%	25%
25,001 to 50,000	1,891,682	1,848,817	2.3%	22%
Greater than 50,000	115,959	103,730	11.8%	21%
Total	7,171,325	7,379,518	-2.8%	

Checks were also performed to confirm that 75% of the freeway links were within +/- 20% of the traffic counts, and that 50% were within +/- 10% of the traffic counts. For links with volume greater than or equal to 10,000 vehicles per day (vpd), checks were performed to confirm that 75% of the links were within +/- 30% of the traffic counts, and that 50% within +/- 15% of the traffic counts. The freeway links are within the target range while the links greater than or equal to 10,000 vpd are slightly below the target values, as summarized in Table 145.

Table 145 Individual Link Targets

Category	Target	Model
Freeway links within +/- 20% of traffic counts	75%	86%
Freeway links within +/- 10% of traffic counts	50%	58%
Links with greater than 10,000 vehicles per day within +/- 30% of traffic counts	75%	73%
Links with greater than 10,000 vehicles per day within +/- 15% of traffic counts	50%	49%

Finally, the observed and estimated daily volumes by link were plotted and the r-squared value was calculated as a final indication of the degree to which the counts and estimated volumes match. The r-squared value is, in part, a function of the number of observations and therefore it is difficult to establish a guideline for acceptable values of r-squared. In general, a high r-squared value is desirable.

Figure 61 shows a scatter plot of observed versus estimated volumes by link. The diagonal line on the graph is defined by the set of points where the estimated count equals the observed count. If all counts fell along this line the r-squared value would be equal to one. The highway traffic assignment for the FBRMPO model shows a very tight fit between the observed and estimated values.

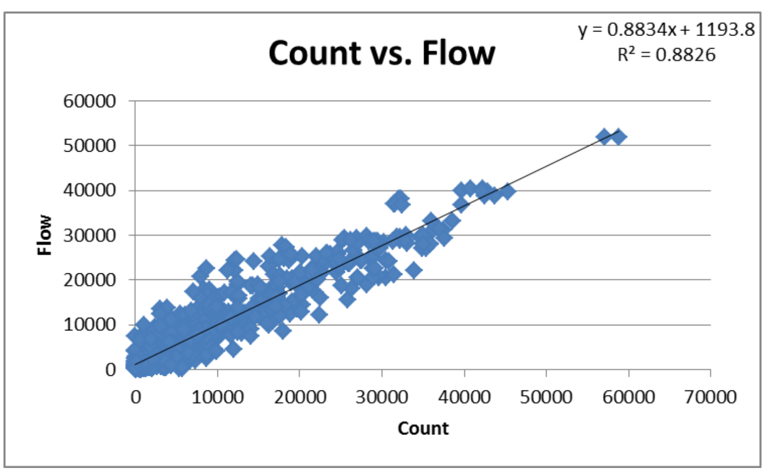


Figure 61 Scatter Plot of Observed Count and Estimated Flow

Figure 62 is a plot of the traffic count against the percent deviation of the modeled volume. The maximum desirable deviation curve is also plotted on this figure. This graph is useful in determining which links exceed the maximum desirable deviation so that validation efforts can be focused on these links. The graph shows that more deviation is acceptable for lower volume links, whereas estimates of high volume links should deviate less from the observed flows. The results show a good fit of the model estimated flows against traffic counts, especially for the higher volume locations. It is expected that some locations will be above the maximum desirable deviation curve, as it is extremely important not to over calibrate a model just to get all of the link flows to match the traffic counts. One reason is that all traffic counts include some degree of error, but the most important reason is that the model should not be forced to match traffic counts through individual link adjustments as the model must remain sensitive to future changes in travel demand and traffic flow.

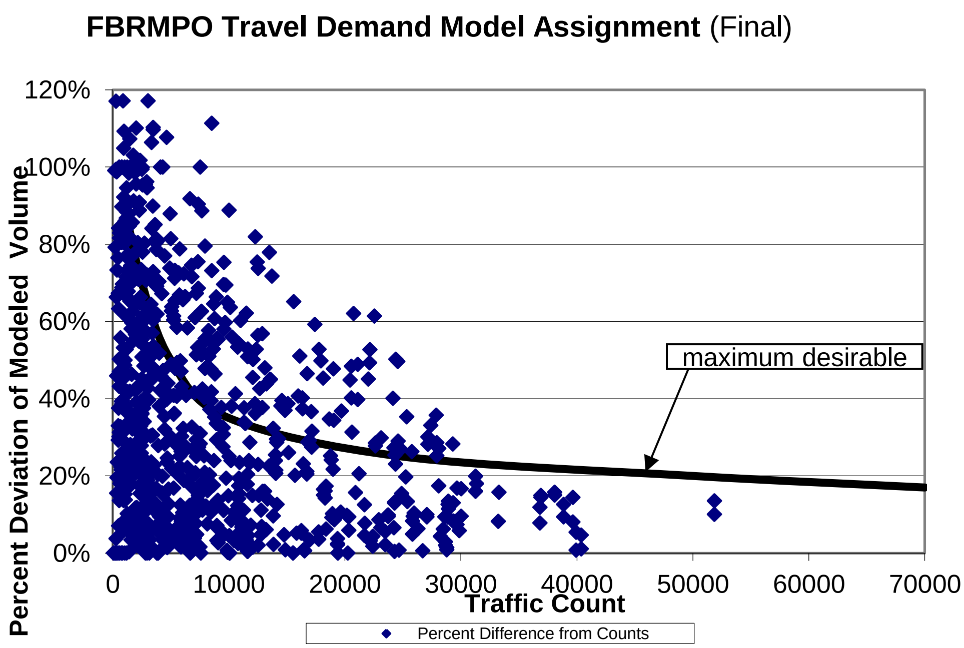


Figure 62 Plot of Traffic Count against the Percent Deviation of Modeled Flow

Transit Assignment

Transit assignment is the process of routing linked passenger trips over the available transit network, including all transit access and egress modes. Transit assignment differs from highway assignment in that flow in the transit assignment reflects passengers, not vehicles. The impedance functions for transit include a larger number of level-of-service variables than the impedance function for highway, including in-vehicle time, wait time, walk access and egress time, auto access time, fare, and transfer activity. The path choice in transit assignment often has complex associated choices between competing routes, or between express and local service.

The FBRMPO model uses a path-finder transit assignment methodology, a widely-accepted approach that produces transit boardings and alightings by optimally seeking user path choices as influenced by transit level of service. The path builder finds multiple "efficient" paths through the transit network based on criteria such as walk time, drive time, wait time, IVT, transfer time, transfer penalties, egress time, and fare. The multipath method may include multiple paths for each interchange even if the alternate paths do not minimize total travel impedance. The inclusion or exclusion of alternate paths is based on a specified set of decision rules. This assignment procedure better captures ridership across competing routes. The transit assignment results are reported as estimated and observed ridership by route. Validation measures are reported for the region and by system: Asheville Redefines Transit (ART) and Apple Country Transit (ACT).

Transit assignment results by system and for the MPO region are reported in Table 146. The overall results for the region are within an acceptable percentage range, though by system the results for ACT are over-estimated by close to 650 boardings. Much time and effort was invested to improve this forecast from the initial model output. Summarized below are the detailed investigations and recommended potential future strategies for the FBRMPO transit assignment.

Table 146 Transit Assignment Results by System and Region

System	Survey	Model	%Diff
Asheville Redefines Transit	5,875	4,335	-26%
Apple Country Transit	380	1,036	173%
FBRMPO Region	6,255	5,408	-14%

Investigations and Potential Future Steps:

1. The assignment of the transit on-board survey is used to set and validate transit path parameters for walk weights, max run time, max access/egress distance, transfer penalties, fares, the combination factor, and other general path settings. The results validate the path settings for the system.
2. Calibration of the mode choice model resulted in model results that match the person trips reported in the on-board survey. However, during the assignment we were unable to match the survey reported number of transfers (1.41 vs 1.14). Investigations show that we are not getting the transit trips in the right locations for the Hendersonville downtown. This is supported by the district to district summaries from mode choice, showing that the results are slightly low in the Asheville downtown and high in the Hendersonville downtown.
3. The following checks and improvements were made to improve the overall transit assignment results: checked paths, revised walk access & egress distances, revised fares by agency, recalibrated the auto ownership and destination choice models to reflect the transit path updates via logsums, revised transit speeds, introduced intra-zonal constant, introduced downtown constants, ran a program trace to identify and understand the source of differences between the Asheville downtown and Hendersonville downtown utilities, probabilities, and transit shares.
4. Advanced investigations that would require additional time and budget are summarized below:

a. Additional processing and investigations of the on-board survey data to profile the specific transit riders and to try and better understand the downtown Hendersonville transit market. If there are differences discovered in the transit rider profiles, then constants could be introduced and calibrated to better capture the behavior of these specific rider types (e.g. high income, zero car households, etc.)
b. Additional processing and investigations of the on-board survey data to profile the specific transit riders and to try and better understand the Asheville transit market, with mode choice model modification to better capture these riders as discussed above.
c. The mode choice program trace analysis showed that the potential transit riders in Asheville also have access to a very good walk network; as a result, many of these trips that could be using transit actually walk to their destinations. Downtown Hendersonville also has a road network that facilitates walking between origins and destinations, but the current coding of the highway network and traffic analysis zone structure in downtown Hendersonville does not capture that very well. As a result, trips that could and should be walk trips, become transit trips. Modifications could be made to increase this walk share through the coding of a walk network, by adding more detail to the highway network and zone system, or through the introduction of a downtown walk constant.

Final transit assignment results by route are summarized in Table 147.

Table 147 Transit Assignment Results

	Survey Observed			Onboard Assignment		Model Est (07/15) - Final	
Route Names	**Samples**	**Trips**	**Boardings**	**Boardings**	**Diff.**	**Boardings**	**Diff.**
170	29	125	229	147	(82)	173	(56)
BLUE	10	77	96	155	59	355	259
CROSSTOWN	25	176	210	233	23	316	106
EAST1	134	767	967	810	(157)	529	(438)
EAST2	34	227	311	503	192	216	(95)
NORTH	34	140	186	149	(37)	165	(21)
NORTH1	62	332	466	508	42	400	(66)
NORTH2	24	217	262	453	190	442	180
NORTH3	37	203	323	473	150	176	(147)
RED	14	73	119	105	(14)	438	319
SOUTH1	46	316	421	490	68	447	26
SOUTH2	27	114	134	215	81	148	14
SOUTH3	47	301	403	188	(214)	114	(289)
SOUTH4	40	196	303	399	96	157	(146)
WEST1	71	547	634	564	(70)	311	(323)
WEST2	47	287	380	541	161	261	(119)
WEST3	52	356	476	295	(181)	284	(192)
WEST4	19	106	167	194	27	197	30
WHITE	11	116	165	144	(21)	244	79
Total	764	4,676	6,255	6,576	321	5,370	(885)

Summary of Trip Assignment

The reported results indicate that the model is performing well within acceptable standards, indicating that the model is effectively representing base year travel demand within the FBRMPO region.

Sensitivity Testing

Sensitivity testing evaluates the model's readiness for application by determining whether or not the model responds in a rational way to changes in inputs. For the FBRMPO, sensitivity testing was also used to evaluate the model's response to premium transit, a mode which is not available in the base year. In order to test the sensitivity of the model to future year land use and transportation supply changes, a future year model run was performed using 2040 land use and zonal data while holding the base year highway and transit route system constant. Sensitivity tests were also performed by making changes to the highway network and transit route system, and then reviewing the associated model outputs for reasonableness.

Evaluation of Land Use Changes

2040 Land Use on 2010 Networks

To evaluate the model's sensitivity to changes in land use, the model was run using the 2040 socio-economic (SE) data and the 2010 highway and transit networks. For this evaluation, our expectation was that:

- speeds and travel times would degrade significantly
- significant capacity constraint would lead to more route diversion and increased vehicle miles traveled (VMT)
- a plot of the volume to capacity (V/C) would show significant congestion
- the model is able to reach convergence prior to reaching the maximum number of iterations

The results of this test confirm that the model is performing as expected. The average weighted speed for all facilities went from 45 mph in the base year to 40 mph with this scenario, a drop in the average speed of 9%. The VMT increased by 23% overall, with a 43% increase on minor thoroughfares, showing that more travelers are diverting their route to avoid highly congested corridors. Figure 63 is a plot of the V/C ratio, showing a significant amount of congestion in the region. The maximum number of iterations required to meet the convergence criteria did not exceed the maximum allowable iterations set for the model indicating that the system was able to reach equilibrium.

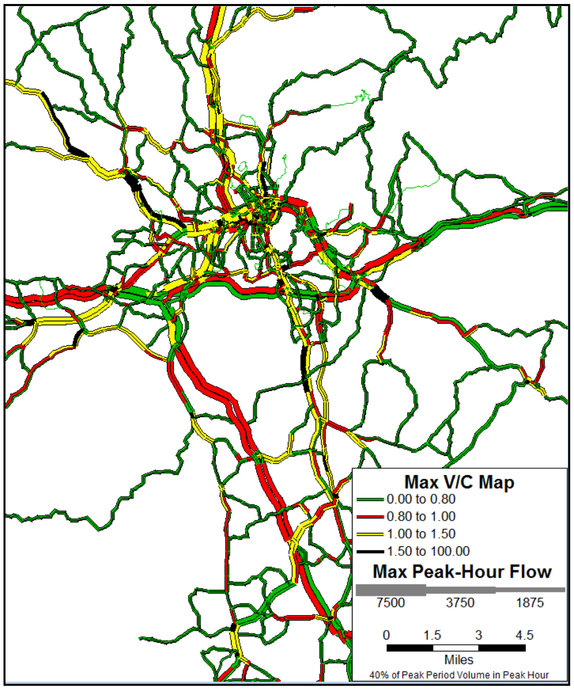


Figure 63 Peak Period V/C Ratio for 2040 SE Data on 2010 Networks

Increased Employment Data for a Specific Traffic Analysis Zone

To test the model's response to increases in employment data for a specific traffic analysis zone (TAZ), the retail employment in TAZ 565 was increased from 0 to 200 employees. For this evaluation our expectation was that an increased number of home-based shopping (HBS) and home-based other (HBO) trips would be attracted to this TAZ, and that roadway volumes would increase slightly.

In the base scenario, the destination choice model allocated 197 HBO trips and no HBS trips to this TAZ. With the increase of 200 retail employees, the destination choice model allocated 566 HBO and 1,145 HBS trips to this TAZ, an increase of 948 combined HBO and HBS trips as a result of the new retail employment. This test shows that the model is sensitive to changes in employment data at a small scale.

Evaluation of Transportation Supply

2040 Land Use on 2010 Networks with a New Location Roadway

In order to evaluate the model's responsiveness to new capacity and path options in a congested network, a new location roadway was coded into the 2010 network. The new location roadway was for testing purposes only and does not represent any project on the current long range plan. The new roadway was coded parallel to an existing congested facility. Our expectation for this test was that the congestion and travel time on the existing facility would improve as the traffic spread out to utilize both facilities, and that the V/C ratio on the existing facility would improve significantly. We would also expect that under highly congested traffic conditions that the two parallel roadways would have assigned flows comparable to each other if coded with similar attributes.

In application, the new facility does alleviate congestion on the existing roadway. The congested speed improves from around 26 miles per hour (mph) without the facility to 40 mph with the new facility. The reduction in congestion is demonstrated through a comparison of the V/C ratio as shown below in Figure 64.

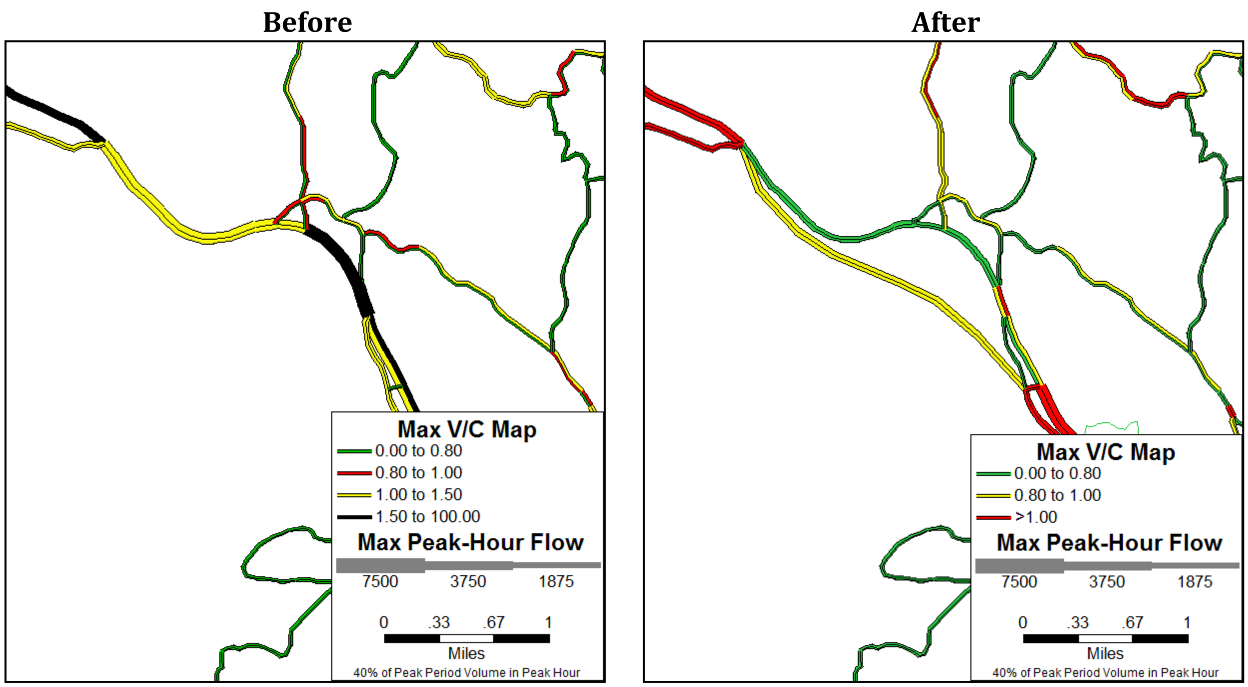


Figure 64 Before and After Comparisons of Adding New Highway Capacity

2010 Land Use on New Transit Networks

The FBRMPO mode choice model includes a nest for express bus (EB) and two premium transit modes: bus rapid transit (BRT), and light rail (LRT). Since these modes do not exist in the base year, it was important to perform sensitivity analysis on these three modes to assure that the model would run without error and that the forecast results would make sense. Three separate model runs were performed, one for each of the new modes. If working correctly, the model should run without error, generating reasonable transit skims and the forecast ridership within a reasonable range. Reviewing the results of reasonableness is particularly important as the coefficients for express bus and the premium modes were asserted based on experience and understanding of Federal Transit Administration guidelines on mode choice modeling, and base year calibration could not be applied to these modes because observed ridership data does not exist in the FBRMPO region.

For the test scenario, a specific route was selected and then modified, first to operate as an express bus (EB), then again to operate as a BRT, and finally to operate as LRT. It is important to note that the level of coding detail typically associated with the coding of a BRT or LRT route was not implemented as the main role of the test was to evaluate the model's sensitivity to change, not to perform ridership analysis.

The initial model runs did uncover incompatibilities with several of the input files and model settings that had to be addressed through model script revisions and updates to several parameter files. Once these changes were made, the model ran without error for all three tests. The initial review of the express bus assignment indicated that the ridership forecast was unreasonably high in comparison to the observed ridership on local bus. An investigation into the issue uncovered improper coding of the accessibility values for the express bus mode. Once corrected, the ridership result for the express bus was in the expected range. The ridership results for the two premium modes also showed reasonable ranges, given the test scenario. The final results of the test are summarized below:

- Local Bus = 93 riders
- Express Bus = 90 riders
- BRT = 113 riders
- LRT = 116 riders

The surprising result was that the local bus got a few more riders than the express bus. Further investigation showed that the Mode Combination Factor is playing a role for this particular test case. In this example, multiple local bus routes serve the same corridor as the route being tested. When this happens, the model will use the Model Combination Factor to combine the headway for the shared section such that a rider who is waiting at a stop is given the option to take any of the routes. Because of the multiple options for the local bus in this corridor and limited option for the express bus, the local bus is actually seen as slightly better resulting in a slightly higher ridership for the local bus mode.

Summary of Sensitivity Analysis

Performing a sensitivity analysis of a travel demand model prior to application is a critical component of understanding the predictive nature of the model. Unfortunately this step is far too often lost in the focus on overall model calibration and validation. A model that is insensitive to changes in land use and transportation supply, or that forecasts unrealistic results in response to that change is not an effective tool for supporting transportation planning analysis. Based on the tests performed with the FBRMPO model, the model is sensitive to changes in the major inputs, performs reasonably in the application mode, and is ready to be used to evaluate land use and transportation scenarios.

Future Enhancements

The FBRMPO model reflects state of the practice in trip based travel modeling. All resident models were estimated and calibrated using locally collected travel survey data. The external trip model was also estimated and calibrated using locally collected travel data. Recognizing the importance of tourism in the FBRMPO region, the model includes a model for visitor travel. The rates and parameters for this model were asserted based on experience in other areas and calibrated to reflect locally collected visitor data at key locations around the region. Given the importance of this special market in the FBRMPO region, the MPO should consider a future data collection effort focused on visitor travel. This data could then be used to enhance the existing visitor model. Consideration should be given to developing an advanced tour-based model to better capture the unique travel behavior and travel patterns of visitors.

The influence of industrial land uses and a transportation system that includes several routes of statewide and regional significance increases the amount of truck traffic moving to and through the FBRMPO region. THE FBRMPO region is also likely to see changes in truck volumes and truck travel patterns arising from the new South Carolina in-land port located in Greer, South Carolina just south of the FBRMPO region. For these reasons, and others, the FBRMPO may want to consider the collection of freight specific data. The collection of freight related data could be as simple as the development of a freight node geodatabase with key data elements and attributes. This database could be supplemented with survey data related to commodities and trips per data collected through the administration of a postcard survey.

Finally, the unique characteristics of the FBRMPO region make this MPO a prime candidate for advanced modeling components designed to better capture travel behavior for specific segments of the population and to better support advanced transportation analysis related to equity analysis, active transport analysis, energy analysis, and financial and social welfare measures, This could be represented through the implementation of a population synthesizer and the development of a microsimulation based model design that follows either individual households or individuals through the entire modeling process.

Acronyms

This final section provides a list of acronyms and definitions commonly used in travel modeling and transportation planning.

- TAZ – traffic analysis zone
- HBW – home-based work trips
- HBE – home-based escort trips
- HBS – home-based shop trips
- SCH – home-based school trips
- HBO – home-based other trips
- HBU – home-based university trips
- NHBW – non-home-based work trips
- NHBO – non-home-based other trips
- NHB – non-home-based trips
- HBSR – home-based social and recreational
- HBDE – home-based dining and entertainment
- NHBNR – non-home-based non-resident
- EE – external to external trips
- IE – internal to external trips
- EI – external to internal trips
- PA – production-attraction
- OD – origin-destination
- MNL – multinomial logit
- DA – drive alone
- SR – shared ride
- CV – commercial vehicle
- PUMS – public use micro-data sample (US Census data product)
- CTPP – Census Transportation Planning Products
- ACS – American Community Survey (US Census data product)
- HHS – Household Survey
- HH – households
- EMP – employment
- SE – socio-economic
- INC – income
- CBD – central business district
- CTP – comprehensive transportation plan
- AWDT – average weekday traffic
- VMT – vehicle miles traveled
- VHT – vehicle hours traveled
- MPO – metropolitan planning organization