Hampton Roads Transportation Planning Organization, Regional Travel Demand Model V2 Technical Documentation

FINAL REPORT

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1. Introduction

The 2017 Hampton Roads Transportation Planning Organization (HRTPO) regional Travel Demand Model (Model) represents an advanced practice four step model to support air quality, long range planning and transportation planning activities in the HRTPO region. The model is an update to the 2009 HRTPO Model with several updates both in methodology and geographic coverage. This version of the model is being titled HRTPO Model, V2.

As part of the 2017 Model development, the model was re-estimated and calibrated based on 2015 observed data, 2009 National Household Travel Survey (NHTS) data for Virginia and GPS OD data from Streetlight. The final validation was based on 2017 observed AWDT traffic counts from VDOT.

The purpose of this report is to document the HRTPO Model inputs, estimation and calibration process and final results of the 2017 Model Validation. Additional information related to the application of the model is covered in the HRTPO 2017 Travel Demand Model Application Guide, v2.0.

1.1 Model Enhancement Summary

At the onset of the 2017 Model Development, several enhancements were requested by HRTPO and VDOT including:

- Update the model with a 2015 calibration year and 2017 validation and 2045 forecast horizon
- Expand model area to include the City of Franklin and Southampton County
- Incorporate zonal boundary changes and renumber the zones sequentially by locality
- Make necessary network improvements
    - Network link consolidation
    - Network simplification where possible
    - Provide network attributes to support post processing functions by the HRTPO staff
    - Update speed and logic to improve model results on bridges and tunnels
    - Store network in Cube Geodatabase with TrueShape display properties for both input and scenario output
- Update Non-home-based (NHB) trips according to FHWA's Travel Model Improvement Plan (TMIP) recommendations and consistent with other projects in VA
- Update transit, mode choice, and toll components to align with base and future year services
- Implement model enhancements including:
    - Select link tools
    - Automated reporting of model outputs
    - Calculation of model metrics specific to HRTPO's reporting needs

As the output model will be used for other studies that will require the testing of policies related to connected and autonomous vehicles (CAV), further model enhancements were coded into the model structure on an independent track from the model validation efforts.

Objectives for the update of the model included:

- Maintain overall model structure with only minor revisions based on improving overall model calibration and validation

- Removal of hard coded adjustments and parameters within the model scripts and input files
- Establish improved daily model validation results with the use of available data from VDOT and the HRTPO while expanding the model area.

1.2 Report Organization

The remainder of this report provides technical documentation on the model design, calibration of the model and finally model validation results.

	Chapter	Description
2	Data Inputs	Description of model inputs including zonal datasets, networks and calibration data.
3	Trip Generation	Production and external model calibration.
4	Trip Distribution	Estimation of gravity models by purpose and periods.
5	Mode Choice	Model choice structure and calibration.
6	Non-home Based Trips	Non Home Based model structure and calibration.
7	Trip Assignment	Traffic assignment including time of day parameter calibration.
8	Truck Model	Truck model calibration
9	Feedback	Feedback model structure and convergence criteria
10	Validation	Static and dynamic validation results
11	Connected and Autonomous Vehicle	Model structure and parameter selection

1.3 Document Note

The 2017 HRTPO Model V2 documentation follows the same structure as the 2009 HRTPO Model V1 documentation. The consistency was made to assist model users in finding relevant information quickly. Where major model components were not changed from V1.0, the documentation was used directly and only updated where necessary for consistency with the latest model.

2 Data Inputs

This chapter describes the methodology for development of the data inputs to the HRTPO Model. The following is a list of the information in this chapter:

- TAZ Structure
- Land Use Data (Socioeconomic and Demographic)
- Area Type Procedures
- Highway Network
- Transit Network
- Calibration Data

2.1 TAZ Structure

The HRTPO Model includes 2049 internal TAZs spread across the 15 jurisdictions covered in the model area. Surry County is included in the TAZ structure but is not part of the model area. Table 2-1 provides a summary of the TAZ number range assigned to each jurisdiction along with the district number used by the model for reporting purposes. The zone ranges by jurisdiction were set by HRTPO in the development of the 2017 zone structure and allows for future zonal expansion of the model.

Table 2-1: TAZ Distribution by Jurisdiction

Jurisdiction	District Number	Zone Range
Norfolk	2	1-299
Virginia Beach	5	300-599
Chesapeake	1	600-799
Portsmouth	3	800-899
Suffolk	4	900-1099
Isle of Wight	6	1100-1199
Franklin	14	1200-1249
Southampton	15	1250-1299
Hampton	8	1300-1499
Newport News	7	1500-1699
Poquoson	9	1700-1749
Williamsburg	10	1750-1799
James City	11	1800-1899
York	12	1900-1999
Gloucester	13	2000-2049
Surry	N/A	2100-2199

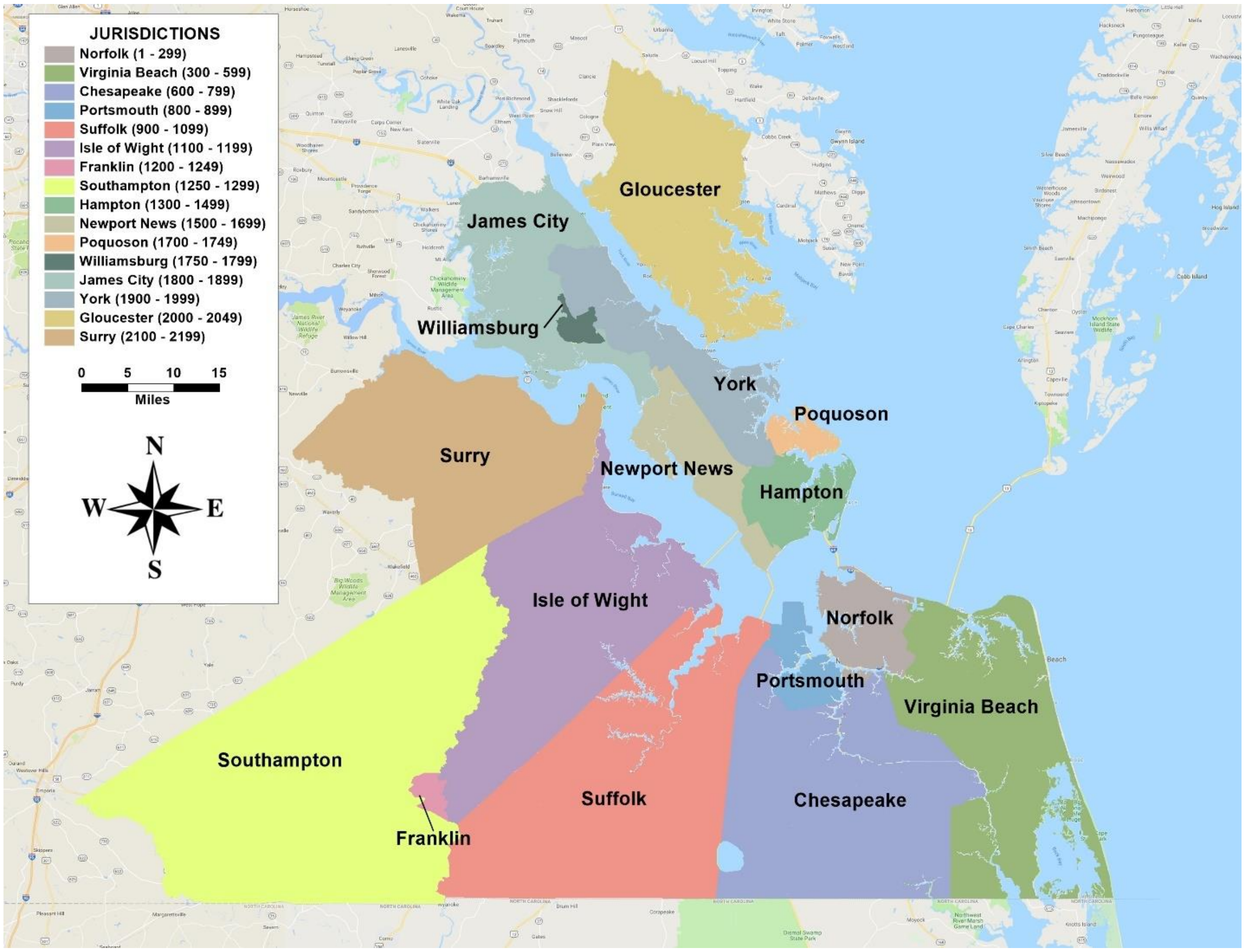


Figure 2-1: HRTPO - Model Area

In addition to the internal zones, the HRTPO Model includes thirty-four external zones numbered from 3000 to 3033 as shown in Figure 2-2 below.

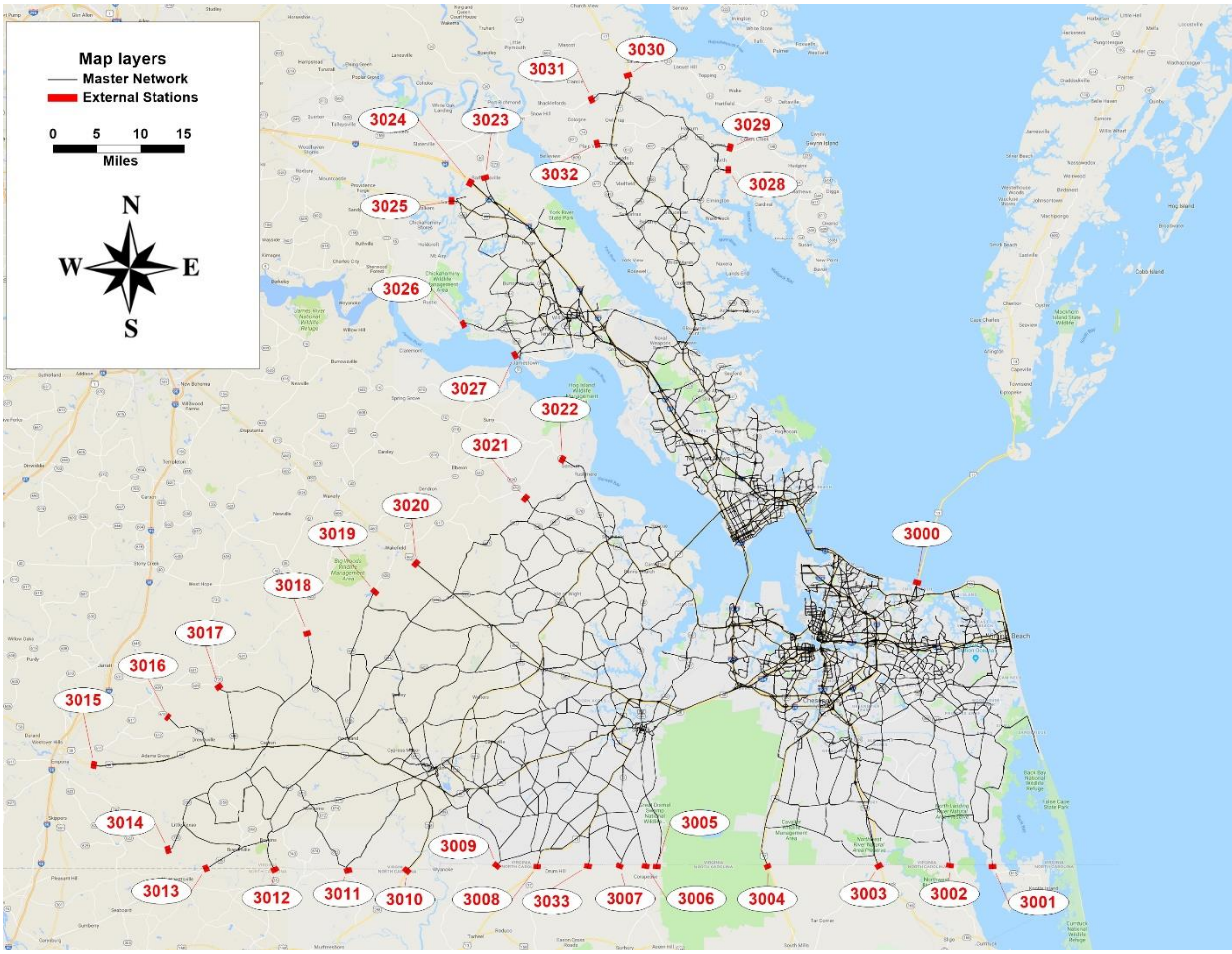


Figure 2-2: HRTPO Externals

Table 2-2 below provides a summary of the Stations, associated route and jurisdiction or county where the roadway enters the study area.

Table 2-2: External Locations

Station	Route	Jurisdiction
3000	ROUTE 13	Virginia Beach
3001	PRINCESS ANNE RD	Virginia Beach
3002	BLACKWATER RD	Virginia Beach
3003	CHESAPEAKE EXPY	Chesapeake
3004	HIGHWAY 17	Chesapeake
3005	CR 604	Suffolk
3006	CAROLINA RD	Suffolk
3007	ADAMS SWAMP	Suffolk
3008	WHALEYVILLE	Suffolk
3009	PITTMANTOWN	Suffolk
3010	US-258	Southampton
3011	STATESVILLE RD	Southampton
3012	NC-35	Southampton
3013	HUGO RD	Southampton
3014	LOW GROUND RD	Southampton
3015	AIRPORT DR	Southampton
3016	SC-610	Southampton
3017	COURTHOUSE RD	Southampton
3018	PLANK RD	Southampton
3019	WAKEFIELD RD	Southampton
3020	MAHONE HWY	Southampton
3021	JONES	Isle of Wight
3022	COLONIAL	Isle of Wight
3023	NEW KENT	James City
3024	I 64	James City
3025	RICHMOND	James City
3026	RTE 5	James City
3027	JAMESTOWN RD	James City
3028	JOHN CLAYTON MEMORIAL	Gloucester
3029	BUCKLEY HALL	Gloucester
3030	GEORGE WASHINGTON MEMORIAL	Gloucester
3031	LEWIS B PULLER MEMORIAL	Gloucester
3032	ADNER	Gloucester
3033	GREAT FORK	Suffolk

2.2 Land Use Data

HRTPO provided the zonal input data for 2015 and 2045 as part of the model development effort. The WRA Team developed the 2017 socioeconomic and demographic datasets by first interpolating between the 2015 and 2045 data. The allocation of growth was reviewed by HRTPO and areas with recently completed development were identified or where future growth was expected were noted and used to adjust the allocation. The final 2017 input data by jurisdiction totals is reported in Table 2-3.

Table 2-3: 2017 Zonal Input Totals by Jurisdiction

Jurisdiction	District Number	Tot Pop	Group Quarters	POP	HH	AUTOS	WORKER	TOTEMP	RETEMP	NRETEMP	BA_OFF	BA_IND	BA_OTH
Norfolk	2	273781	25648	248133	87329	157468	123052	212151	39475	172676	79906	37387	55383
Virginia Beach	5	469750	11902	457848	167841	352142	234437	256046	60594	195452	99377	36736	59339
Chesapeake	1	249703	6384	243319	83432	191724	112186	127893	32769	95124	44359	24084	26681
Portsmouth	3	99122	2191	96931	36778	66836	42168	61125	12320	48805	21161	12231	15413
Suffolk	4	93679	653	93026	32028	73159	41263	39950	9696	30254	14001	7552	8701
Isle of Wight	6	37706	203	37503	14195	36056	17619	15717	3205	12512	4483	4933	3096
Franklin	14	8547	0	8547	3457	6437	3330	5892	2148	3744	1917	591	1236
Southampton	15	20076	1412	18664	6722	16403	7819	5768	847	4921	1693	1934	1294
Hampton	8	142287	4228	138059	52706	101787	63705	75486	17481	58005	26521	11916	19568
Newport	7	192183	8295	183888	69288	143182	88063	124414	25169	99245	38799	33837	26609
Poquoson	9	12428	51	12377	4653	11436	5941	2117	649	1468	712	196	560
Williamsburg	10	18695	3974	14721	4593	17385	5785	16305	4367	11938	4325	2018	5595
James City	11	77323	836	76487	29321	56684	32861	40493	9946	30547	14694	5676	10177
York	12	71612	1082	70530	24442	56730	32848	31573	8401	23172	10770	5220	7182
Gloucester	13	37623	275	37348	14388	36239	17952	14082	4035	10047	4450	2650	2947
Total		1804515	67134	1737381	631173	1323668	829029	1029012	231102	797910	367168	186961	243781

Figure 2-3 and Figure 2-4 show the location of households and total employment respectively by TAZ across the model area.

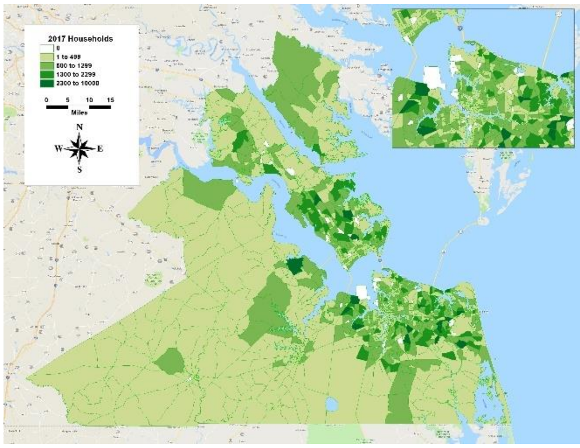


Figure 2-3: HRTPO 2017 - Households

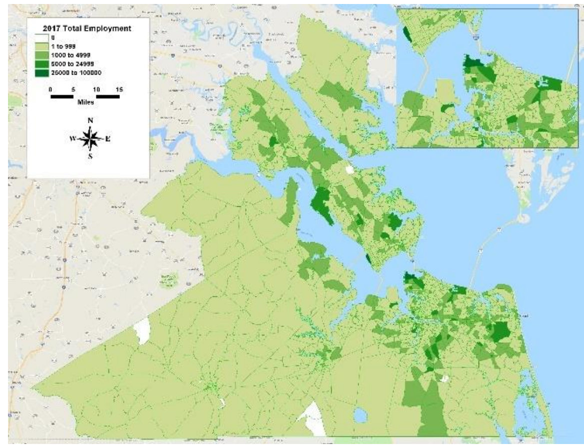


Figure 2-4: HRTPO 2017 - Total Employment

The figures below provide the distribution of employment by industrial, office, retail and other.

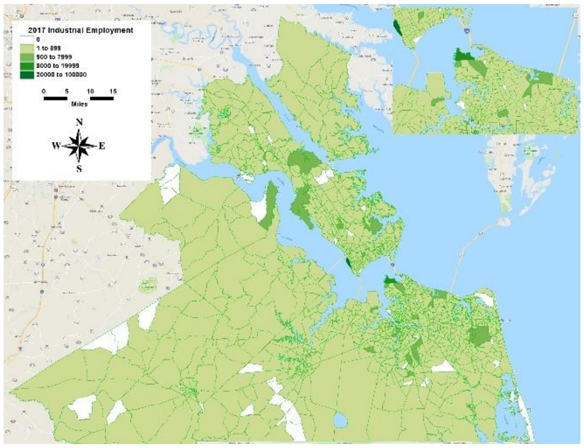


Figure 2-5: HRTPO 2017 - Industrial Employment

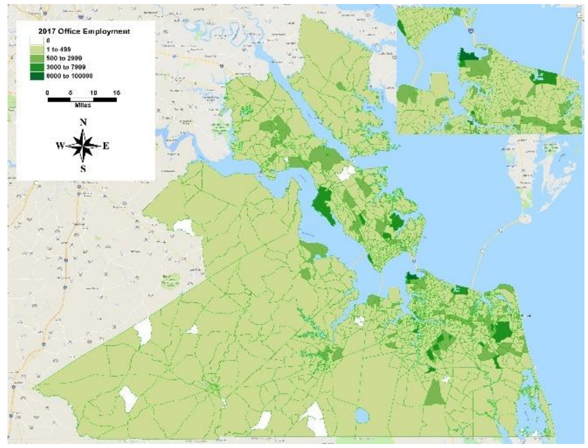


Figure 2-6: HRTPO 2017 - Office Employment

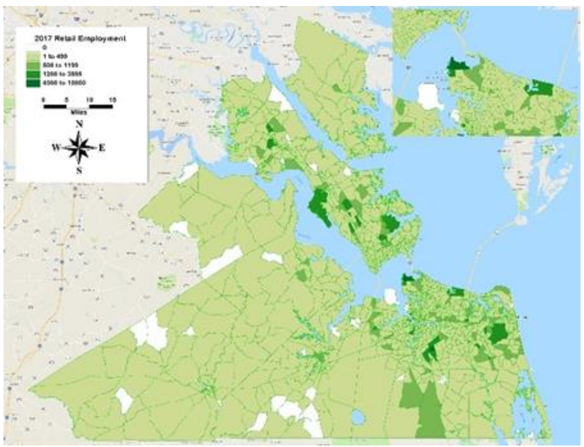


Figure 2-7: HRTPO 2017 - Retail Employment

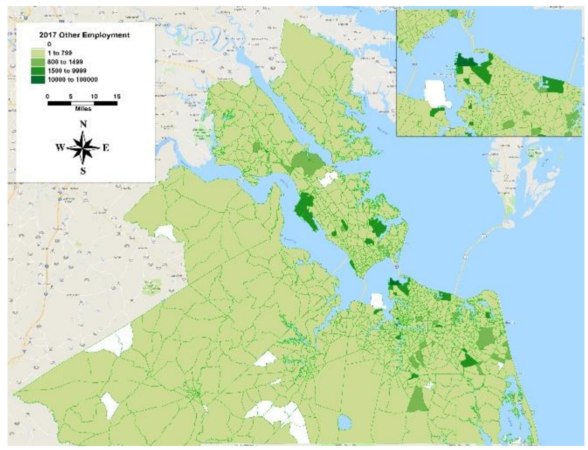


Figure 2-8: HRTPO 2017 - Other Employment

2.3 Area Type Procedure

Area Type is a measure of the relative population and employment density for each TAZ. Consistent with the VDOT Policy Manual, five Area Types are used for HRTPO.

Table 2-4: Area Type Definition

Area Type	Description
1	CBD
2	Urban
3	Dense Suburban
4	Suburban
5	Rural

The Area Type determines the link speeds and capacities and is used in demand elements of the model. The Area Type is estimated by stratifying the population and employment density into seven bins. Based on the associated bin of the population and employment densities, and Area Type is assigned based on the values in Table 2-5.

Table 2-5: Area Type Assignment by Density

Population Density	Employment Density						
	<2.998	2.998 to 3.317	3.317 to 3.954	3.954 to 4.591	4.591 to 5.288	5.288 to 5.865	>5.865
<3.887	5	5	4	3	3	3	2
3.887 to 4.508	5	5	4	3	3	3	2
4.508 to 5.750	4	4	4	3	3	3	2
5.750 to 6.992	4	4	4	3	3	3	2
6.992 to 8.223	3	3	3	3	3	3	2
8.223 to 9.475	3	3	3	3	3	3	2
>9.475	2	2	2	2	2	2	2

The density bins are calculated based on the population and employment densities and distributed into the seven bins based upon a factor using the mean density and standard deviation.

The use of a dynamic system to categorize the calculated population and density allows the Area Type scheme to be easily applied to future scenarios and maintains the meaning of each Area Type. As part of the network and land use processes in the model, the zonal area type is calculated and associated to the network links.

The central business district (CBD) has been defined as a set of TAZs consistent with the core area of Norfolk. This manual definition of the CBD ensures consistency of the area regardless of the density of each zone. Figure 2-9 provides a map showing the assigned area types to the 2017 network.

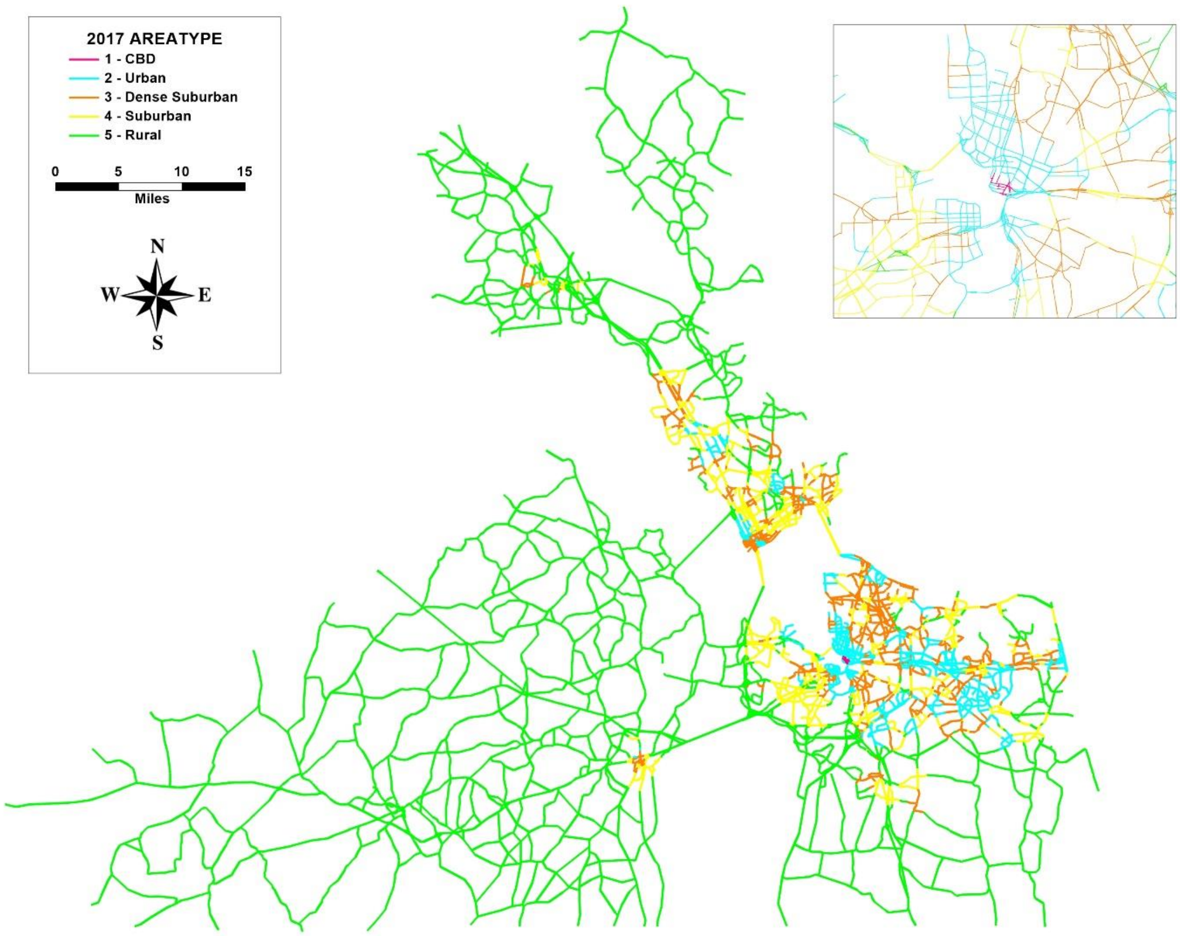


Figure 2-9: HRTPO 2017 AREATYPE

2.4 Highway Network

The Hampton Roads highway network was developed in CUBE and follows the structure developed for the 2009 HRTPO Model. The refined network includes approximately 42,849 links and covers freeways, major arterials, minor arterials and major collectors in the modeling area. The network also includes minor collectors and local streets to provide appropriate connectivity in the network. The highway network contains link attributes defined by VDOT in the Policy and Procedures Manual. They include Distance, Route Name, Facility Type, Area Type, Speed Class, Capacity Class, and Link Capacity that are used in the development of highway level of service estimates (time and costs) and assignment procedures. A complete list of the standard link attributes is shown in Table 2-6. The link attributes are based upon values established in the 2009 network and updated to the current conditions for 2015 and 2017.

Table 2-6: Master Network Attributes

Field	Description
A	A node
B	B node
DISTANCE	Distance of link
ID	Link ID
LANES	Base year number of lanes

Field	Description
FACTYPE	Base year facility type
TWLTL	Two-way left turn lane indicator
ONEWAY	One-way link designation
REVERSIBLELANE	Reversible lane designation
DIR	DIR node
TRK_PHB	Truck Prohibit designation
POST_SPD	Posted speed
SPDCLASS	Speed class
LINK_CAP	Link class
CAPCLASS	Capacity lass
AWDT	Average Weekday Daily Traffic
AWDT_AUTO	Average Weekday Daily Traffic - Autos
AWDT_TRK	Average Weekday Daily Traffic - Trucks
RTE_NAME	Route Name
RTE_NO	Route Number
RTE_ID	Route ID
PROJ_ID	Project ID
PROJ_NAME	Project Name
YR_OPEN	Year Project Opens
YR_CLOSE	Year Poject Closes
JURIS_NO	Jurisdiction Number
COUNTY	County Number
FEDFUNC	Federal Functional Class
AREATYPE	Base Area Type designation
FEDAT	Federal Area Type designation
VDOT_AT	VDOT Area Type designation
MPO_ID	MPO ID
LINENAME	Linename
SCRLN_ID	Screen line ID
CORD_ID	Cordon line ID
CUTLN_ID	Cut line ID
COUNT_FLAG	Count Flag Field
TMS_ID	TMS ID
CMPID	CMP ID
REGCOR	all link values null
JRSTAG	all link values 0
BEGIN_MP	Begin Mile point
END_MP	End Mile point
HOVTYPE	HOV designation
TOLL_GRP	Toll Group designation for toll corridors
TOLL_GRP1	Toll Group 1 designation
TOLLGATE	Tollgate designation for gantry tolling
ZN	Zone association
R_AREATYPE	Base Year Area Type override field
R_FFLOWSPEEED	Base Year Free Flow Speed override field
R_LINK_CAP	Base Year Link Capacity override field
LINKFLAG	LINKFLAG designation
NETXX	Active link designation for network year
LANESXX	Number of Lanes for network year
FACTYPEXX	Facility Type designation for network year
HOVTYPEXX	HOV Type designation for network year
TOLLGATEXX	Tollgate designation for network year
TOLL_GRPXX	Toll Group designation for network year
R_AREATYPEXX	Area Type Override designation for network year
R_FFLOWSPEEDXX	Free Flow Speed Override designation for network year

Field	Description
R_LINK_CAPXX	Link Capacity Override designation for network year
PROJ	PROJ Identifier
LANESPRJ	Number of lanes for PROJ project
FACTYPEPRJ	Facility Type designation for PROJ project
HOVTYPEPRJ	HOV designation for PROJ project
TOLLGATEPRJ	Toll Gate designation for PROJ project
TOLL_GRPPRJ	Toll Group designation for PROJ project
R_AREATYPEPRJ	Area Type override designation for PROJ project
NOTE	NOTE field
NETEC	Active link identifier for EC projects
LANESEC	Number of lanes for EC project
FACTYPEEC	Facility Type designation for EC project
HOVTYPEEC	HOV designation for EC project
TOLLGATEEC	Toll gate designation for EC project
TOLL_GRPEC	Toll Group designation for EC project
R_AREATYPEEC	Area Type override for EC project
R_FFLOWSPEEDEC	Free Flow Speed override designation for EC project
R_LINK_CAPEC	Link Capacity override designation for EC project
NETEX	Active link identifier for EX projects
LANESEX	Number of lanes for EX project
FACTYPEEX	Facility Type designation for EX project
HOVTYPEEX	HOV designation for EX project
TOLLGATEEX	Toll gate designation for EX project
TOLL_GRPEX	Toll Group designation for EX project
R_AREATYPEEX	Area Type override for EX project
R_FFLOWSPEEDEX	Free Flow Speed override designation for EX project
R_LINK_CAPEX	Link Capacity override designation for EX project
NEW_SPDCAP17	Legacy field
VT15	2015 Count data
VT15DIF	Difference between 2015 Count data and 2015 model run
LENGTH	LENGTH of link
SHAPE_LENG	GIS field
GEOMETRYSO	GIS field
AB	A and B node concatenation for link Iding
PSI	PSI node

The HRTPO Model utilizes a master network structure. Base attributes are set for 2015 conditions. The user then selects a defined network year or predefined scenario. When the scenario is created, attribute data for the desired year is used to populate the scenario network attributes as shown in Table 2-7.

Table 2-7: Scenario Network Attributes

Field	Description
A	A node
B	B node
COUNTAM	AM Count for link
COUNTMD	MD count for link
COUNTPM	PM count for link
COUNTNT	NT count for link
ZN	Zone association
DISTANCE	Distance of link
LANES	Number of lanes for scenario
FACTYPE	Facility type designation for scenario
TWLTL	Two-way left turn lane indicator

Field	Description
ONEWAY	One-way link designation
REVERSIBLELANE	Reversible lane designation
DIR	DIR node
TRK_PHB	Truck Prohibit designation
POST_SPD	Posted speed
SPDCLASS	Speed class for scenario - populated by macro
LINK_CAP	link capacity for scenario - populated by macro
CAPCLASS	Capacity class for scenario - populated by macro
AWDT	Average Weekday Daily Traffic
AWDT_AUTO	Average Weekday Daily Traffic - Autos
AWDT_TRK	Average Weekday Daily Traffic - Trucks
RTE_NAME	Route Name
RTE_NO	Route Number
RTE_ID	Route ID
PROJ_ID	Project ID
YR_OPEN	Year Project Opens
YR_CLOSE	Year Poject Closes
JURIS_NO	Jurisdiction Number
COUNTY	County Number
FEDFUNC	Federal Functional Class
AREATYPE	Area Type designation for scenario
FEDAT	Federal Area Type designation
VDOT_AT	VDOT Area Type designation
MPO_ID	MPO ID
SCRLN_ID	Screen line ID
CORD_ID	Cordon line ID
CUTLN_ID	Cut line ID
COUNT_FLAG	Count Flag Field
TMS_ID	TMS ID
CMPID	CMP ID
BEGIN_MP	Begin Mile point
END_MP	End Mile point
HOVTYPE	HOV designation for scenario
TOLL_GRP	Toll Group designation for scenario
TOLLGATE	Toll gate designation for scenario
R_AREATYPE	Area Type override designation for scenario
R_FFLOWSPEED	Free Flow Speed override designation for scenario
R_LINK_CAP	Link capacity override designation for scenario
LINKFLAG	LINKFLAG designation
VT15	
VT15DIF	
LENGTH	LENGTH of link
AREA_TYPE	
FFLOWSPEED	Free Flow Speed for scenario
SPEEDCAPFAC	Speed Capacity Factor
FFTIME	Free Flow Time for scenario - populated by macro
FDBKTIME	Feedback Time (congested) - populated by macro
FDBKVOL	Feedback Volume - populated by macro
VMTAM	AM Vehicle Miles Traveled - populated by macro
VMTMD	MD Vehicle Miles Traveled - populated by macro
VMTPM	PM Vehicle Miles Traveled - populated by macro
VMTNT	NT Vehicle Miles Traveled - populated by macro

2.4.1 2017 Network Attributes

The model validation was based on the definition of a 2017 network using the master network system. Facility types classify roadway links according to their function and/or design characteristics whereas the area types represent the development density near each link. A combination of the area type and facility type is used in representing the speeds and capacities of the roadway facilities. The definitions of the 12 facility types are shown in Table 2-8.

The number of links, directional miles and lane miles by facility type is reported in Table 2-8. The majority of links in network fall into Minor and Principal Arterials compromising nearly 38% of all links when combined.

Table 2-8: 2017 Network Summary by Facility Type

FACTYPE		Number of Links	Directional Miles	Lane Miles
1	Interstate/Principal Freeway	810	341.04	770.81
2	Minor Freeway	334	125.85	268.40
3	Principal Arterial/Highway	3924	547.03	1237.04
4	Major Arterial/Highway	2153	340.36	489.00
5	Minor Arterial/Highway	11663	1403.6	2148.88
6	Major Collector	3067	771.71	804.34
7	Minor Collector	12200	1408.69	1572.74
8	Local	1435	503.24	505.85
9	High Speed Ramp	176	34.09	62.46
10	Low Speed Ramp	1519	217.17	239.08
11	Centroid Connector	5391	2571.16	5136.2
12	External Station Connector	68	33.25	66.5

Table 2-7 provides a summary of the number of links, directional miles and lane miles by jurisdiction. The urbanized counties including Chesapeake, Norfolk and Virginia Beach have the highest percentage of network links and associated directional mileage.

Table 2-9: 2017 Network Summary by Jurisdiction

Jurisdiction		Number of Links	Directional Miles	Lane Miles
1	Chesapeake	4339	939.9	1494.82
2	Norfolk	7630	752.32	1356.96
3	Portsmouth	3001	310.51	521.42
4	Suffolk	3164	1054.36	1479.88
5	Virginia Beach	7174	1271.04	2257.67
6	Isle of Wight	1919	670.98	885.34
7	Newport News	3649	487.28	878.71
8	Hampton	3746	440.44	820.42
9	Poquoson	240	37.82	55.24
10	Williamsburg	885	99.33	148.48
11	James City	1400	418.76	639.4
12	York	1408	329.49	518.24
13	Gloucester	1301	377.33	569.41
14	Franklin	747	102.64	147.51
15	Southampton	2178	991.14	1480.7

Figure 2-10 and Table 2-9 display the 2017 facility and directional lanes in the network.

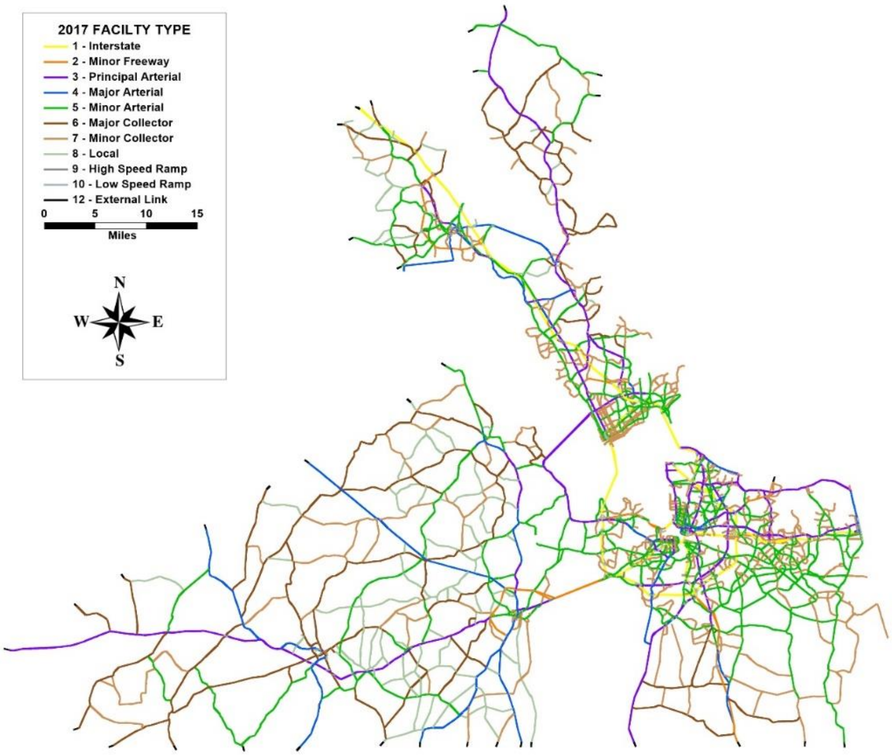


Figure 2-10: HRTPO 2017 - FACTYPE Values

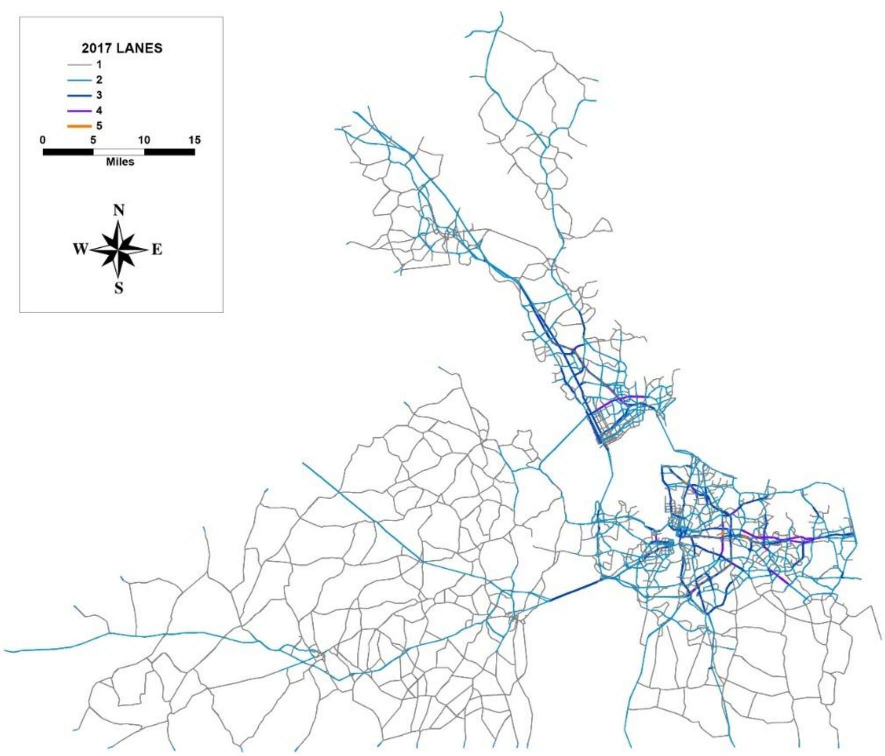


Figure 2-11: HRTPO 2017 - Directional Lanes

The definition of the High Occupancy Vehicle (HOV) lanes is done through a link attribute called HOVTYPE. The attribute is defined by a 4-character code (see Table 2-10). The first character shows the vehicle occupancy in the AM peak period, the second character shows the vehicle occupancy in midday, the third character shows the vehicle occupancy in the PM peak period and the last character shows the vehicle occupancy at night. For example: code "2111" indicates that the lane is HOV-2 in the AM peak and is SOV during midday, PM peak and night. Similarly, code "9121" indicates that the lane is non-operational in the AM peak, SOV during midday, HOV-2 during PM peak and SOV at night. Code "9999" represents transit only links.

Table 2-10: HOV Codes

Code	Meaning
If Lane is not HOV then:	
0 or ' '	All vehicles allowed
If Lane is HOV then:	
1	All vehicles allowed
2	HOV2+ only
3	HOV3+ only
9	Closed to all vehicles

2.4.2 Speed and Capacities

The HRTPO Model uses the link level free flow speed to estimate the impedance used in the initial trip distribution / mode choice steps of the model as well as the initial iteration of assignment. The HRTPO Model assumes that free flow speed is a function of the facility type, posted speed limit and a factor that accounts for the difference between posted and free flow speed. Posted speed was updated on the network using data from VDOT (https://www.virginiaroads.org/datasets/vdot-speed-limits-map) and is shown on the HRTPO 2017 Model network in Figure 2-12.

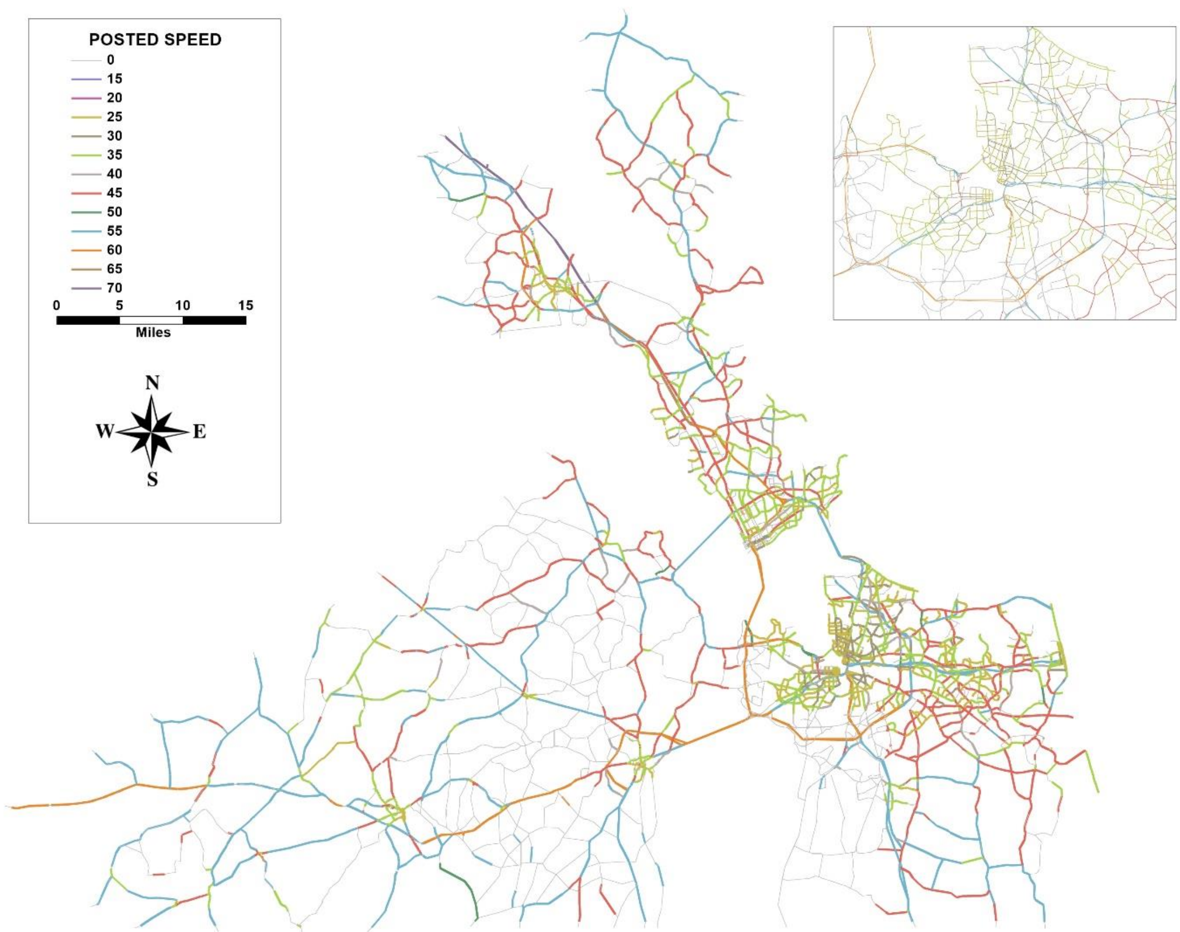


Figure 2-12: HRTPO Posted Speeds

Where posted speed limits were not available, an estimate of posted speed was made using locations with data stratified by facility and area type.

Table 2-11: Estimated Posted Speed

Facility Type		CBD	Urban	Dense Suburban	Suburban	Rural
1	Interstate	55	55	55	60	60
2	Minor Freeway	55	55	55	55	55
3	Principal Arterial	35	35	35	45	55
4	Major Arterial	25	30	35	35	55
5	Minor Arterial	30	**30**	35	35	45
6	Major Collector	30	30	35	45	45
7	Minor Collector	25	25	25	25	35
8	Local	25	25	25	35	55
9	High Speed Ramp	45	55	55	**55**	55
10	Low Speed Ramp	35	35	35	45	45

The starting point for the adjustment factors came from "Evaluation of Volume Delay Functions and Their Implementation in VDOT Travel Demand Model", VDOT Project Number 0095078. The report used observed speed data to estimate the ratio between posted and free flow speeds for freeways and arterials. The use of the local adjustment factor of 1.0 was based on the validation of the HRTPO Model.

Table 2-12: Free Flow Speed Adjustment Factors

Roadway Class	Free Flow Speed Adjustment
Interstate	1.130
Freeway	1.130
Arterial	1.035
Local	1.000

Link Capacity is assigned in a per hour per lane unit and is a function of the link facility type and area type combined into a link class variable. In Table 2-13, the first digit of class refers to the facility type and last digit is the area type.

Table 2-13: Per Hour Per Lane Capacity

Class	Capacity	Class	Capacity
100	0	700	0
101	1,850	701	550
102	1,900	702	600
103	1,900	703	650
104	1,900	704	700
105	2,000	705	800
200	0	800	0
201	1,200	801	400
202	1,250	802	425
203	1,300	803	450
204	1,400	804	475
205	1,500	805	500
300	0	900	0
301	900	901	1,500
302	950	902	1,550
303	1,000	903	1,600
304	1,100	904	1,650
305	1,150	905	1,700
400	0	1000	0
401	850	1001	800
402	900	1002	900
403	950	1003	900
404	1,000	1004	1,000
405	1,050	1005	1,000
500	0	1100	0
501	800	1101	9,999
502	850	1102	9,999
503	900	1103	9,999
504	950	1104	9,999
505	1,000	1105	9,999
600	0	1200	0
601	700	1201	9,999
602	750	1202	9,999
603	800	1203	9,999
604	850	1204	9,999
605	900	1205	9,999

Using a method similar to calculation of a peak hour, using the hourly data, a max hour volume and total period volume were identified. A period specific K-factor was then calculated and is used to calculate a period specific capacity in the traffic assignment phase of the model. This method provides a period capacity that reflects the peaking characteristic of the period. The period factors were calculated using a summary of hourly count data in 2015 as provided by VDOT (March 7, 2019)

Table 2-14: Period Capacity Factors

Period	Hours	Max Hour	Total Period Volume	K Factor
AM	6am to 9am	56630928	155489236	2.75
MD	9am to 3pm	63156919	334339814	5.29
PM	3pm to 6pm	71492433	210672386	2.95
NT	6pm to 6am	55428803	257687310	4.65
DAILY		71492433	958188746	13.403

2.4.3 Traffic Counts

Traffic counts in Virginia are assigned/identified via a TMS identification. For two-way links, the TMS value represents the total two way volume. On freeway and interstates, VDOT assigns a unique TMS by direction. In the HRTPO Model, there are 1,883 unique TMS locations in the network that include a combination of one way and two way counts. The following tables provide a summary of the number of counts by Facility Type (Table 2-15), Area Type (Table 2-17) and jurisdiction (Table 2-16).

Table 2-15: AWDT Locations by Facility Type (FACTYPE)

FACTYPE		Number of Unique Counts
1	Interstate/Principal Freeway	158
2	Minor Freeway	40
3	Principal Arterial/Highway	221
4	Major Arterial/Highway	119
5	Minor Arterial/Highway	676
6	Major Collector	156
7	Minor Collector	510
8	Local	11
Total		1891

Table 2-16: AWDT Locations by Jurisdiction (JURIS)

Jurisdiction		Number of Unique Counts
1	Chesapeake	228
2	Norfolk	301
3	Portsmouth	167
4	Suffolk	140
5	Virginia Beach	323
6	Isle of Wight	72
7	Newport News	147
8	Hampton	168
9	Poquoson	13
10	Williamsburg	38
11	James City	72
12	York	78
13	Gloucester	44
14	Franklin	39
15	Southampton	61
Total		1891

Table 2-17: AWDT Locations by Area Type (ATYPE)

ATYPE		Number of Unique Counts
1	CBD	6
2	Urban	375
3	Dense Suburban	393
4	Suburban	412
5	Rural	705
Total		1891

2.5 Transit Network

The transit routes operated by Hampton Roads Transit (HRT), Williamsburg Area Transit Authority (WATA), and Suffolk Transit are coded in the CUBE network. The bus service from Gloucester to Newport News is also added to the transit network. The transit network used in the HRTPO model includes the following services:

1. Southside Services
2. Peninsula Services
3. Virginia Beach Wave Services
4. Peninsula Commuter Services
5. MAX Services
6. LRT/Ferry Services
7. Suffolk Services
8. WATA services

All transit routes were coded to replicate the scheduled service, routing patterns and stops for peak period and off-peak periods, the peak period being 5-9 am and 3:00-6 pm, and the off-peak period being 9am-3:00pm and 6pm-6am.

The transit networks and the processes are stored and executed within the Public Transport (PT) module in CUBE Voyager. Transit access, egress and transfer links are built using PT procedures. The transit system is modeled as walk-to-transit and drive-to-transit in the peak and off-peak periods. The base year networks consist of nine PNR lots for all transit routes and four PNR lots for LRT as follows:

1. Silver Leaf
2. Greenbrier Mall
3. Indian River
4. Magnolia
5. Ferry PNR
6. Route 17/Hayes Plaza in Gloucester
7. Courthouse in Gloucester
8. Hampton Transfer Center
9. Denbigh (US 60 and Old Courthouse Way)
10. Newton Road LRT Station # 412
11. Newton Road LRT Station # 413
12. Newton Road LRT Station # 414139
13. Newton Road LRT Station # 415

PNR accesses to transit routes are defined using the highway network to simulate drive to transit opportunities.

The transit networks also include a fringe-park transit mode for the HBW trip purpose in the peak period. The fringe transit mode represents the opportunity of the daily commuters to park their cars in the outskirts of the CBD and then walk to their workplace. This differs from the traditional PNR in that the majority of the trip is done by using an automobile. Harbor Park, Harrison Opera House and Lot 39 are the fringe parking locations in the base year network.

The following modes have been used in the Hampton Roads model:

- Modes 1-2 represent HRT local buses and Suffolk Transit
- Mode 6 represents WATA buses
- Modes 3, 4 and 9 represent WAVE, Ferry and MAX respectively
- Mode 10 represent Fringe
- Mode 11 represents LRT
- Modes 16, 15 and 12 represent walk access, drive access and transfer respectively
- Mode 17 represents walk access/egress for WATA buses

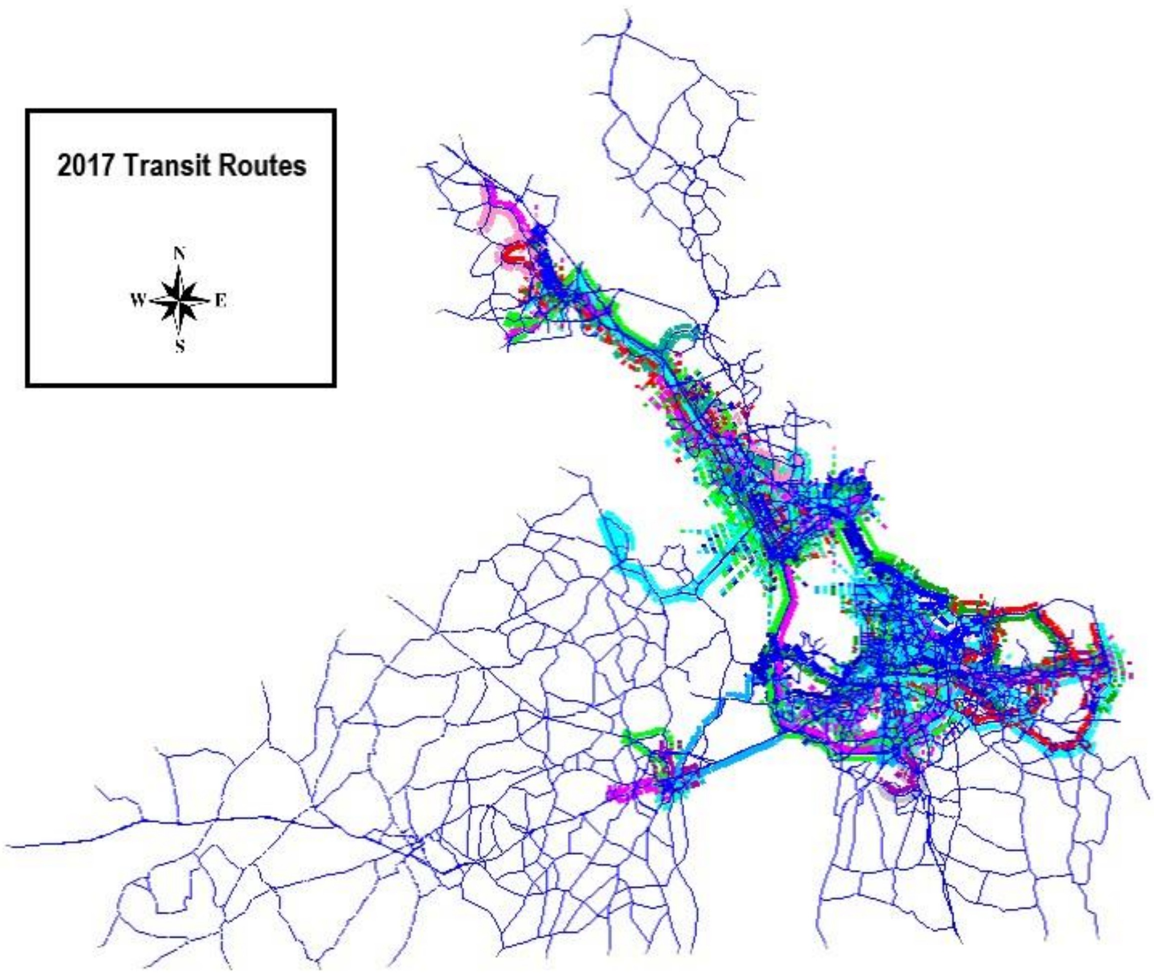


Figure 2-13: HRTPO 2017 Transit Networks

2.6 Travel Surveys and Other Observed Data

The following section describes the application of the 2009 NHTS datasets, transit survey data and additional observed data used for the model calibration from Streetlight and AirSage.

2.6.1 NHTS

The National Household Travel Survey data collected in 2009 and specific to the HRTPO area was used for several parts of the model calibration including:

- Estimation of Trip Production Rates
- Time of Day Factors (peak and off peak, and AM/PM, MD/NT)
- Average trip length and trip length frequency distribution
- Auto ownership distribution
- Mode choice calibration

Based on the NHTS dataset for all of Virginia, one thousand seven hundred and eighty-five households (1,785) were included in the HRTPO region that met the criteria to be included in the analysis. Criteria included:

- All household members included in the survey data collection
- Survey data was collected for a non-weekend travel day
- Survey data was collected during non-summer months

For those 1,785 households, the NHTS reported nearly 20,000 trips classified by trip purpose (HBW, HBO, HBShop, HBSocialRec, NHB) and by geography of the trip including those made internal the model area as well as those with trip ends outside the area.

2.6.2 Streetlight GPS OD Data

Streetlight GPS Origin Destination Data was used for several purposes as part of the HRTPO Model development. Uses included:

- Development of External to External through matrices (auto and truck)
- Development of External / Internal ratios (auto and truck)
- Validation targets for jurisdiction to jurisdiction distributions by purpose

Data was extracted from the Streetlight InSight portal made accessible using VDOT's statewide agreement with the data vendor.

2.6.3 AirSage Cell Phone OD Data

VDOT provided the WRA Team access to the statewide AirSage Cellphone based origin destination data. AirSage data is based on cellphone provider information and expanded to the population by the data provider. For purpose of the calibration of the HRTPO Model, jurisdiction to jurisdiction flows were defined by HBW, HBO and NHB from AirSage. The data was then further refined to look at the distribution pattern from each jurisdiction to its destination counties.

AirSage estimates the following number of person trips by purpose that are internal to the model area:

- HBW = 811,092
- HBO = 1,908,572
- NHB = 1,330,018

Table 2-18 below provides a summary of the jurisdiction to jurisdiction trips from AirSage.

Table 2-18: AirSage Cellphone Trip Tables by Jurisdiction

HBW	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	51137	19517	10109	5217	22448	614	2281	1593	9	26	125	149	32	72	65
Norfolk City	17258	44746	7640	3348	35034	471	3048	3156	103	30	114	520	54	58	83
Portsmouth	9620	8083	13035	4528	5470	709	2159	1362	40	19	57	151	10	132	95
Suffolk	5436	3977	4833	17682	2045	2077	2451	1465	41	25	67	215	9	612	465
VA Beach	22376	38352	5875	1930	140750	204	2469	1986	20	30	112	216	46	46	40
Isle of Wight	646	603	812	2230	206	6219	2222	955	18	10	157	111	19	649	472
Newport News	2095	3133	1917	2090	2125	1850	45290	22212	1118	1149	4532	9796	1912	97	120
Hampton City	1585	3670	1373	1336	2049	821	23437	30325	837	336	1303	4997	450	31	27
Poquoson	12	137	45	50	20	14	1302	978	260	18	62	413	36	0	0
Williamsburg	22	37	19	24	23	8	998	305	16	589	2935	1063	154	0	0
James City	122	146	55	69	105	157	4578	1237	63	3317	13828	4182	632	0	10
York	139	668	159	208	214	95	10504	5341	440	1148	3998	7586	1215	14	6
Gloucester	42	67	13	14	51	20	2340	535	40	202	708	1283	7489	0	0
Franklin	75	76	125	593	40	611	104	38	0	0	0	6	0	218	1881
Southampton	88	110	136	575	44	480	149	37	0	0	14	7	0	2078	3311

HBO	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	173623	21053	18357	10020	31166	1024	2393	1984	51	72	501	406	83	229	264
Norfolk City	20653	145050	9147	3639	43321	581	3800	4664	118	113	390	873	203	127	177
Portsmouth	18207	9206	57031	8065	6602	845	2006	1486	27	36	189	249	86	94	160
Suffolk	9496	3731	7972	77432	3072	3765	2200	1482	36	39	220	273	50	910	840
VA Beach	31337	44166	6642	3097	405704	474	3044	3101	75	143	710	778	167	101	181
Isle of Wight	1011	608	827	3845	500	32612	2632	1507	34	29	349	255	38	1050	1671
Newport News	2401	3734	1974	2177	2997	2704	141983	30200	1561	1031	5405	16689	2820	105	161
Hampton City	1994	4601	1518	1473	3180	1495	30275	107528	1626	255	1665	6727	667	35	73
Poquoson	42	118	38	32	88	28	1522	1586	5617	27	154	1562	67	1	2
Williamsburg	76	104	27	36	147	33	1021	287	30	4599	4486	1758	235	2	4
James City	406	402	177	188	640	343	5276	1658	132	4369	56247	7157	935	13	35
York	416	910	239	259	825	262	16786	6901	1509	1741	7274	41080	2327	4	14
Gloucester	82	213	87	51	182	42	2750	696	74	252	959	2318	41077	0	4
Franklin	222	139	89	889	93	1045	112	43	1	1	11	6	0	6927	3292
Southampton	254	178	173	881	193	1627	174	71	1	4	41	16	9	3131	22279

NHB	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	98961	17087	11675	9003	28429	1258	2125	1907	73	75	401	441	147	212	427
Norfolk City	22735	91498	8820	4998	45136	839	3896	5039	172	178	494	1020	280	134	261
Portsmouth	14162	8720	26284	6649	6912	992	1670	1449	55	32	183	336	118	122	234
Suffolk	8731	3581	5541	51702	3443	4536	1965	1539	47	53	218	313	61	1050	1095
VA Beach	29508	37132	4986	3493	250422	569	2667	2833	64	201	746	862	200	86	208
Isle of Wight	1008	630	688	4138	541	22556	2441	1362	31	35	305	216	38	1182	2101
Newport News	3027	3406	1811	2646	3567	3292	70400	22600	1288	1113	5009	13314	3684	94	245
Hampton City	2089	4069	1210	1625	3162	1540	20911	51024	1283	343	1470	5684	888	31	95
Poquoson	53	96	17	26	39	20	1028	1083	1746	25	93	930	67	0	1
Williamsburg	85	122	35	50	266	45	1166	394	24	3744	5647	2788	359	1	3
James City	365	388	151	266	778	531	4932	1603	117	5470	38355	8593	1161	6	40
York	464	718	193	293	857	261	12622	4832	1018	2687	8712	22582	3148	9	18
Gloucester	112	207	63	45	190	39	2750	711	82	292	1005	2750	32191	3	6
Franklin	194	106	100	951	97	1132	56	26	0	0	6	9	3	3461	3478
Southampton	381	212	147	936	278	2086	166	91	2	7	37	26	8	3437	19328

2.6.4 Transit Ridership and Park and Ride Utilization

Transit ridership data was provided by HRTPO from 2014 to 2018 by transit route. October 2015 was selected as the base for the model calibration and validation. Transit ridership for this month, therefore, was collected from different sources. Total daily transit ridership in 2015 is 58,612 and Table 2-19 reports the daily ridership by service in 2015.

Table 2-19 Daily Observed Transit Ridership by Service (2015)

Service	Ridership
Southside	32,794
Peninsula	14,891
VB Wave	4
Peninsula Commuter	467
Max	1,736
LRT/Ferry	5,541
Suffolk	243
WATA	2,935
Total	58,612

3 TRIP GENERATION

The first phase in the model is Trip Generation where the zonal productions and attractions by purpose are calculated. As part of the Trip Generation phase, trips are assigned to the peak and off peak periods. A change to the 2017 HRTPO Model is the use of a data driven external model that captures the external-external as well as external-internal movements.

3.1 Trip Production Rate Calibration

Using the updated NHTS dataset as described in 2.6.1, updated production rates were calculated using the weighted data. The trip rates were further stratified by internal vs internal-external travel as well as total travel. The analysis included only trips made by households internal to the HRTPO region, where all household members were surveyed and the survey day was a Monday to Friday during the non-summer months consistent with the definition of the model. Because of the approach taken to developing the household weights in the NHTS dataset being focused on matching a statewide total and not weighted for local populations, it is not possible to use the number of reported trips from NHTS as a comparison to the model.

Using the number of households in the sample stratified by household size and vehicle ownership, the number of households in each bin were calculated from NHTS as shown in Table 3-1. This represents a total of 1785 surveyed households. Using the household expansion factors, the expanded sample is 339,609 households, or approximately ½ of the total HRTPO 2017 area household number as per the 2017 TAZ land use data.

Table 3-1: NHTS Weighted Household Distribution

Weighted HH		**Vehicles per Household**				
		0	**1**	**2**	**3**	Total
Household Size	**1**	20,193	61,389	19,146	5,960	106,688
	2	2,432	20,081	56,181	23,540	102,234
	3	1,159	8,961	23,170	25,633	58,922
	4	1,779	6,237	30,737	33,011	71,765
Total		25,563	96,667	129,234	88,145	339,609

The productions rates were calculated by first assigning the reported trips from NHTS to the respective size categories consistent with the household distributions. Trip rates were then calculated on a cell by cell basis. The total trips by purpose and geography (II vs IE) are shown in Table 3-2.

Table 3-2: Total Trips by Purpose and Geography

	NHTS	Daily	II	IE	II + IE Rate	II Rate
HBW	216,572,977	593,351	211,252,178	5,320,799	1.75	1.70
HBS	232,480,373	636,933	229,338,343	3,142,030	1.88	1.85
HBSR	139,729,838	382,821	135,695,481	4,034,357	1.13	1.09
HBO	257,930,119	706,658	249,667,124	8,262,995	2.08	2.01
NHB	332,607,928	911,255	322,810,264	9,797,664	2.68	2.60
HH Weight	339,609				9.51	9.27

Once the raw trip rates were calculated, different strategies were considered to improve the overall logic of the trip rates to ensure increasing rates by household size and ownership. Approaches considered included:

- Option 1: Adjustment of the 2009 rates to the revised rate totals. Using the 2009 production rates, the overall rates were adjusted based on a factor to the ratio of the 2009 to revised rates.
- Option 2: Iterative Proportional Fitting (IPF) applied to the raw production rates matrices to align with desired marginal trip rates by household size and vehicle ownership.
- Option 3: Cell compression of household size and vehicle ownership and manual adjustment.

Each method was tested based on ability to maintain consistency of the trip rate marginals and overall pattern of increasing trip rates by size variable. Option 3 was selected as the preferred option. Cells were compressed based on either low frequency of observed trips or cases were trips would not logically increase (ie vehicle ownership exceeds household size).

As part of the model calibration, an analysis was also done with the NHTS data to evaluate the difference in trip making by area type to see if unique production rates by area type were warranted. The directionality of the adjustments by area type was not consistent across trip purposes (Table 3-3). Also due to limited samples by area type, there was not confidence in the factors to be applied.

Table 3-3: Area Type Production Rate Variation

Purpose	AreaType	Ratio (Area Type / Average)
HBW	1	
	2	1.034
	3	0.850
	4	1.152
	5	0.980
HBShop	1	
	2	1.296
	3	0.906
	4	0.876
	5	1.056
HBSocRec	1	
	2	0.945
	3	0.832
	4	1.085
	5	1.077
HBO	1	
	2	1.298
	3	0.634
	4	0.962
	5	1.187

The following tables provide the production rates input into the model by purpose stratified by household size and vehicle availability and area type. In addition to the cell compression (Option 3) described above, the final production rates were increased by 20% based on validation results of the model. The additional factor on trip generation accounts for potential under reporting in the NHTS.

Table 3-4: Input Production Rates - HBW

TRIPPURP	AREATYPE	PERSHH	AUTOHH0	AUTOHH1	AUTOHH2	AUTOHH3+
HBW	1	1	0.633	1.052	1.052	1.052
HBW	1	2	0.633	1.231	1.893	1.893
HBW	1	3	1.010	2.511	2.511	3.880
HBW	1	4	1.010	2.609	2.609	4.591
HBW	2	1	0.633	1.052	1.052	1.052
HBW	2	2	0.633	1.231	1.893	1.893
HBW	2	3	1.010	2.511	2.511	3.880
HBW	2	4	1.010	2.609	2.609	4.591
HBW	3	1	0.633	1.052	1.052	1.052
HBW	3	2	0.633	1.231	1.893	1.893
HBW	3	3	1.010	2.511	2.511	3.880
HBW	3	4	1.010	2.609	2.609	4.591
HBW	4	1	0.633	1.052	1.052	1.052
HBW	4	2	0.633	1.231	1.893	1.893
HBW	4	3	1.010	2.511	2.511	3.880
HBW	4	4	1.010	2.609	2.609	4.591
HBW	5	1	0.633	1.052	1.052	1.052
HBW	5	2	0.633	1.231	1.893	1.893
HBW	5	3	1.010	2.511	2.511	3.880
HBW	5	4	1.010	2.609	2.609	4.591

Table 3-5: Input Production Rates - HBS

TRIPPURP	AREATYPE	PERSHH	AUTOHH0	AUTOHH1	AUTOHH2	AUTOHH3+
HBS	1	1	0.688	1.001	1.001	1.001
HBS	1	2	1.352	1.380	2.208	2.208
HBS	1	3	1.352	2.865	2.865	2.865
HBS	1	4	1.352	3.911	3.911	4.324
HBS	2	1	0.688	1.001	1.001	1.001
HBS	2	2	1.352	1.380	2.208	2.208
HBS	2	3	1.352	2.865	2.865	2.865
HBS	2	4	1.352	3.911	3.911	4.324
HBS	3	1	0.688	1.001	1.001	1.001
HBS	3	2	1.352	1.380	2.208	2.208
HBS	3	3	1.352	2.865	2.865	2.865
HBS	3	4	1.352	3.911	3.911	4.324
HBS	4	1	0.688	1.001	1.001	1.001
HBS	4	2	1.352	1.380	2.208	2.208
HBS	4	3	1.352	2.865	2.865	2.865
HBS	4	4	1.352	3.911	3.911	4.324
HBS	5	1	0.688	1.001	1.001	1.001
HBS	5	2	1.352	1.380	2.208	2.208
HBS	5	3	1.352	2.865	2.865	2.865
HBS	5	4	1.352	3.911	3.911	4.324

Table 3-6: Input Production Rates - HBSR

TRIPPURP	AREATYPE	PERSHH	AUTOHH0	AUTOHH1	AUTOHH2	AUTOHH3+
HBSR	1	1	0.405	0.405	0.695	0.695
HBSR	1	2	0.697	0.794	1.182	1.182
HBSR	1	3	0.697	1.508	1.508	2.087
HBSR	1	4	0.697	2.562	2.562	2.976
HBSR	2	1	0.405	0.405	0.695	0.695
HBSR	2	2	0.697	0.794	1.182	1.182
HBSR	2	3	0.697	1.508	1.508	2.087
HBSR	2	4	0.697	2.562	2.562	2.976
HBSR	3	1	0.405	0.405	0.695	0.695
HBSR	3	2	0.697	0.794	1.182	1.182
HBSR	3	3	0.697	1.508	1.508	2.087
HBSR	3	4	0.697	2.562	2.562	2.976
HBSR	4	1	0.405	0.405	0.695	0.695
HBSR	4	2	0.697	0.794	1.182	1.182
HBSR	4	3	0.697	1.508	1.508	2.087
HBSR	4	4	0.697	2.562	2.562	2.976
HBSR	1	1	0.405	0.405	0.695	0.695
HBSR	1	2	0.697	0.794	1.182	1.182
HBSR	1	3	0.697	1.508	1.508	2.087
HBSR	1	4	0.697	2.562	2.562	2.976

Table 3-7: Input Production Rates - HBO

TRIPPURP	AREATYPE	PERSHH	AUTOHH0	AUTOHH1	AUTOHH2	AUTOHH3+
HBO	1	1	0.601	0.520	0.520	0.520
HBO	1	2	2.885	1.567	1.209	1.209
HBO	1	3	2.885	3.010	3.467	3.467
HBO	1	4	2.885	3.010	6.785	6.785
HBO	2	1	0.601	0.520	0.520	0.520
HBO	2	2	2.885	1.567	1.209	1.209
HBO	2	3	2.885	3.010	3.467	3.467
HBO	2	4	2.885	3.010	6.785	6.785
HBO	3	1	0.601	0.520	0.520	0.520
HBO	3	2	2.885	1.567	1.209	1.209
HBO	3	3	2.885	3.010	3.467	3.467
HBO	3	4	2.885	3.010	6.785	6.785
HBO	4	1	0.601	0.520	0.520	0.520
HBO	4	2	2.885	1.567	1.209	1.209
HBO	4	3	2.885	3.010	3.467	3.467
HBO	4	4	2.885	3.010	6.785	6.785
HBO	5	1	0.601	0.520	0.520	0.520
HBO	5	2	2.885	1.567	1.209	1.209
HBO	5	3	2.885	3.010	3.467	3.467
HBO	5	4	2.885	3.010	6.785	6.785

The Trip Generation phase of the model calculates NHB trip productions using a cross classification process similar to the home based purposes. The production rates were estimated from the NHTS data in a similar approach as described above. The resulting productions and attractions are not used by the model stream as they are replaced by the output of the new NHB model described in later chapters of this documentation.

3.2 Attraction Rates

The HRTPO Model uses linear regression models to estimate the trip attractions by TAZ for each trip purpose. The resulting attractions are balanced to the production totals for the home based trip purposes. Attractions are a function of employment (retail, non-retail and total employment) as well as households and population for home based other trips. The attraction models were taken from the 2009 (V1) model.

Table 3-8: Attraction Rates

PURP	RETEMP	NONRETEMP	ALLEMP	HH	POP	DESCRIPTION
AHBW	1.154	0.477	0.000	0.000	0.000	HBW
AHBS	1.840	0.000	0.000	0.000	0.257	HBS
AHBO	0.000	0.000	0.000	2.220	0.000	HBO
ANHB	2.416	0.180	0.000	0.753	0.000	NHB

3.3 External Models

As part of the Trip Generation phase of the model, the external passenger and trucks are developed and assigned to the peak and off peak periods. The basis for the external demand is the Streetlight GPS Origin Destination data. An analysis was completed using Streetlight data based on 2015 where a trip table was generated capturing the external to external, external to internal and internal to internal movements. The resulting matrix is used as a seed in the model. Estimates of external demand distributed by auto and truck and purpose (EE vs EI) are input to the model. The model then uses the observed data from Streetlight to generate a year specific trip table of auto and truck trips by purpose.

3.3.1 Distribution of Internal – External Trips by Purpose

Initial estimates of the distribution of traffic at the external stations were based upon applying observed splits from the Streetlight datasets. The resulting proportions are applied to both auto and truck and result in the volume of trips by external through and external – internal by station. Table 3-9 provides a summary by external station. Based on the Streetlight data and 2017 count data assigned to the external stations, auto through trips represent less than 8% of the total external auto demand and less than 11% of truck external trips.

Table 3-9: 2017 External Distribution of Traffic

Station	Route	Jurisdiction	Auto	Auto EE	Auto EIIE	Truck	Truck EE	Truck EIIE	Total Volume
3000	ROUTE 13	Virginia Beach	9,473	973	8,500	397	78	319	9,870
3001	PRINCESS ANNE RD	Virginia Beach	3,406	224	3,182	143	6	137	3,549
3002	BLACKWATER RD	Virginia Beach	842	134	708	46	4	42	888
3003	CHESAPEAKE EXPY	Chesapeake	23,699	406	23,293	735	53	682	24,434
3004	HIGHWAY 17	Chesapeake	12,953	246	12,707	828	73	755	13,781
3005	CR 604	Suffolk	236	0	236	7	0	7	243
3006	CAROLINA RD	Suffolk	3,877	128	3,749	384	87	297	4,261
3007	ADAMS SWAMP	Suffolk	412	5	407	115	0	115	527
3008	WHALEYVILLE	Suffolk	4,703	36	4,667	643	68	575	5,346
3009	PITTMANTOWN	Suffolk	888	31	857	398	21	377	1,286
3010	US-258	Southampton	5,091	157	4,934	385	88	297	5,476
3011	STATESVILLE RD	Southampton	201	0	201	20	6	14	221
3012	NC-35	Southampton	1,297	104	1,193	177	90	87	1,474
3013	HUGO RD	Southampton	743	37	706	234	41	193	977
3014	LOW GROUND RD	Southampton	132	8	124	8	4	4	140
3015	AIRPORT DR	Southampton	9,877	167	9,710	2,170	93	2,077	12,047
3016	SC-610	Southampton	706	0	706	22	7	15	728
3017	COURTHOUSE RD	Southampton	305	51	254	35	8	27	340
3018	PLANK RD	Southampton	1,895	326	1,569	475	139	336	2,370
3019	WAKEFIELD RD	Southampton	417	0	417	21	4	17	438
3020	MAHONE HWY	Southampton	8,579	217	8,362	1,757	116	1,641	10,336
3021	JONES	Isle of Wight	321	0	321	4	2	2	325
3022	COLONIAL	Isle of Wight	3,930	15	3,915	297	8	289	4,227
3023	NEW KENT	James City	9,852	169	9,683	1,097	43	1,054	10,949
3024	I 64	James City	47,210	859	46,351	4,104	121	3,983	51,314
3025	RICHMOND	James City	5,544	96	5,448	115	10	105	5,659
3026	RTE 5	James City	3,128	22	3,106	65	2	63	3,193
3027	JAMESTOWN RD	James City	1,710	99	1,611	52	10	42	1,762
3028	JOHN CLAYTON MEMORIAL	Gloucester	13,177	121	13,056	370	35	335	13,547
3029	BUCKLEY HALL	Gloucester	921	287	634	30	21	9	951
3030	GEORGE WASHINGTON MEMORIAL	Gloucester	12,609	5,013	7,596	259	155	104	12,868
3031	LEWIS B PULLER MEMORIAL	Gloucester	7,129	5,572	1,557	620	355	265	7,749
3032	ADNER	Gloucester	4,307	143	4,164	277	18	259	4,584
3033	GREAT FORK	Suffolk	1,102	12	1,090	24	6	18	1,126

3.4 Initial Time of Day

The final phase of Trip Generation is to define the productions and attractions by purpose for the peak and off peak periods. For each trip in the NHTS dataset, the midpoint time of the trip was defined based upon the reported departure and arrival time. Using this midpoint time, each trip was assigned to an hour of the day (0 to 23). The distribution by hour by purpose is shown below in Figure 3-1. The distributions show a peaking of HBW trips in both the AM and PM periods as well as increasing discretionary travel through the day of both HBO and HBSH purposes.

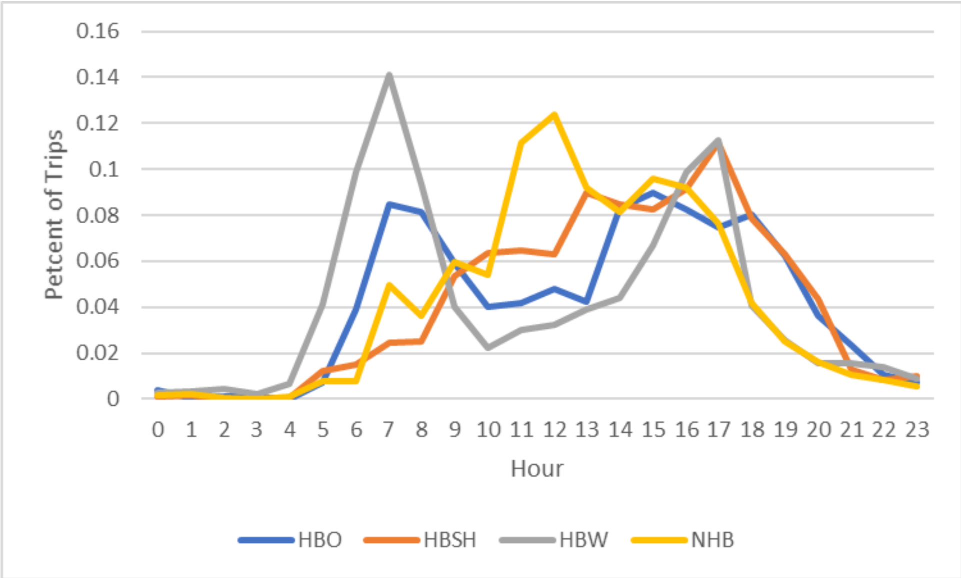


Figure 3-1: Hourly Distribution of Trips (Source: NHTS)

An analysis of the percent of trips by period led to the definition of time periods for the model as shown in Table 3-10.

Table 3-10: Time of Day Period Definitions

Period	Time
AM	6am to 9am
MD	9am to 3pm
PM	3pm to 6pm
NT	6pm to 6am

The daily production and attractions are distributed into peak and off-peak trips based on factors calculated from the NHTS observed trips. As expected, over 60% of work trips occur in the peak period as compared to a higher proportion of discretionary travel occurring in the off peak (Table 3-11).

Table 3-11: Peak vs Off Peak Time of Day Factors

	PURPOSE	Peak (6am – 9am, 3 – 6pm)	OP (6pm – 6am, 9am – 3pm)
TRIPS	HBW	356,563.41	222,209.69
	HBO	700,112.81	983,999.37
	NHB	317,836.08	566,575.60
PERCENT	HBW	0.616	0.384
	HBO	0.416	0.584
	NHB	0.359	0.641

VDOT provided a sample of counts within the HRTPO model area that included hourly distributions. From those counts a percentage of total VMT by peak and off peak periods was calculated. A comparison of the NHTS distribution of trips to the distribution of traffic observed by hour of day shows a good comparison.

Table 3-12: Trip Distribution NHTS vs Count Data

Period	NHTS Total Trips	Hourly Count AWDT
Peak	43.7%	40.0%
Off Peak	56.3%	60.0%

4 Trip Distribution

The demand and assignment steps of the HRTPO 2017 Model are separated into a peak and off peak set of model steps. Each period has an independent feedback process described later in this report. The peak and off peak productions and attractions from trip generation are read into the distribution models along with a skim of travel times between each zone. Friction factors were calibrated for the HRTPO Model using the NHTS dataset along with modeled travel times.

4.1 Level of Service Inputs

The HRTPO Model uses the travel time plus terminal time between each zone as input to the trip distribution model. The path for the associated travel time is based on the shortest travel time using the travel time plus toll time and is purpose specific. An additional penalty is added to trips crossing the Hampton Roads Harbor and is applied to both I-64 and I-664 corridors. The penalty was added during the model validation phase to improve the overall distribution and assignment results.

The toll times on each link are converted to a time value using a VOT that is specific to each purpose and mode (SOV, HOV2, HOV3). Table 4-1 presents the VOT used in the trip distribution phase of the model for peak and off peak models. The “Class” row refers to the mode and represents SOV, HOV2 and HOV3 respectively. The values of time are a compression of the values used in assignment which include an income dimension.

Table 4-1: Vale of Time (Trip Distribution)

Period	CLASS	HBW	HBO	NHB	EIIE	EE	VIS	TRK
Peak	1	16.44	9.81	11.27	14.68	18.90	11.96	38.00
	2	29.67	16.28	18.95	24.58	31.64	19.48	38.00
	3	44.17	22.93	26.95	34.64	43.81	27.59	38.00
Off Peak	1	16.48	9.82	11.25	14.59	18.78	11.52	38.00
	2	29.84	16.30	18.85	24.41	31.42	19.34	38.00
	3	44.81	22.96	26.83	34.38	43.48	27.38	38.00

Terminal Times are a measure of time required by a person traveling to or from a zone to access the transportation system. In urban cores this can represent the time to travel to parking lots which may be further from the trip activity. Values are typically lower in suburban and rural locations because of closer parking access. The terminal time is added to both the origin and destination end of the trip.

Table 4-2: HRTPO Terminal Time

Area Type	Terminal Time
CBD	4
Urban	4
Dense Suburban	2
Suburban	2
Rural	2

Intrazonal travel is based on the calculating the travel time to the nearest zone and taking a proportion of that value as the time to access the network from the TAZ. Based on the model validation, 40% of the travel time to the nearest zone was used in the urbanized areas and 50% in more rural jurisdictions.

These percentages were based on analysis of the intrazonal travel reported by NHTS as well as observed vs model count conditions.

The skimming process in the model generates a skim matrix for each trip purpose and mode specific to the values of time, corresponding terminal time and intrazonal travel time of the origin and destination zone. The associated travel time of the shortest time + toll time path is used assigning the friction factor value.

4.2 Gravity Model and Friction Factor Calibration

Trip Distribution for home based purposes is based on the application of a gravity model. Friction factors were estimated for peak and off peak home based trip purposes using an iterative estimation process. The 2009 friction factors were used as the starting point for the model estimation. The model was run through feedback. The resulting trip length frequency distributions were then compared to distributions generated from the peak and off peak observed trips from NHTS using the same travel time skims. Adjustment values were then calculated at each minute by purpose. The resulting friction factors were then fed back to the model where the distribution phase was rerun. The process was repeated until the modeled trip lengths and distribution patterns were in alignment with the observed data. The final set of friction factors were then smoothed to ensure they were a continuously decreasing value.

Table 4-3 reports the modeled and observed average trip lengths by peak and off peak purposes for the home based and external-internal trip purposes. The observed trips for the IE and EI purposes is based on the Streetlight seed matrix used in the Trip Generation phase of the model. All internal home based purposes have an average trip length within + or – 10% of the observed data using the consistent travel time skims.

Table 4-3: Trip Distribution Calibration Results

Period		HBW	HBS	OTH	IE	EI
Peak	Model	26.5	15.5	14.7	33.4	38.1
	Observed	24.7	14.2	14.1	29.8	34.8
	% Diff	7%	9%	4%	12%	9%
	Diff	1.8	1.2	0.6	3.6	3.3
Off Peak	Model	21.3	14.6	14.0	35.9	36.3
	Observed	21.5	14.3	14.7	32.3	34.2
	% Diff	-1%	2%	-5%	11%	6%
	Diff	-0.1	0.3	-0.7	3.6	2.1

The following series of figures provide a comparison of the observed and model trip length frequency distributions.

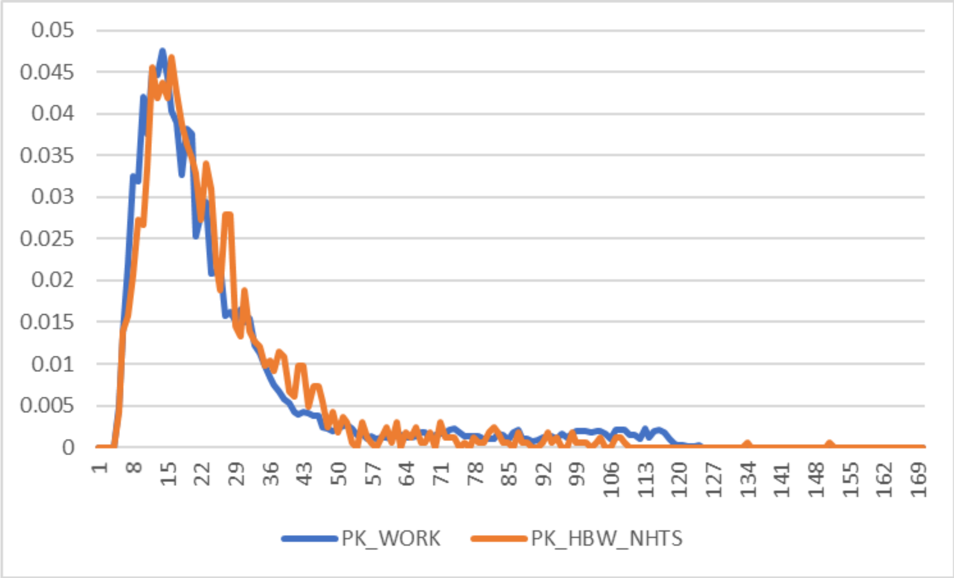


Figure 4-1: HBW Peak Trip Distribution Calibration

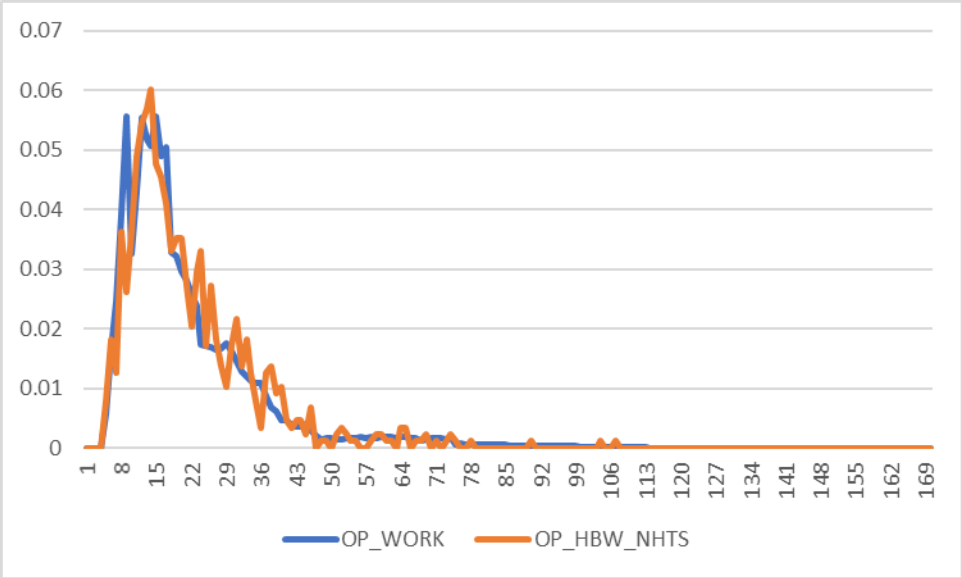


Figure 4-2: HBW Off Peak Trip Distribution Calibration

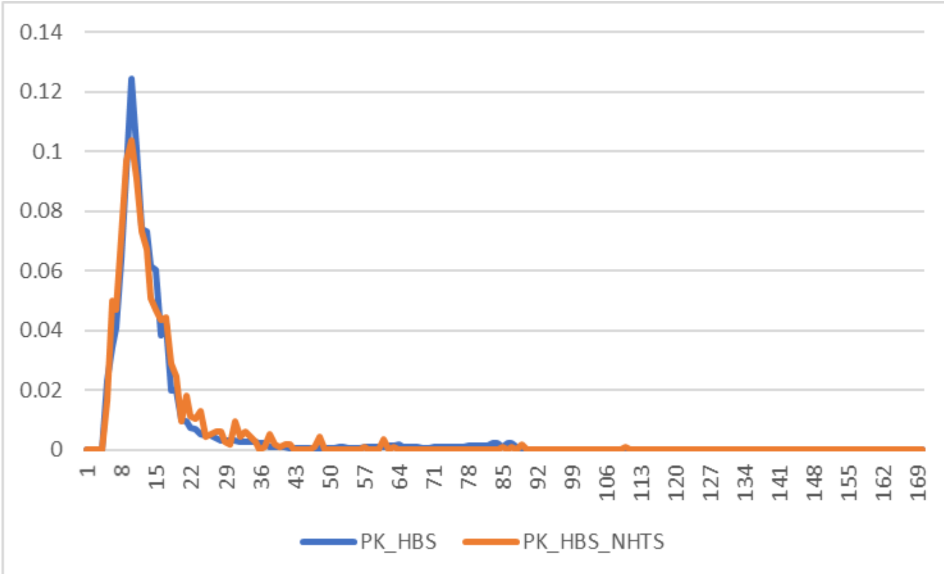


Figure 4-3: HBS Peak Trip Distribution Calibration

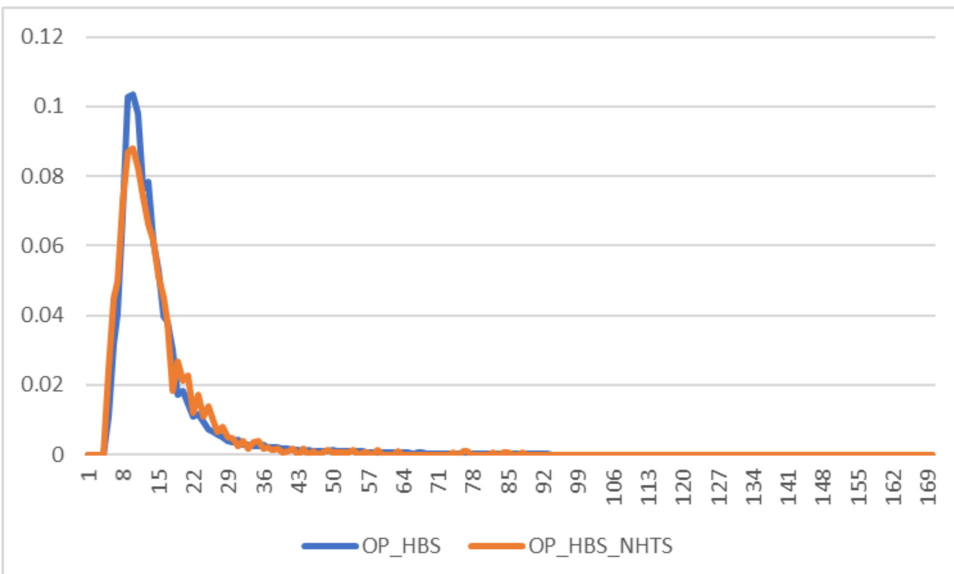


Figure 4-4: HBS Off Peak Trip Distribution Calibration

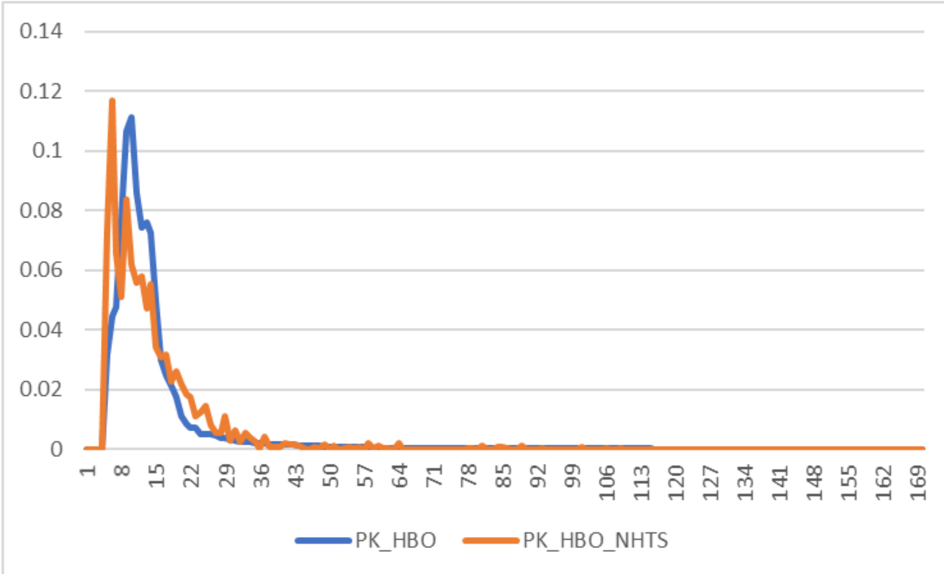


Figure 4-5: HBO Peak Trip Distribution Calibration

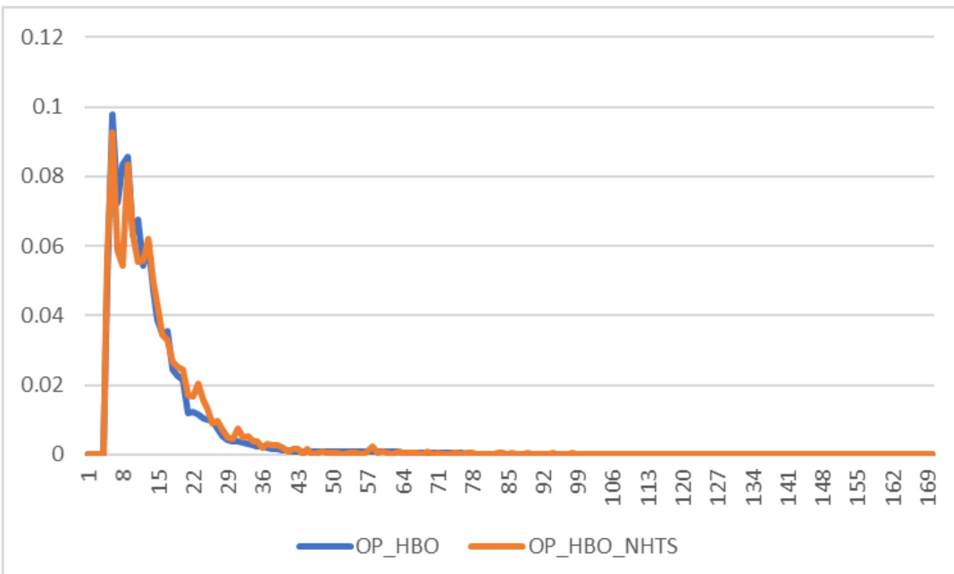


Figure 4-6: HBO Off Peak Trip Distribution Calibration

4.3 Zero Car Household Trips

Output from the trip generation model includes the productions and attractions by trip purpose stratified by auto availability. This includes trips made by zero car and 1+ car households. Prior to trip generation the zonal households are distributed into household size and auto ownership to support the cross-classification production models, the resulting trips from those households are retained. Figure 4-7 and Figure 4-8 below show the household stratification curves for household size and auto ownership respectively. The model calculates the average household size and average autos per household for each TAZ based upon the zonal input data and applies the corresponding distribution of zones for the given independent variable.

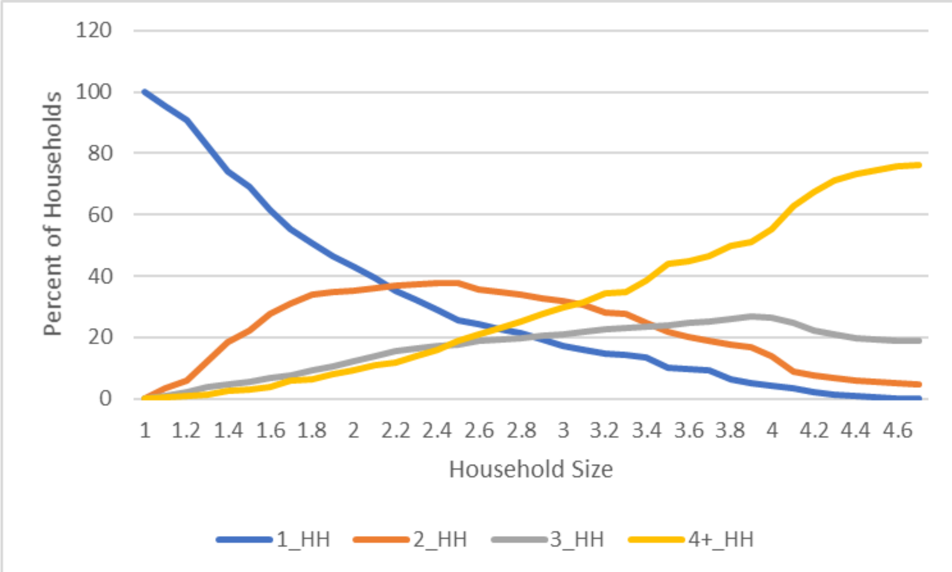


Figure 4-7: Household Size Household Stratification Curves

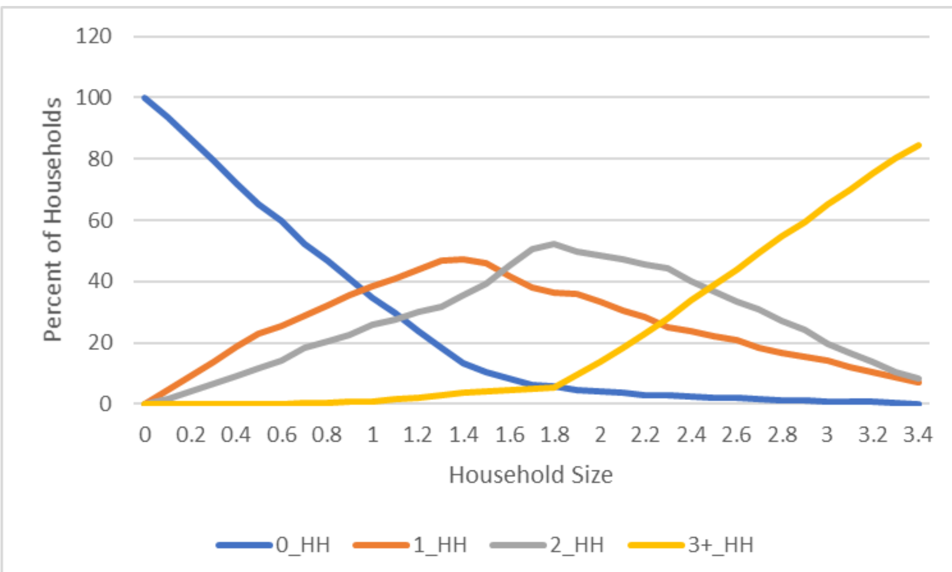


Figure 4-8: Auto Ownership Household Stratification Curves

After the total trips for all auto ownership sizes are distributed for peak and off peak periods, the model uses the outputs from trip generation to estimate the specific zone to zone trips that are made for the zero and non-zero households. The process uses the identified zero car household productions and attractions to establish a control total of P's and A's by purpose. The output trip table from distribution then split into a zero car and non-zero car share using a FRATAR method based on the calculated production and attraction targets.

Table 4-4 below reports the 2017 trips by trip purpose for zero and non-zero car households as output by the final step of the trip distribution phase of the model for both peak and off peak periods. These trips are then used by mode choice.

Table 4-4: 0 Car Household Trips by Purpose

Purpose	Auto	Peak	Off Peak
HBW	0	25,998	25,093
	1+	780,041	477,157
HBS	0	19,666	28,710
	1+	487,671	910,793
HBO	0	85,207	86,620
	1+	1,027,057	1,248,491

For model application, if it is desired to change the distribution of zero car household trips for a given zone, the zonal data must reflect a lower auto availability per household by adjusting the number of autos in the TAZ.

5 MODE CHOICE

The mode choice model was updated as part of the HRTPO model update. The new mode choice model includes a new trip mode which is called Mobility as a Service (MaaS). The mode choice model was updated for peak and off-peak periods. It computes the mode shares for drive alone, shared ride 2, shared ride 3+, walk-to-transit, drive to transit, fringe to walk, MaaS shared ride 2, and MaaS shared ride 3+ for each trip purpose in both the periods. Fringe to walk mode is only used for HBW trips during peak period.

This chapter explains the structure and methodology for the mode choice models It also describes the methodology for the transit path-building procedures.

5.1 Transit Path and Skims

For the purposes of the mode choice model, transit skimming is separately run for walk to transit routes in peak and off-peak periods. The transit path-building parameters such as the in-vehicle time weight, out-of-vehicle time weight, transfer penalty, and walk speed are based on the HRTPO Model Version 1.0 and are consistent with FTA national experience. Similarly, the other parameters such as walk access capture area and transfer distances are also based on the HRTPO Model Version 1.0.

Table 5-1 shows the in-vehicle weight, out-of-vehicle weights, transfer penalty, nest coefficients, and value of time used in mode choice model. The path weights reflect the way in which travelers perceive different aspects of travel time by transit. For example, walking to a bus stop or waiting for a bus is perceived as 2.5 times onerous than traveling on the bus. The parameters and weights are used to determine the shortest transit path from zone to zone. The evaluation of the transit path is done using CUBE Voyager's "Best Path" method in PT. The waiting times are assumed as half of the coded headways.

Table 5-1: Transit Model Weights

Coefficient	Value
In-Vehicle Travel Time (min)	-0.025
Out-of-Vehicle Travel Time (min)	-0.0625
Cost (cent)	-0.0015
Number of Transfers	-0.05
Auto/Transit/Fringe/MaaS Nest	0.5
Walk/Drive to Transit Nest	1.0
Drive Alone/Shared Ride Nest	1.0
Fringe to Walk Egress	-
MaaS Drive Alone/Shared ride nest	1.0
Auto Operating Cost (Cents/Mile)	10.5
Shared Ride 2 Occupancy	2
Shared Ride 3+ Occupancy	3.2
Value of Time ($/Hour)	10

Transit skimming is done for walk to transit and drive to transit in both peak and off-peak periods. Fringe paths are also used only for HBW purpose in the peak period. The model generates the following skims for fringe sub-modes:

- Fringe parking to charter bus (shuttle) egress
- Fringe parking to transit egress
- Fringe parking to walk egress

No shuttle or transit routes were used in 2015 by fringe parking users. As a result, the model is only generating trips for fringe parking to walk egress mode. Three dummy transit routes were defined in the transit route file (Dummy 1, Dummy 2, and Dummy 3 with mode 10) which connect major fringe parking lots to the highway network. These three major fringe parking lots are Harbor Park, Harrison Opera House, and Lot 39. The model, therefore, allows people to drive from zone centroids to fringe parking lots, take the dummy transit route to get to the highway network, and walk to their final destinations. The model can take fringe to transit and shuttle egress modes into consideration; however, it does not assign trips to these modes as there is no transit route or shuttles in the transit file to connect fringe parking lots to the highway network. Fares are coded as based on the single-trip cash fare in 2015 as shown in Table 5-2.

Table 5-2 Fares as Coded in the Model

Transit Mode	Fare ($)
Hampton Roads Buses	0.9
Peninsula Transit	0.9
Trolley	0.6
Ferry	0.9
WATA	0.75
Express MAX	1.80
LRT	0.9

A few assumptions and adjustments are done in skimming as a part of the transit validation process:

- The walk access capture distance for WATA buses is set to 1 mile unlike all other bus routes which have 0.75 miles as the walk access capture distance. Moreover, a 25% discount is given to the walk distance and time for the walk access/egress mode from/to WATA buses is 0.25% lower than other routes. Zones in Williamsburg and James City are generally larger than other areas in the model, which needs these adjustments to capture the walk access movements around College of William and Mary.
- A different walk access mode (mode 17) is, therefore, defined to build walk paths to WATA routes. All other transit routes use mode 16 for walk access/egress.

Transit times in the network are calculated as a function of the network highway times. An adjustment to the highway times was required, as transit times need to account for the stop-and-go conditions and for the acceleration and deceleration of the buses approaching and departing each bus stop. Transit times in the network are calculated using delay functions based on the area type and facility type of the links.

Transit time = Highway time + Distance x Delay in minutes/mile

The delay is expressed in minutes per mile. For example, a bus traveling in the CBD area on an arterial has more delay due to stop-and-go conditions, and a bus traveling on a freeway in a rural area with no stops has less or no delay. The delay in minute/mile by facility and area types were created as part of the model calibration process. Table 5-3 shows the delay in minutes/mile by facility and area types applied in Hampton Roads model for the peak period. Table 5-4 shows the delay in minute/mile for the off-peak period.

Table 5-3: Delay by Facility and Area Type in Minutes/Mile in Peak

Facility Type	CBD (1)	Urban (2)	Dense Suburban (3)	Suburban (4)	Rural (5)
Freeways (1)	0.00	0.00	0.00	0.00	0.00
Minor Freeways (2)	0.00	0.00	0.00	1.00	0.00
Principal Arterial (3)	2.00	2.00	2.00	2.50	2.50
Major Arterial (4)	2.00	2.00	2.00	2.00	2.00
Minor Arterial (5)	3.00	0.00	2.00	3.00	2.00
Major Collector (6)	2.00	2.00	0.30	0.30	0.30
Minor Collector (7)	4.50	3.50	0.30	2.00	0.30
Local Roads (8)	2.00	2.00	0.30	0.30	0.30
High Speed Ramp (9)	0.00	0.00	0.00	0.00	0.00
Low Speed Ramp (10)	0.00	0.00	0.00	0.00	0.00
Centroid Connector (11)	0.00	0.00	0.00	0.00	0.00
Ext Sta. Connector (12)	0.00	0.00	0.00	0.00	0.00

Table 5-4: Delay by Facility and Area Type in Minutes/Mile in Off-Peak

Facility Type	CBD (1)	Urban (2)	Dense Suburban (3)	Suburban (4)	Rural (5)
Freeways (1)	0.00	0.00	0.00	0.00	0.00
Minor Freeways (2)	0.00	0.00	0.00	1.00	0.00
Principal Arterial (3)	2.00	2.00	2.00	2.50	2.00
Major Arterial (4)	2.00	2.00	2.00	2.00	2.00
Minor Arterial (5)	3.00	0.50	2.00	2.00	2.00
Major Collector (6)	2.00	2.00	0.30	0.30	0.30
Minor Collector (7)	4.50	3.50	0.30	2.00	0.30
Local Roads (8)	2.00	2.00	0.30	0.30	0.30
High Speed Ramp (9)	0.00	0.00	0.00	0.00	0.00
Low Speed Ramp (10)	0.00	0.00	0.00	0.00	0.00
Centroid Connector (11)	0.00	0.00	0.00	0.00	0.00
Ext Sta. Connector (12)	0.00	0.00	0.00	0.00	0.00

5.2 Mode Choice Model Structure

The mode choice models subdivide the total person trip tables from the trip distribution model into separate trip tables for each travel mode by trip purpose. The share attracted to each mode is based on the travel characteristics of competing highway and transit services. This section describes the overall structure and methodology of the mode choice models used in the Hampton Roads model.

The HRTPO model has eight alternatives as follows:

1- Drive Alone (DA)
2- Shared Ride 2 (HOV2)
3- Shared Ride 3+ (HOV3+)
4- Walk to Transit
5- Drive to Transit
6- Fringe to Walk
7- Mobility as a Service with 1 passenger
8- Mobility as a service with 2+ passengers

Transportation network companies (TNC) that offer mobility as a service (MaaS) was added as an upper level mode, in competition with private auto, transit, and fringe. This new mode includes Uber and Lyft which are getting more popular and should be added to travel demand models; however, the calibration of the mode choice model for this mode is very challenging as there is no data to support the calibration.

In general, the proportion of trips selecting each mode is estimated using a logit function that relates the probability of selecting a mode to the relative utility of that mode compared to that of all other modes. The form of this function is as follows:

$$P_{g,i} = \frac{e^{[U_{g,i}(x_{g,i})]}}{\sum e^{[U_{g,m}(x_{g,m})]}}$$

where:

$P_{g,i}$ is the probability of a traveler from group g choosing mode i;

$x_{g,i}$ are the attributes of mode i that describe its attractiveness to group g; and

$U_{g,m}(x_{g,m})$ is the utility (or attractiveness) of mode m for travelers in group g.

The mode choice model for Hampton Roads is based on the nested logit form of this function which allows for sub-modal trade-offs to be more sensitive to service measures than higher level choices of the “main” modes.

The relative attractiveness or Utility of each travel mode takes the following form:

$$U_{g,m}(x_{g,m}) = a_m + b_m LOS_m + c_{g,m} SE_g + d_m TRIP$$

where:

$U_{g,m}(x_{g,m})$ is the utility (or attractiveness) of mode m for travelers in group g

LOS_m is a variable set describing levels-of-service by mode m;

SE_g is a variable set describing the socioeconomic characteristics of group g;

TRIP is a variable set describing the characteristics of the trip;

b_m is vector of coefficients describing the importance of each LOS_m variable;

$c_{g,m}$ is vector of coefficients describing the importance of each SE_g characteristic of group g with respect to mode m

d_m is vector of coefficients describing the importance of each TRIP characteristic of with respect to mode m, and

a_m is a constant specific to mode m.

The utility of each mode is based on the weighted average of the utilities of each sub-mode (shown in the utility diagram). Ultimately the utility of each sub-mode is defined as a function of travel times and costs depicted in the basic utility equations taking the nest coefficient into account as a factor to the utility. The contribution of each sub-mode's utility to the "full" mode utility is determined by the overall utility of each mode, which incorporates a relative contribution measure or nesting coefficient for each sub-mode. More details about the calibrated mode choice model are presented in the next section.

The Hampton Roads mode choice models are implemented using CUBE's XCHOICE module. A total of 8 mode choice models were developed in the model for all combinations of auto ownership, purpose (only home-based trips), and time period. The choice set for the mode choice model is depicted in Figure 5-1.

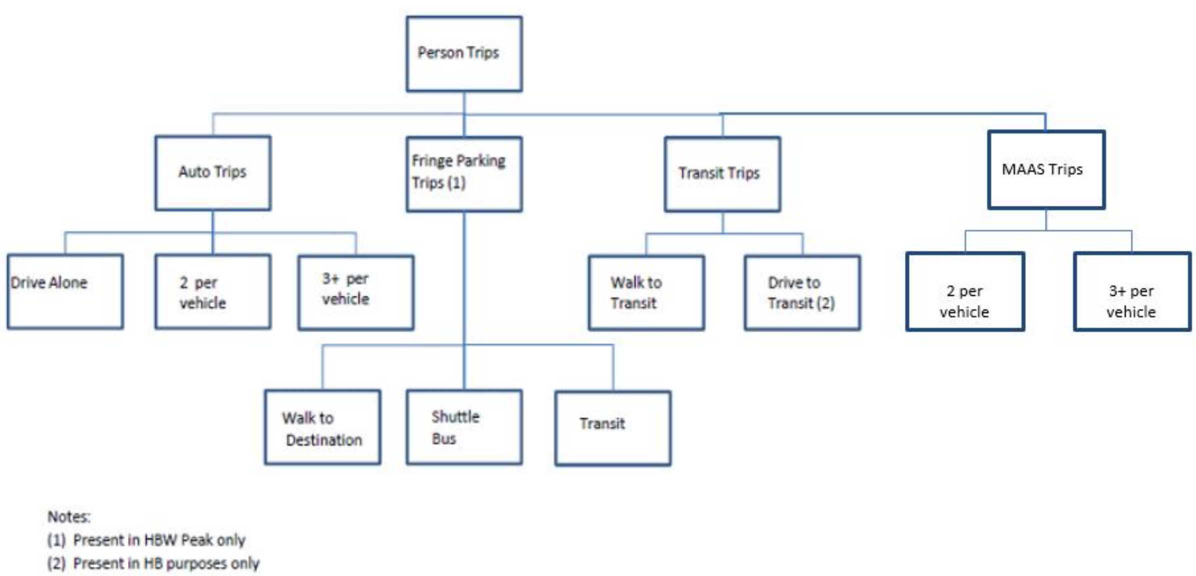


Figure 5-1: Mode Choice Nesting Structure

The mode choice models are carried out for I-I trips only for peak and off-peak periods and two trip purposes – HBW and HBO. Note that Home-Based Other and Home-Based Shopping local trips were combined and share the same mode choice model as they both behave similarly with respect to mode choice. Since no data was available for MAAS mode, this mode has a very high alternative specific constant to avoid sharing in daily trips. The utility function for MAAS should be calibrated in the next version of the model when the data becomes available.

5.3 Mode Choice Model Calibration

The mode choice model was calibrated to year 2015 conditions using auto/transit level of service data and 2015 modal usage targets by mode. Calibration involved adjusting the constants in the utility equations iteratively until the output trip totals by mode match the target values. This process is repeated for all the mode choice models. The project team analyzed the National Household Travel Survey (NHTS) 2009 data to calculate mode shares by trip purpose and time of day.

Moreover, the mode shares were calculated by using trip weights which exist in the NHTS data. Table 5 5 presents target mode shares obtained from NHTS analysis by trip purpose and time of day for I-I trips.

Table 5-5: Mode Shares by Trip Purpose and Time Periods for I-I Trips (NHTS 2015)

Mode	Peak			Off-Peak		
	HBW	HBO	NHB	HBW	HBO	NHB
Drive Alone	89.5%	41.9%	59.9%	89.0%	49.3%	56.5%
Shared Ride 2	7.1%	35.3%	25.6%	9.3%	31.5%	27.7%
Shared Ride 3+	2.9%	22.1%	13.6%	1.8%	19.0%	15.4%
Transit	0.5%	0.7%	0.9%	0.0%	0.2%	0.3%

Although walk to transit and drive to transit are two separate modes for trips in peak and off-peak periods, NHTS does not have enough data for each mode. As a result, the total mode share for transit is reported in Table 5 5. NHTS does not show any transit trips for HBW trips during off-peak period, which is due to the small sample size; however, the model assigns a few trips to transit for HBW.

6 Non-home Based Trips

Many of the well-recognized issues with the four-step model design are related to non-home-based (NHB) trips. Some of these issues include the inconsistency of the model with tours, the disconnection of NHB locations from home locations and HB trip locations, the disconnection of NHB trip modes from HB trip modes and mode choices, the inability to segment NHB trips by income for toll modeling, vehicle ownership for mode choice, special populations for EJ/equity analysis or home location for carbon accounting or fiscal analyses. In recent years activity- and tour-based models have risen in popularity in part in response to these issues with NHB trips. However, FHWA's Travel Model Improvement Program (TMIP) is soon to release a new report, which is being authored by RSG, illustrating simple methods for making a modest change to the structure of trip-based models which largely addresses all of the problematic issues with NHB trips.

6.1 Trip Generation and Mode Choice

The methods presented by TMIP derive from a basic insight into the inadequacy of the four-step model's approach to NHB trips. In the four-step model, trips are developed through the first two steps of generation and distribution. Behaviorally, these steps represent a traveler's choice of whether or how frequently to engage in an out-of-home activity (generation) and where to engage in that activity (distribution or destination choice). However, a trip is not generally defined by these two choices. Choosing to go out to eat and choosing where to eat out does not define a trip to the chosen restaurant without a third choice of where to go to the restaurant from; the origin is taken for granted. This is, of course, not a problem for HB trips, if it is known the home is the origin, but in general, and for NHB trips, in particular, these two choices or these two steps (generation and distribution) are not adequate to define a trip. A second spatial choice or distribution model is necessary to assign both an origin and destination to a NHB trip. The TMIP methods, therefore, correct this design flaw of four-step models by putting NHB distribution in series (rather than in parallel) with HB distribution and without requiring any changes to the HB model components. Sequenced together in this way, HB and NHB distribution can reasonably assign both the origin and destination to NHB trips. TMIP tested these methods with the Salt Lake City model and demonstrated their ability to resolve or improve most of the key problems with NHB trips in traditional four-step models.

The new method which is shown in Figure 6-1 requires no changes to the home-based trip models, but replaces traditional NHB models which run in parallel with the HB model components with new NHB generation and distribution models that run after and conditional on the HB model component results.

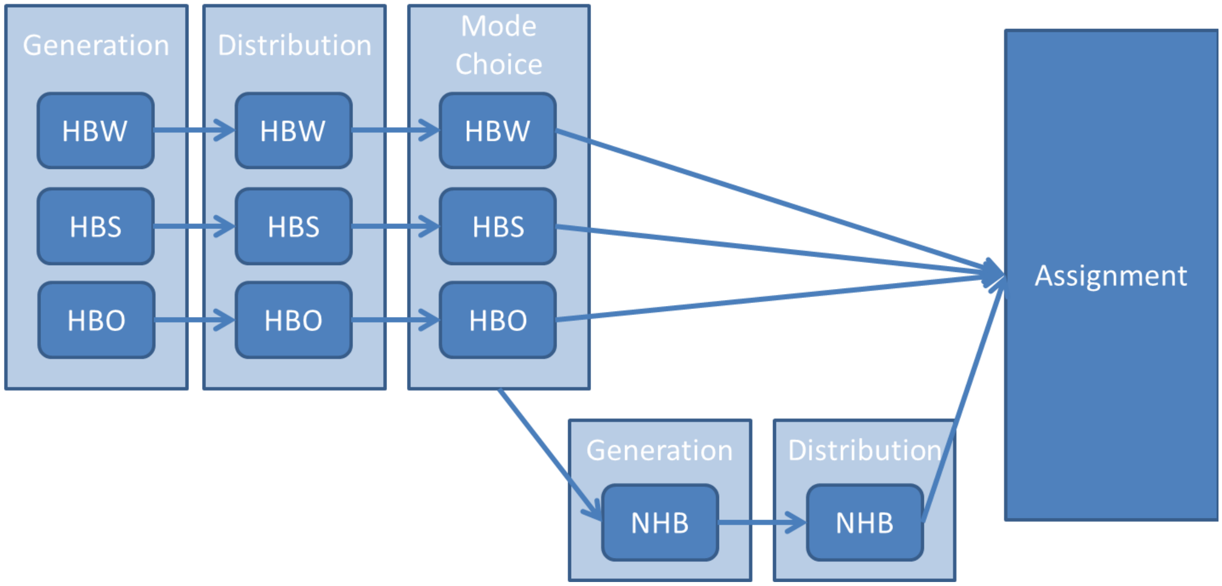


Figure 6-1 New TMIP Method for Improving NHB Trips

This new methodology to generate NHB trips includes two steps: in the first step, NHB trips are generated by mode using the home-based trips attracted to the zones. In the second step, NHB trips produced in the first step are scaled based on zonal accessibility.

Although the NHTS records for the HRTPO model area has limited sample size, it was used to calibrate eight models to estimate NHB productions/attractions by SOV, HOV2, HOV3+, and transit and time-of-day from home-based auto trip attractions by mode. Several configurations of trip purposes and modes were considered and tested by SPSS using linear regression to minimize the square error of the rates. Equations below present the best models calibrated based on the available NHTS data for peak period.

$$NHB_{SOV,i} = 0.12322 * HBW_{SOV,i} + 0.25612 * HBO_{SOV,i} + 0.24726 * HBO_{HOV2,i} + 0.22135 * HBO_{HOV3,i} - 0.18174 * HBW_{TRN,i}$$

$$NHB_{HOV2,i} = 0.01446 * HB_{SOV,i} + 0.14316 * HBW_{HOV2,i} + 0.13300 * HBO_{HOV2,i} + 0.04672 * HBO_{HOV3,i} - 0.08917 * HBW_{TRN,i}$$

$$NHB_{HOV3,i} = 0.00331 * HB_{HOV2,i} + 0.05834 * HBW_{HOV3,i} + 0.13940 * HBO_{HOV3,i} - 0.03585 * HBW_{TRN,i}$$

$$NHB_{TRN,i} = 0.30550 * HBW_{TRN,i}$$

Equations below present the best models calibrated based on the available NHTS data for off-peak period.

$$NHB_{SOV,i} = 0.36023 * HBW_{SOV,i} + 0.54531 * HBO_{SOV,i} + 0.07748 * HBO_{HOV2,i} - 0.04289 * HBO_{HOV3,i} + 0.07803 * HBO_{TRN,i}$$

$$NHB_{HOV2,i} = 0.02202 * HB_{SOV,i} + 0.10421 * HBW_{HOV,i} + 0.23211 * HBO_{HOV2,i} + 0.03305 * HBO_{HOV3,i} - 0.02033 * HB_{TRN,i}$$

$$NHB_{HOV3,i} = 0.05213 * HBW_{HOV2,i} + 0.01853 * HBO_{HOV2,i} + 0.24285 * HBO_{HOV3,i} + 0.00604 * HBO_{TRN,i}$$

$$NHB_{TRN,i} = 0.37185 * HBW_{TRN,i}$$

Where:

$NHB_{X,i}$: is the non-home based production\attraction of zone *i* by mode X,

$HBW_{X,i}$: is the home-based work attraction of zone *i* by mode X

$HBO_{X,i}$: is the home-based other attraction of zone *i* by mode X

$HB_{X,i}$: is the summation of home-based work and home-based other attraction of zone *i* by mode X

According to NHB trip generation equations, the NHB auto trip production and attraction of each zone is calculated using its home-based (HB) work and home-based other trip attractions by auto modes. Distribution and mode choice for HB trips, therefore, must be run before NHB trip generation.

As NHB trip generation equations present, home-based trips by HOV affect NHB trips by SOV although their impact is lower than SOV home-based trips. Similarly, SOV home-based trips impact on HOV NHB trips. These patterns are reasonable enough as people drive to work alone but they share their rides to go to a restaurant for lunch or people share their rides to go to work in the morning and the driver goes to another trip for other purposes in the middle of day. The same pattern exists for NHB transit trips too.

The second step of the NHB trip generation scales the NHB trips produced in the first step based on zonal accessibility. The main idea of this step is that NHB trips are shifted a little bit from zones with low trip attraction to zones with higher trip attraction. Accessibility is the measure defined to represent the attractiveness of zones for NHB trips. Equation below presents how general accessibility is calculated and Figure 6-2 presents the resulted general accessibility in the model area.

$$General\ Accessibility_i = \ln[\sum_{j=1}^{N} HBOA_j \times Exp(-0.7 \times t_{ij})]$$

Where:

$HBOA_j$: is the HBO attraction of zone *j*, and

t_{ij}: is the SOV travel time from zone *i* to zone *j*

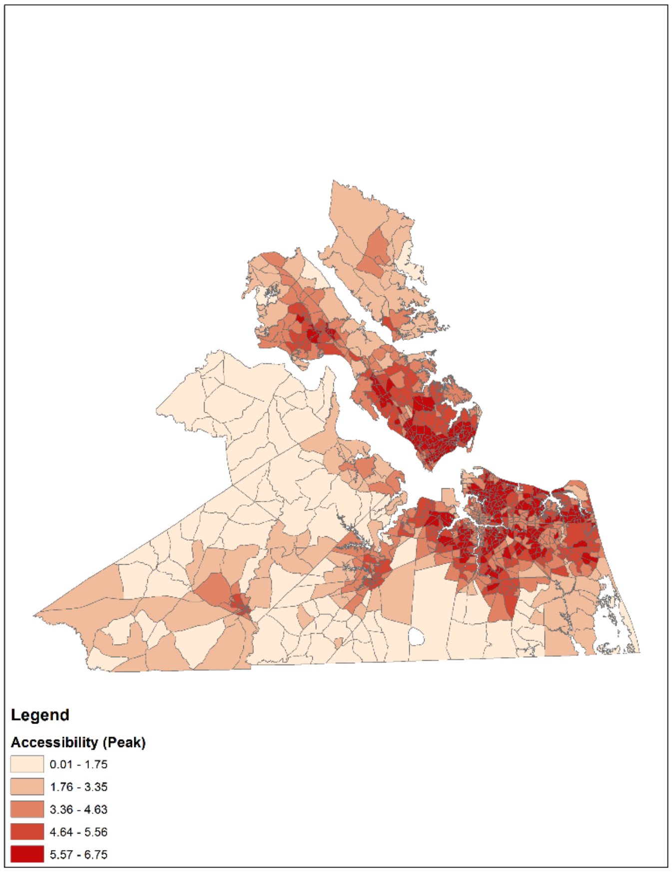


Figure 6-2 Zonal General Accessibility in the Model Area

Although the NHB trips are generated by analyzing NHTS data in the first step, the estimated NHB trips are not exactly match with the NHB trips in the survey. The second step, therefore, attempts to make the estimated NHB trips to the observations using general accessibility as follows:

$$ScaledNHB_{SOV,i} = 0.5845 \times Accessibility_i^{0.2721} \times NHB_{SOV,i}$$

$$ScaledNHB_{HOV,i} = 1.3308 \times Accessibility_i^{0.2210} \times NHB_{HOV,i}$$

$$ScaledNHB_{TRN,i} = 1.4104 \times Accessibility_i^{0.1351} \times NHB_{TOV,i}$$

Where:

$ScaledNHB_{X,i}$: is the scaled non-home based production\attraction of zone *i* by mode X,

$Accessibility_i$: is the general accessibility of zone *i*, and

$NHB_{X,i}$: is the non-home based production\attraction of zone *i* by mode X generated in the first step.

Coefficients used in the scaled NHB trip equations have been calibrated based on NHTS data using regression method. It should be mentioned that the HB trips are segmented by household income. The trip tables for each household group are then used to generate NHB trips for the corresponding household income group. In fact, the trip generation coefficients are the same over household income groups, but the input trip tables are different. Table 6-1 reports the NHB trips generated by this new methodology by mode and time period. Table 6-2 compares the resulted NHB mode shares with the target NHB mode shares. According to Table 6-2, the modeled NHB mode shares are very close to the targets.

Table 6-1 NHB Trips Generated Using Home-Based Trips by Time Period (2015)

TOD	DA	HOV2	HOV3+	TRN	Total
Peak	423,451	180,832	95,671	6,670	706,624
Off-peak	703,711	345,190	195,360	3,687	1,247,948
Daily	1,127,162	526,022	291,031	10,357	1,954,572

Table 6-2 Target and Modeled NHB Mode Shares by Time Period (2015)

Mode	Peak		Off-Peak	
	NHTS	Model	NHTS	Model
Drive Alone	59.9%	59.9%	56.5%	56.4%
Shared Ride 2	25.6%	25.6%	27.7%	27.7%
Shared Ride 3+	13.6%	13.6%	15.5%	15.6%
Transit	0.9%	0.9%	0.3%	0.3%

Similar to the previous version of the model, NHB transit trips are considered as walk to transit as NHTS does not provide sufficient data to split NHB transit trips between walk to transit and drive to transit.

6.2 Trip Distribution

The resulted NHB rips are then distributed using the corresponding skim (DA, HOV2, and HOV3+) and the recalibrated NHB friction factors. The recalibrated NHB friction factors are monotonically decreasing as the travel time increases, which is reasonable assumption. Figure 6-3 and Figure 6-4 illustrate the NHB friction factor for peak and off-peak period, respectively. Figure 6-5 and Figure 6-6 also show the modeled and observed NHB trip distributions for peak and off-peak periods. The modeled NHB trip distribution replicates the observed NHB trip distribution very well.

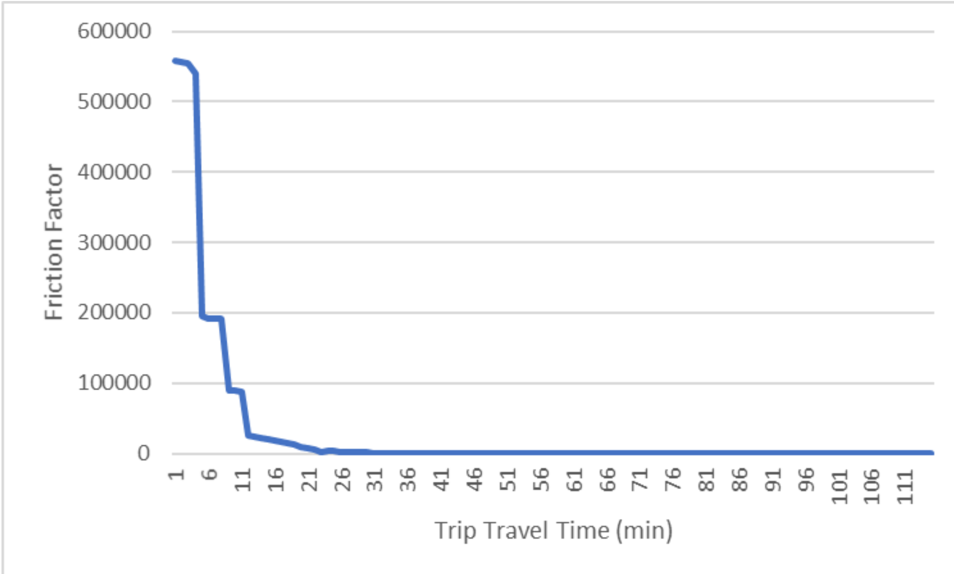


Figure 6-3 NHB Friction Factor in Peak Period

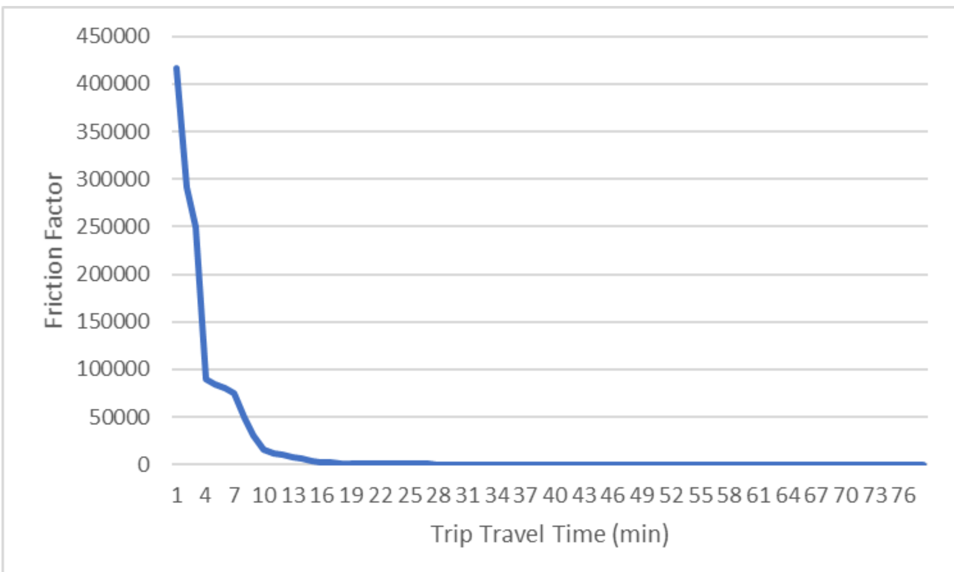


Figure 6-4 NHB Friction Factor in Off-Peak Period

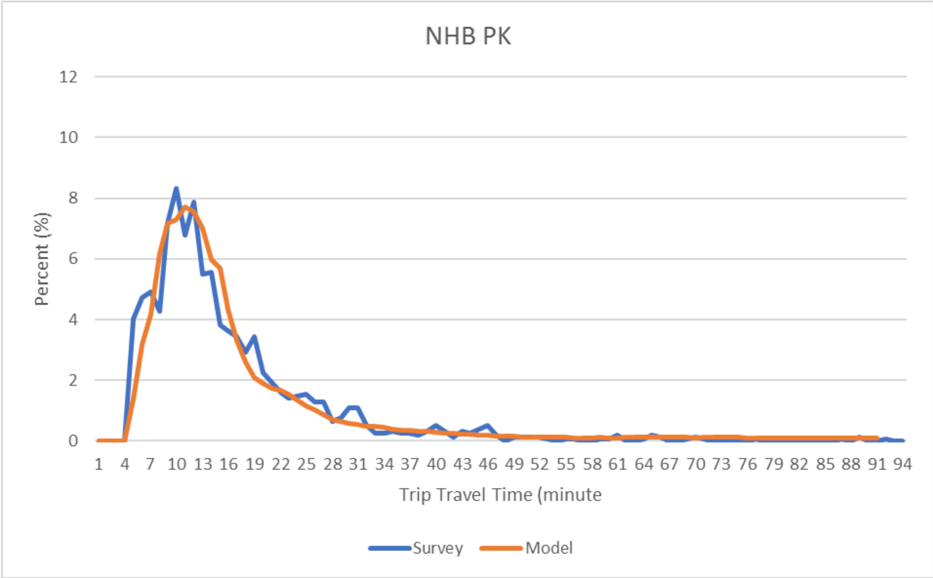


Figure 6-5 Observed and Modeled NHB Trip Travel Time Frequency Distribution in Peak Period

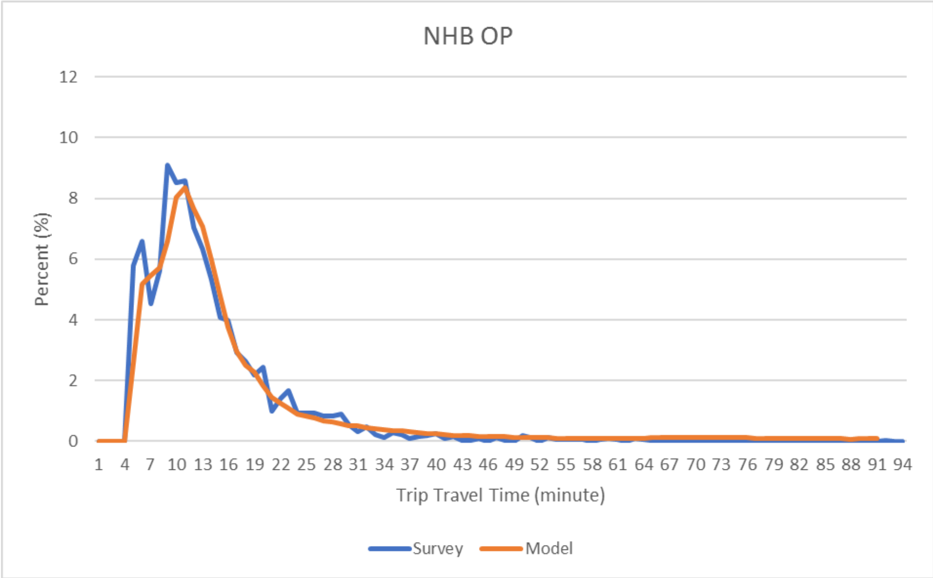


Figure 6-6 Observed and Modeled NHB Trip Travel Time Frequency Distribution in Off-Peak Period

7 TRIP ASSIGNMENT

7.1 Time of Day

The HRTPO Model develops the peak and off peak demand through trip distribution and mode choice. Prior to assignment, the period trips are distributed into AM and PM and Mid-Day and Overnight for the Off Peak. NHTS data was used to develop the distributions of peak and off peak trips by period as shown in Table 7-1.

Table 7-1: Observed Time of Day Trips by Period – NHTS

PERIOD	HBW	HBO	NHB	TOTAL
1: Peak AM (6am-9am)	194,165.39	257,310.32	83,273.40	534,749.10
3: Peak PM (3pm-6pm)	162,398.02	442,802.49	234,562.69	839,763.20
2: Mid-Day (9am-3pm)	119,002.63	594,579.46	460,998.47	1,174,580.56
4: Late PM (6pm-6am)	103,207.05	389,419.91	105,577.13	598,204.09
Grand Total	578,773.09	1,684,112.19	884,411.68	3,147,296.96

Using the total trips by period, factors were calculated to distribute the production and attractions from trip generation trips to peak and off peak trip ends. The period factors are reported in Table 7-2 as percentages. The peak and off peak trip ends are then input to the respective peak and off peak models to create the trip distribution and mode choice PA trip tables.

Table 7-2: Time of Day Factors by Period – NHTS Percentages (Peak and Off Peak)

PERIOD	HBW	HBO	NHB	TOTAL
PK	61.6%	41.6%	35.9%	43.7%
OP	38.4%	58.4%	64.1%	56.3%

Following mode choice and prior to traffic assignment, the peak and off peak trips are further disaggregated to the specific periods using the factors reported in Table 7-3. The period distribution factors are applied to the corresponding peak and off peak trips.

Table 7-3: Time of Day Factors by Period – NHTS Percentages (AM/PM and Mid Day/Night)

PERIOD	HBW	HBO	NHB	TOTAL
AM	54.5%	36.8%	26.2%	38.9%
PM	45.5%	63.2%	73.8%	61.1%
MD	53.6%	60.4%	81.4%	66.3%
NT	46.4%	39.6%	18.6%	33.7%

Once the Peak and Off Peak Period trips are disaggregated to the AM/PM and MD/NT in the respective model chains, the trips are converted to Origin / Destination format by applying the directional factors in Table 7-4. The PA to OD directional factors are based on the 2009 model.

Table 7-4: Period Directional Factors (PA to OD)

Period	Direction	HBW	HBO	NHB
AM	P -> A	99.37%	86.38%	50.00%
AM	A -> P	0.63%	13.62%	50.00%
PM	P -> A	7.65%	31.76%	50.00%
PM	A -> P	92.35%	68.24%	50.00%
Midday	P -> A	64.43%	55.82%	50.00%
Midday	A -> P	35.57%	44.18%	50.00%
Night	P -> A	37.51%	42.43%	50.00%
Night	A -> P	62.49%	57.57%	50.00%

7.2 Highway Assignment

Highway Assignment refers to the routing of auto trips estimated in the mode choice step along with vehicle trips such as externals and trucks. The HRTPO Model has four time periods, i.e., AM peak, Midday off-peak, PM peak and Night off-peak, and separate highway assignments are developed for each of those time periods. The peak and off-peak trip tables are split into four time periods using the time of day factors. The trips from the mode choice model are in production-attraction (P-A) format and the highway assignment requires the trips to be in origin-destination (O-D) format. The factors shown in Table 7-5 derived from NHTS data are applied by purpose and time period for the P-A to O-D conversion as previously described.

The highway assignments estimate the travel on roadway facilities for the vehicles. Hence, the drive-alone, shared ride 2, and shared ride 3+ from the mode choice outputs are converted to vehicle trips using vehicle occupancy factors. The vehicle occupancy factor is assumed as 1.0 for drive alone trips, 2 for shared ride 2 trips, and a trip purpose specific value for the shared ride 3+ trips:

- HBW = 3.42
- HBO = 3.37
- NHB = 3.54

Each time of day has a capacity factor associated with it. The capacity factor is applied to the link capacity of the lanes to define the full capacity of the facilities in a particular time period. The basis for the capacity factor is the hourly count data by time periods. For each period, the maximum hour was identified and the factor is based on the total volume in the period divided by the peak hour. The four capacity factors as shown in Table 7-5 were used in the model.

Table 7-5 Capacity Factors by Time of Day

Time of Day	Capacity Factor
AM	2.75
MD	5.29
PM	2.95
NT	4.65

The results from the four highway assignments were evaluated using 2015 traffic count data of the VDOT's Traffic Monitoring System (TMS) throughout the model region. More details regarding the highway assignment validation are presented in Chapter 10.

7.3 Volume Delay Functions

The Volume Delay Functions (VDFs) are used to simulate the degradation of highway speeds as modeled volumes approach capacity. The VDFs employed in the highway assignment process determine the change in travel speed as a function of the Volume/Capacity (V/C) ratio. This calculation occurs in each iteration of the highway assignment until the convergence criteria are met and optimal path routing is identified given the impacts of congestion from vehicle trips loaded on the networks. In Hampton Roads model, the user-equilibrium model of traffic assignment is applied with the following default convergence criteria:

RELATIVEGAP = 0.010
MAXITERS = 30

The above assignment closures were tested and it was found that increased iterations or higher gap closure criteria yielded small changes in the results with significant impact to the overall model run time. For most applications, these values are suitable, but if alternative analysis or other comparisons of model runs is being completed, it is recommended that higher convergence thresholds be used to minimize undesired noise or change in the assignment results.

The VDFs used in the Hampton Roads Model were built on the VDF optimization research done at the Virginia Modeling, Analysis and Simulation Center (VMASC) at Old Dominion University (Source: Evaluation of Volume-Delay Functions and Their Implementation in VDOT Travel Demand Models, May 2011). Conical functions were developed for different groups of facility types such that the resulting highway link volumes matched well with the observed traffic counts. According to VMASC's research, conical functions provide better %RMSE than BPR functions. Table 7-6 summarizes the VDFs used in the current Hampton Roads Model. The equation shown below represents the conical function:

$$T_C = T_0 * \left[2 + \sqrt{\alpha^2 * (1-VC)^2 + \beta^2} - \alpha * (1-VC) - \beta\right]$$

where:
T_c = congested time for next iteration, and T_0 = time

Table 7-6: VDF Values

Facilities	Alpha	Beta
Freeways	9.0	1.06
Minor Freeways/Principal Arterials	7.0	1.08
Major/Minor Arterials, Major Collectors	4.5	1.14
Minor Collectors/Locals	2.0	1.50

Figure 7-1 shows the variation in congested speeds with respect to free flow speeds for various Volume/Capacity ratios.

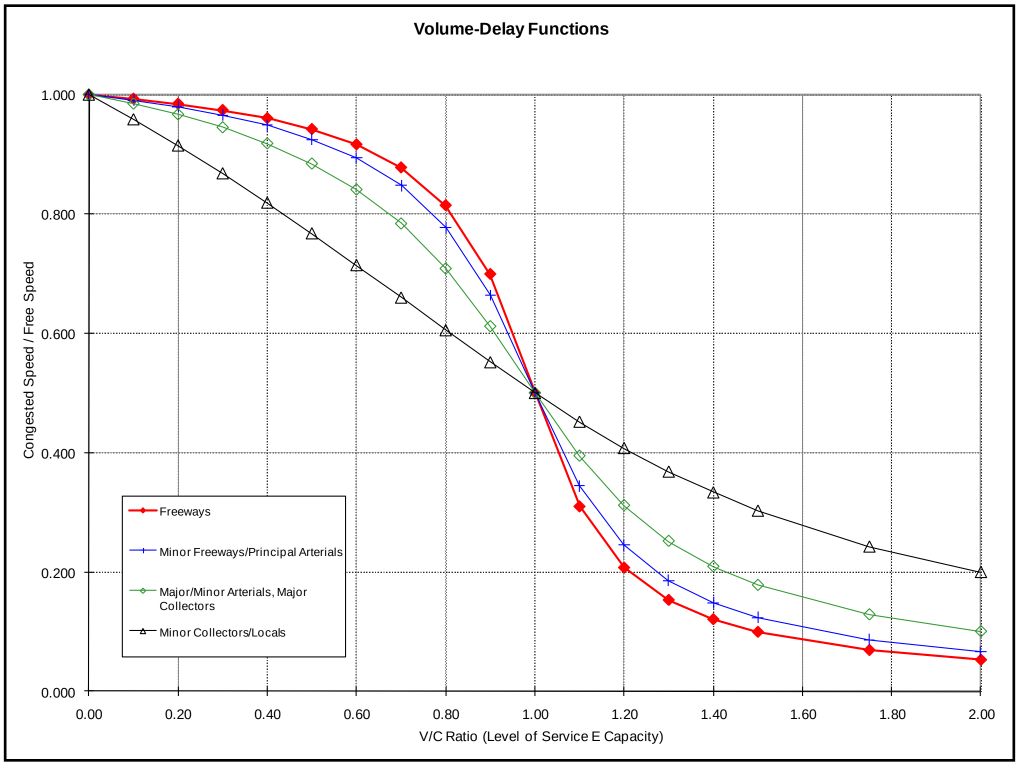


Figure 7-1: Volume Delay Functions

7.4 Toll Procedures

A logit toll diversion methodology for traffic assignment was used in this version of the model. This methodology supports the modeling of the regular toll corridors and High Occupancy Toll (HOT) lanes proposed on I-64 where the commuters have an option to choose between the HOT lanes and the regular non-toll (free) lanes. The assignment procedure develops two highway paths for every zonal interchange for each vehicle type (SOV, HOV2, HOV3+, and Truck). The first path is a free path where toll facilities are excluded from the network. The second path allows all free and toll links to be included in the path building. If a valid toll path exists, the model will apply a logit curve to assign a percentage of each trip purpose in that zonal interchange to the toll path and the remainder to the free path. If there is no valid toll path, all vehicles will be assigned to the free path.

According to toll file which is read by the model, all tolls are fixed and there is no varied toll rate; however, the model can consider different toll rates for the AM and/or PM periods versus the off-peak. The HRTPO model Ver 1.0 uses the same value of time (VOT) in peak and off-peak periods. Moreover, the VOT does not vary by trip purpose and auto vehicle class but they can vary based on the location. In reality, VOT is a characteristic of travelers and is independent of the link location. VOT varies by time of day which leads to higher values in peak periods. VOT varies by trip purpose too, for instance higher VOT is expected for HBW trips. VOT should also have a non-linear correlation with the vehicle occupancy. For instance, VOT of shared ride 2 should be greater than VOT of SOV but less than double the VOT for SOV.

In September 2015, Resource System Group, Inc. (RSG) conducted a stated preference survey of drivers who travel on I-66 between Route 15 and I-495/the Capital Beltway in Washington D.C. The primary purpose of the stated preference survey was to estimate VOT of travelers who use I-66 in Fairfax and

Prince William Counties. The survey gathered information from 2,747 travelers who use the I-66 corridor.

The project team analyzed the collected data and estimated VOT by purpose and vehicle occupancy. The analysis was conducted for work and non-work market segments and all trips longer than 35 miles were considered as E-I\I-E trips. After testing a lot of models with different utility configurations, the best mixed-logit models were selected to estimate VOT for different market segments. It should be noted that due to small sample size especially for high vehicle occupancy in I-E\E-I trips and the issue with the states preference answers by respondents which might report their own willingness to pay and ignore the party size, the HOV2 and HOV3+ VOT curves were generated by using the ratio between SOV, HOV2, and HOV3+ VOTs estimated from multi-nominal logit (MNL) models.

Estimated values of time based on I-66 surveys ranged from $9.90/hr. to $22.17/hr depending on day of week, household income, time of day, trip purpose, and opinion about the proposed express lanes. Results for weekday trips are presented in Table 7-7, with individual VOTs ranging from $11.34 to $19.87. These results suggest that VOT in northern Virginia may not vary a lot across trip-purposes.

Table 7-7 Value of Time by Income for Weekday Trips on I-66 in Northern Virginia

Annual Household Income	Weekday Trips					
	Peak Home-Based Work	Off-Peak Home-Based Work	Peak Home-Based Non-Work	Off-Peak Home-Based Non-Work	Peak Non-Home-Based	Off-Peak Non-Home-Based
$15,000	$11.34	$11.19	$11.70	$10.80	$11.47	$12.73
$37,500	$13.41	$13.23	$13.84	$12.77	$13.57	$15.05
$62,500	$14.57	$14.38	$15.04	$13.87	$14.73	$16.35
$87,500	$15.33	$15.13	$15.82	$14.60	$15.50	$17.21
$112,500	$15.90	$15.69	$16.41	$15.14	$16.08	$17.84
$137,500	*$16.36*	*$16.14*	*$16.88*	*$15.57*	*$16.54*	*$18.35*
$175,000	$16.90	$16.67	$17.44	$16.09	$17.09	$18.97
$225,000	$17.47	$17.24	$18.03	$16.63	$17.67	$19.61
$250,000	$17.71	$17.47	$18.28	$16.86	$17.91	$19.87

Figure 7-2 to Figure 7-4 present the frequency of value of time for work and non-work trips by vehicle class, respectively. Figure 7-5 to Figure 7-7 also illustrate the toll choice by purpose and vehicle class obtained from I-66 surveys.

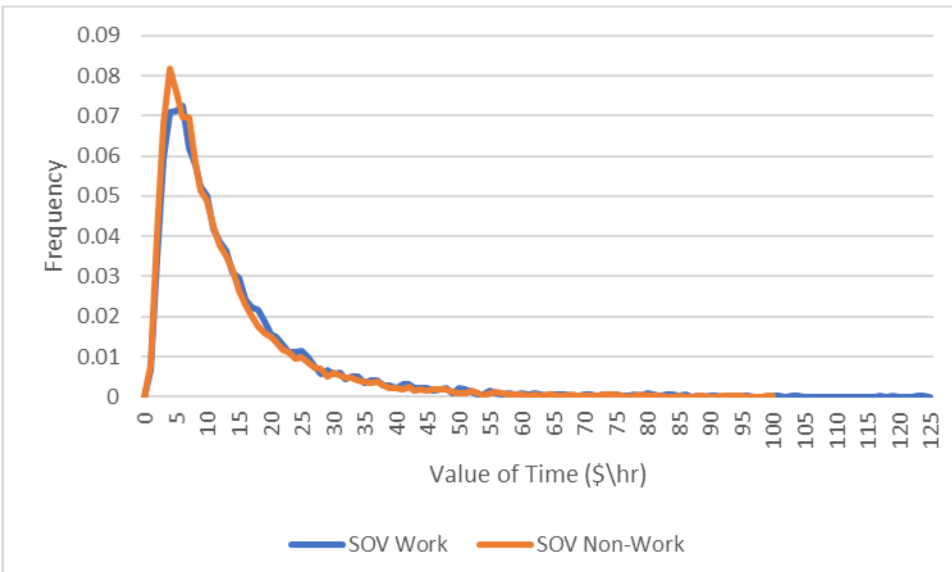


Figure 7-2 Frequency of Value of Time for SOV Trips

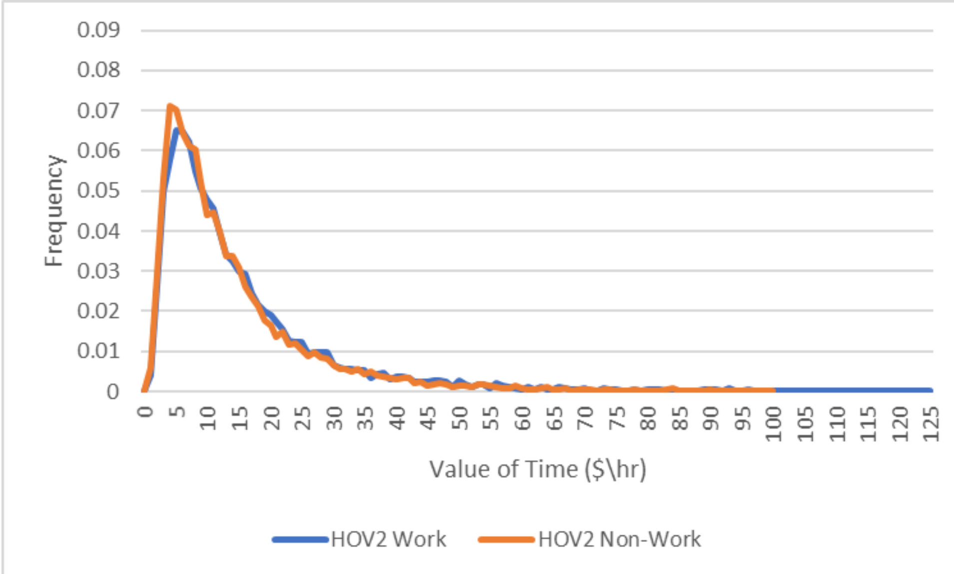


Figure 7-3 Frequency of Value of Time for HOV2 Trips

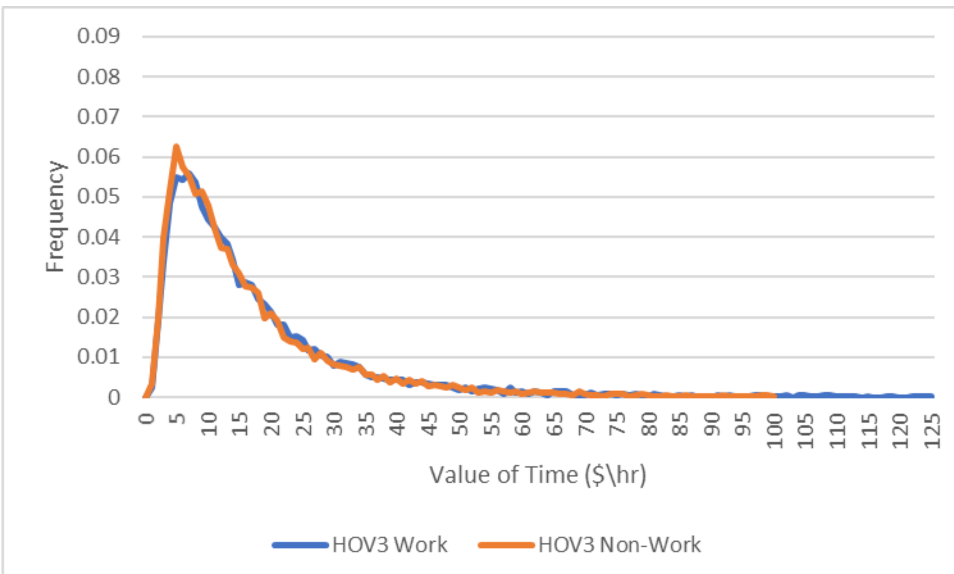


Figure 7-4 Frequency of Value of Time for HOV3+ Trips

Figure 7-5 Toll Choice by Purpose for SOV Trips

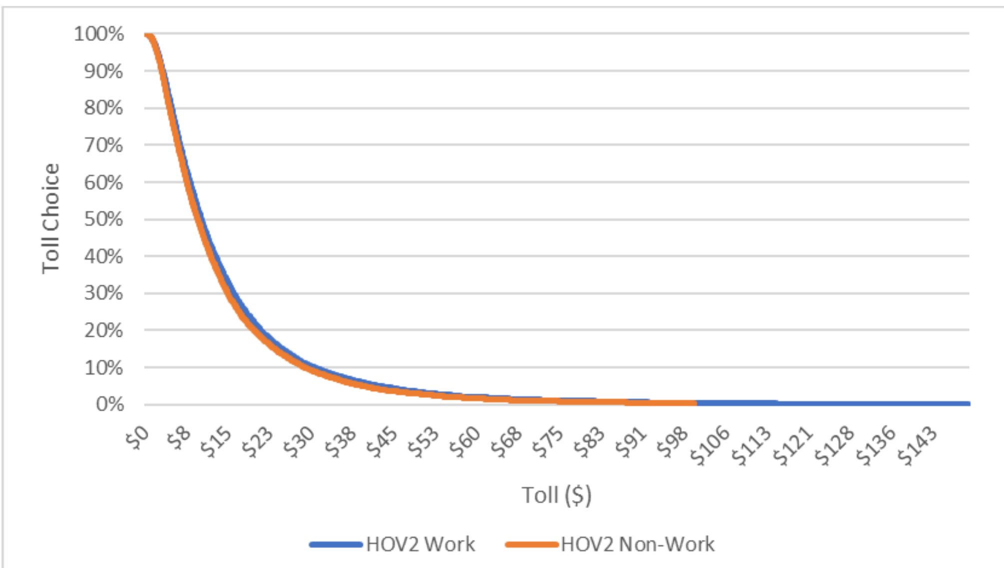


Figure 7-6 Toll Choice by Purpose for HOV2 Trips

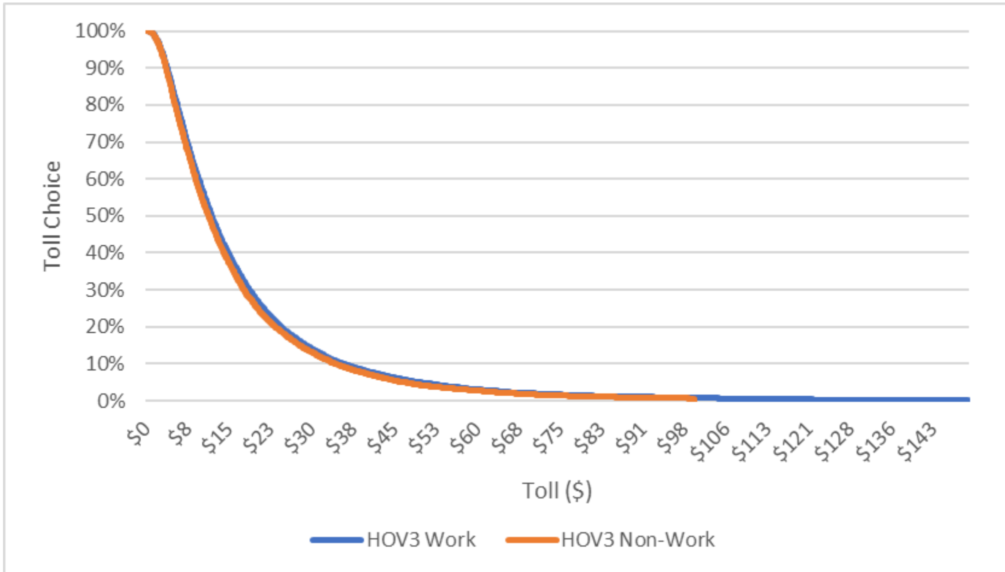


Figure 7-7 Toll Choice by Purpose for HOV3+ Trips

According to Figure 7-2 to Figure 7-4, frequency of higher VOT in HOV3+ trips is slightly more than HOV2 and SOV trips. Moreover, the toll choice for the same amount of toll is higher in HOV3+ trips than other vehicle classes. They also indicate that the VOT has a non-linear correlation with the vehicle occupancy. In addition, the curves show wide range of VOT in the region which means that a single value is not a proper representative of VOTs.

Since the HRTPO model area is far from Washington D.C., which is the location of the stated preference survey, the obtained VOT in 2015 survey cannot be directly used in the model; however, they can be used as a reference to verify VOTs calculated from other methods. The generated trips in HRTPO model are stratified by household income group and the average household income is also available. Since the trip purpose in SHRP2 C04 is not as detailed as the model, the project team decided to use SHRP2 C04 recommendations to calculate VOT by purpose, time period, and vehicle class for resident trips and use the stated preference survey results to estimate VOT for external trips with respect to VOTs for residents in the two sources.

SHRP2 C04 defines VOT as a function of travel distance, income, and car occupancy for each travel segment. Equation 1 presents how the VOT is calculated.

$$VOT = (a_1/b) \times (1 + a_2 \times D + a_3 \times D^2) \times (I^e \times O^f)$$
Eq.1

Where:

a_1 is the basic travel time coefficient,

a_2 and a_3 are coefficients reflecting the impact of travel distance on the perception of travel time,

b is the cost coefficient,

D is the travel distance,

e, f are the coefficients reflecting effect of income and occupancy on the perception of cost,

I is the income of the traveler, and

O is the vehicle occupancy.

The parameters have been calibrated for HBW, HBO, and NHB separately. Table 7-8 presents the coefficients used in VOT equations suggested by SHRP2.

Table 7-8: VOT Model Coefficients by Trip Purpose (SHRP2 C04 2013)

Parameter	HBW	HBO	NHB
a1	-0.0425	-0.03575	-0.038
B	-1.345	-0.72835	-0.9339
a2	0.02024	0.00506	0.01012
a3	-0.00027	-0.0000665	-0.00013
E	0.6	0.525	0.55
F	0.8	0.725	0.75

Equation 1 predicts value of time by vehicle occupancy; however, it needs the average household income and average trip length. The households in the model area were divided in 4 groups and the average income for each group was provided to the project team. Table 7-9 presents the average household income by household group in the model area.

Table 7-9 Average Household Income by Household Group

Household Group	Average Household Income ($)
Group 1	13,343
Group 2	39,799
Group 3	70,568
Group 4	110,960

Average trip length by trip purpose, time period, and vehicle occupancy was computed based on the trip files and highway skims. Exhibit 4 shows the average trip length by time period, trip purpose, and vehicle occupancy.

Table 7-10 Average Trip Length by Trip Purpose and Time of Day (Mile)

Vehicle Class	Peak			Off-Peak		
	HBW	HBO	NHB	HBW	HBO	NHB
SOV	9.11	4.26	8.19	9.30	4.65	7.95
HOV2	12.00	5.23	8.13	12.49	5.58	7.43
HOV3+	14.00	5.68	8.08	15.44	5.95	7.47

VOTs were computed for trip purposes by time period, vehicle class and household group based on the methodology described above. Truck VOT was determined based on a meta-analysis of nine studies on truck VOT. Table 7-11 presents the findings of nine studies on truck value of time and the current value in Cal-BC and USDOT guidance on the value of truck drivers time (in 2012$). USDOT makes a point in its guidance of acknowledging that the value of truck/freight time is more than the value of the driver's time. The same issue should be valid for the Cal-BC's value of truck time.

Table 7-11 VOT for Light and Heavy Trucks ($\hr)

Source	Heavy Trucks	Light Trucks
ATRI, 2010	89.23	
Smalkowski & Levinson, 2005	58.10	
Outwater & Kitchen, 2008	53.32	42.66
Miao et al., 2011	33.94 - 57.65	
Almy et al., 2010	45.15	
Mei et al., 2013	33.29 - 52.22	26.06 - 46.14
BLA, EDRG & RSG, 2013	36.05	22.26 - 27.24
Kawamura, 1999	32.25	
Kawamura, 2003	21.96 - 34.94	
Cal-BC	28.70	
USDOT (Driver's time only)	26.43	

According to a meta-analysis of the nine studies which was conducted for another project and using the midpoint where ranges were given, the mean value of time for heavy trucks is $47.90/hr and the median is $45.15/hr which is also close to the mean if the highest and lowest studies are dropped. The median looks more reasonable because of the adjustment. The mean value of time for light trucks from the three studies is $34.50/hr. Since the HRTPO model includes only one class for trucks, the project team decided to consider $38/hr for truck value of time. Table 7-12 and Table 7-13 show the VOT by purpose, vehicle class, and household income for peak and off-peak, separately.

Table 7-12 VOT by Purpose, Vehicle Class, and Household Income in Peak Period

Market Segment	HBW	HBO	NHB	I-E/E-I	EE	TRK
Households Group 1 - SOV	6.58	4.40	4.87	7.56	4.64	38.00
Households Group 1 - HOV2	11.87	7.31	8.19	12.66	7.8	38.00
Households Group 1 - HOV3	17.68	10.29	11.64	17.53	11.04	38.00
Households Group 2 - SOV	12.68	7.81	8.88	13.61	8.35	38.00
Households Group 2 - HOV2	22.88	12.97	14.93	22.81	14.04	38.00
Households Group 2 - HOV3	34.06	18.27	21.24	31.56	19.88	38.00
Households Group 3 - SOV	17.88	10.55	12.17	18.53	11.37	38.00
Households Group 3 - HOV2	32.26	17.52	20.46	31.04	19.11	38.00
Households Group 3 - HOV3	48.02	24.67	29.10	42.97	27.06	38.00
Households Group 4 - SOV	23.46	13.38	15.61	23.65	14.51	38.00
Households Group 4 - HOV2	42.32	22.21	26.24	39.61	24.38	38.00
Households Group 4 - HOV3	63.00	31.29	37.32	54.82	34.53	38.00

Table 7-13 VOT by Purpose, Vehicle Class, and Household Income in Off-Peak Period

Market Segment	HBW	HBO	NHB	I-E/E-I	EE	TRK
Households Group 1 - SOV	6.60	4.41	4.86	7.52	4.61	38.00
Households Group 1 - HOV2	11.94	7.32	8.14	12.57	7.74	38.00
Households Group 1 - HOV3	17.93	10.30	11.59	17.40	10.96	38.00
Households Group 2 - SOV	12.71	7.83	8.87	13.53	8.30	38.00
Households Group 2 - HOV2	23.00	12.99	14.85	22.64	13.93	38.00
Households Group 2 - HOV3	34.55	18.29	21.14	31.33	19.73	38.00
Households Group 3 - SOV	17.92	10.57	12.15	18.41	11.29	38.00
Households Group 3 - HOV2	32.44	17.54	20.35	30.81	18.96	38.00
Households Group 3 - HOV3	48.72	24.70	28.97	42.64	26.86	38.00
Households Group 4 - SOV	23.51	13.41	15.58	23.50	14.41	38.00
Households Group 4 - HOV2	42.56	22.25	26.11	39.32	24.20	38.00
Households Group 4 - HOV3	63.92	31.33	37.15	54.41	34.27	38.00

The toll choice model has three parameters:

1- VOT
2- Scale factor
3- Constant

The constant is determined in the model validation, but the scale factor represents the unseen error in the data used to calculate VOTs. The source is, therefore, I-66 dataset and the scale factors were borrowed from that study as shown in Table 7-14. The scale factors affect sensitivity of the toll model to toll cost.

Table 7-14 Scale Factors Used in Toll Choice Model

Time Period	HBW	HBO	NHB	I-E/E-I	EE	TRK
Peak	-0.09755	-0.08450	-0.09265	-0.12950	-0.12950	-0.02950
Off-peak	-0.10460	-0.09415	-0.12200	-0.12950	-0.12950	-0.02950

7.5 Transit Assignment

Separate transit assignments are performed for the peak and off-peak periods. The assignment procedures use the trip tables generated as outputs from the mode choice procedure. For the purposes of transit assignment, the trip purposes are combined. The transit assignments are run for walk-to-transit and drive-to-transit in the peak and off-peak periods. The results from the transit assignments are shown in Chapter 10.

8 TRUCK MODEL

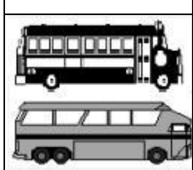
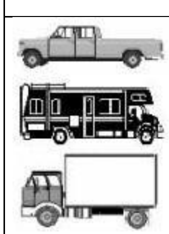
The Truck Model component of the HR Model is unchanged from the 2009 Model with the following exceptions:

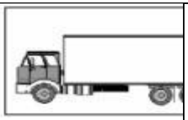
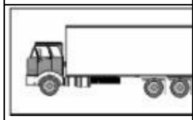
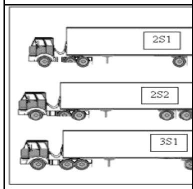
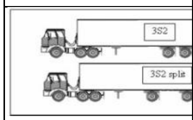
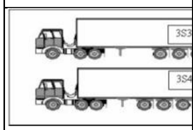
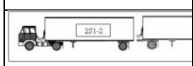
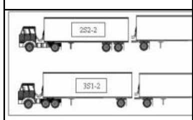
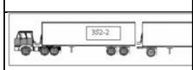
1) *The identified truck zones as part of trip generation have been updated to the new zone structure*
2) *The external-internal truck movements have been replaced by the commercial vehicle data from Streetlight consistent with the Auto trips.*

The text related to the Truck Model is based on the 2009 HRTPO Model V1 documentation and updated where necessary for consistency with this version of the model.

Given the growing importance of trucks and their disproportionate effect on congestion, toll revenues, and other impacts, it was judged necessary to develop a revised model to estimate Truck volumes. In this model, "Truck" means heavy trucks, defined as those with three or more axles or pulling a trailer. In the FHWA standard classification scheme, this is classes 6 through 13, inclusive (see Figure 8-1). In the VDOT classification scheme, this is vehicle classes 4-6.

Figure 8-1: FHWA Vehicle Classification System

	**CLASS 1: *Motorcycles*** -- All two or three-wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles.
	**CLASS 2: *Passenger Cars*** -- All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.
	**CLASS 3: *Other Two-Axle, Four-Tire Single Unit Vehicles*** -- All two-axle, four-tire vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification.
	**CLASS 4: *Buses*** -- All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.
	**CLASS 5: *Two-Axle, Six-Tire, Single-Unit Trucks --*** All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.

	**CLASS 6: *Three-Axle Single-Unit Trucks*** -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
	**CLASS 7: *Four or More Axle Single-Unit Trucks*** -- All trucks on a single frame with four or more axles.
	**CLASS 8: *Four or Fewer Axle Single-Trailer Trucks*** -- All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
	**CLASS 9: *Five-Axle Single-Trailer Trucks*** -- All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
	**CLASS 10: *Six or More Axle Single-Trailer Trucks*** -- All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
	**CLASS 11: *Five or fewer Axle Multi-Trailer Trucks*** -- All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
	**CLASS 12: *Six-Axle Multi-Trailer Trucks*** -- All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
	**CLASS 13: *Seven or More Axle Multi-Trailer Trucks*** -- All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

Source: Traffic Monitoring Guide - May 1, 2001; Section 4: Vehicle Classification Monitoring, http://www.fhwa.dot.gov/ohim/tmguide/tmg4.htm#tab4a1

The principal challenge in developing a Truck model is that usable survey data almost never exists. Most truck surveys are too small, collect data that is not relevant to travel demand modeling, or have results with so much variability as to be useless for model development. The best source of observed data on truck travel is traffic counts, specifically classification counts that identify truck volumes based on vehicle length and/or number of axles. VDOT provided a fairly large number of such counts statewide in its 2009 TMS database. This data includes the annual average weekday traffic count (AAWDT) and the percentage of vehicles by class. The relevant field names in the VDOT count database are PERCENTTRUCK3AXLE (also called PERCENTT_1), PERCENTTRUCK1TRAIL (PERCENTT_2), and PERCENTTRUCK2TRAIL (PERCENTT_3). An indicator of the quality of the count is also provided; this study used counts of quality “F” or higher. The three percentages were summed and multiplied by the AAWDT to determine the daily truck count. Very low counts (less than 10 vehicles per day) were dropped. The counts were transferred from the TMS database to the network via the common TMS_ID field. The total daily count in both directions was posted. These values were carefully examined to eliminate counts that were duplicative, illogical, or inconsistent with network topology. In addition, VDOT provided a separate multi-year database of hourly counts that included a "HEAVY_VEHI" field. This data was used to calculate the percentage of Trucks by the model's four time periods and those were used to split the daily values by period and direction. Detailed examination of the hourly count data indicated that the daily sum of the hourly counts was inconsistent with the daily count totals (the hourly counts had a significantly lower daily total). Therefore, the hourly counts were used only to validate the truck time of day model.

8.1 Truck Trip Generation

The zonal land use data provided by the HRTPO split employment into two categories: Retail and Non-Retail. Most current Truck models require finer detail on the employment data, because different types of workers generate Truck travel at very different rates. A commonly used stratification is: Retail, Office, Industrial, and Other. VDOT obtained detailed breakdowns of employment by zone, stratified by the North American Industrial Classification System, 2007 (NAICS, www.census.gov/eos/www/naics/) from a private vendor. The employment data by NAICS category was allocated to the above four groups as shown in Table 8-1.

This data was used to split the HRTPO's Non-Retail employment category into Industrial, Office, and Other by zone. The result is a more detailed split of employment that uses the NAICS information but is consistent with the HRTPO's data.

Table 8-1: Employment Allocation by NAICS

Group	2-Digit NAICS	Retail	Office	Industrial	Other
Agriculture, Forestry, Fisheries	11	0%	0%	100%	0%
Mining	21	0%	0%	100%	0%
Construction	23	0%	10%	90%	0%
Manufacturing	31, 32, 33	0%	10%	80%	10%
Transportation	48	0%	10%	80%	10%
Communications, Utilities	22	10%	10%	70%	10%
Wholesale Trade	42	40%	10%	20%	30%
Retail Trade	44, 45	90%	10%	0%	0%
Warehousing	49	10%	20%	20%	50%
Information	51	0%	60%	10%	30%
Finance, Insurance, Real Estate	52, 53, 55	0%	100%	0%	0%
Administration & Support	56	30%	30%	10%	30%
Personal Services	72, 81	40%	30%	10%	20%
Entertainment, Recreation	71	30%	10%	0%	60%
Health Services	62	30%	30%	10%	30%
Educational Services	61	0%	20%	0%	80%
Other Professional & Related Services	54	0%	90%	0%	10%
Public Administration	92	10%	40%	20%	30%

Prior truck models were researched as documented in USDOT's Travel Model Improvement Program (TMIP) literature[1]. The TMIP reports highlight a truck trip generation model developed in Phoenix that

[1] NCHRP Synthesis 298, *Truck Trip Generation Data*, 2001)

uses industrial, retail, and office employment and that they considered to be a good example. The truck trip generation equation initially taken from Phoenix and calibrated for HR model is:

Truck trip ends = 0.199 * Industrial Employment + 0.141 * Retail Employment + 0.029 * Office Employment + 0.068 * HH (1)

The above Equation (1) was applied to the zonal data and adjusted to provide approximately the same number of truck trips as an earlier estimate, whose assignment produced an aggregate estimated link total that matched the aggregate count. This required an overall factor of 0.55 on the above equation. The trip generation model also includes area type adjustment factors as shown in Table 8-2. These factors were calibrated during truck model validation to observed counts. Except for AT 1, these factors decrease consistently from AT 5 to AT 2, suggesting that the above equation systematically overestimates Truck trips in the more developed areas.

Table 8-2: Truck Area Type Factors

Area Type Code	Area Type	Factor
1	CBD	1.00
2	Urban	0.68
3	Dense Suburban	0.77
4	Suburban	0.95
5	Rural	1.06

The equation estimates the number of trip productions for each zone. The number of trip attractions is set equal to the number of productions, which is the common convention for Truck models. These trip ends represent the total trip ends.

Another adjustment to the trip ends estimated by Equation (1) is a factor for *truck zones*. Truck zones are zones for which there is reason to believe that the rate of Truck trip ends per employee is likely to be higher than usual. This is because a review of satellite photos or local knowledge indicates the zone may contain a concentration of industrial or warehousing land uses or a specific Truck generating activity, such as a truck stop, an intermodal transfer facility, or a trucking firm office. Truck zones are specified via a 1/0 variable in the land use file: a zone either is a truck zone or it isn’t. The identification of truck zones is somewhat arbitrary. An initial list was developed by the consultant from a review of satellite photos. This was refined after a review by HRTPO staff, HRTPO’s Freight Transportation Advisory Committee, locality planners and was further refined as a result of the assignment process. The final list of truck zones are mapped in Figure 8-2. For such zones, the number of trips estimated by Equation (1) is multiplied by 2.0.

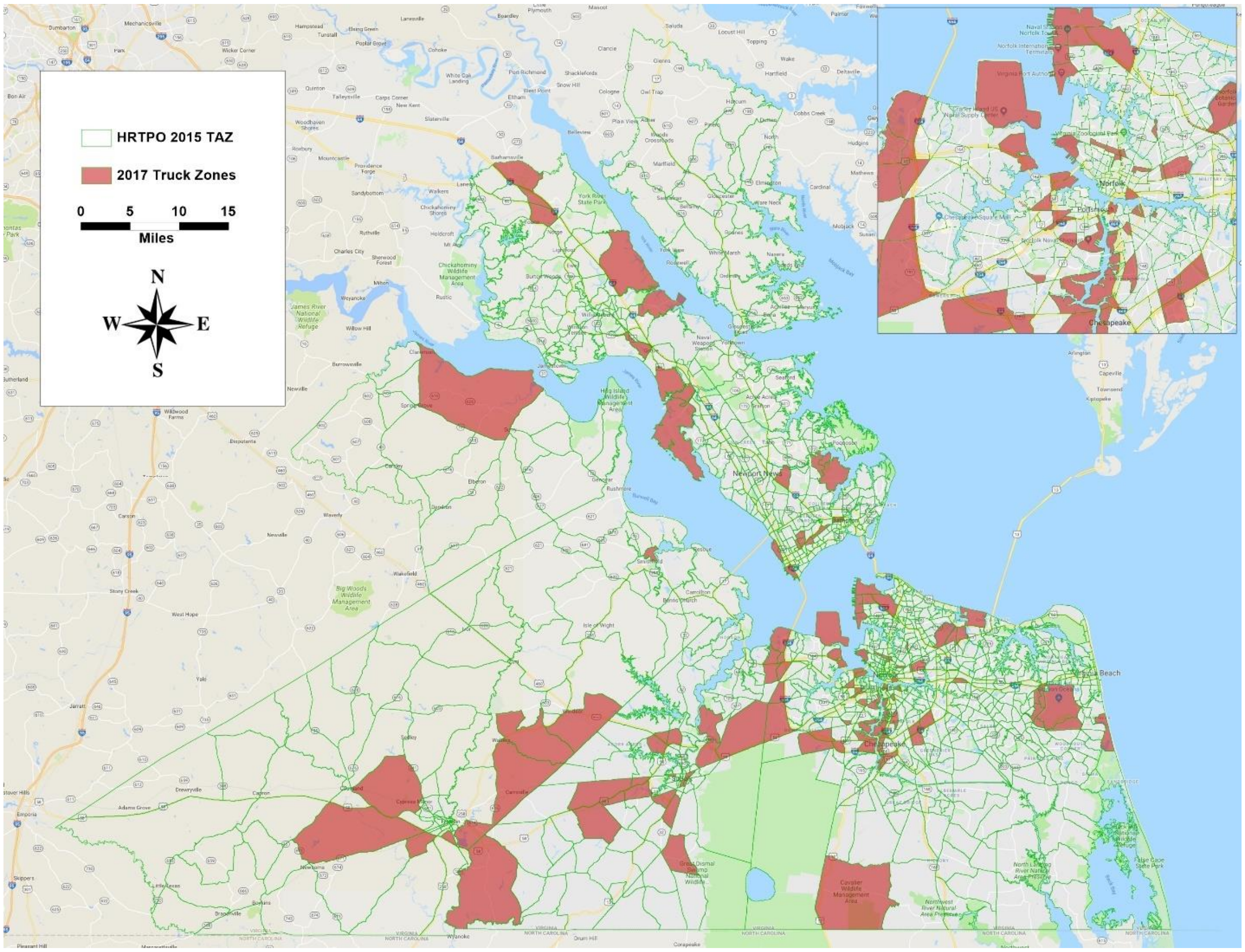


Figure 8-2: Truck Zones

8.2 Truck Distribution

As noted above, there is no actual observed data on the average trip length (ATL) or the trip length frequency distribution (TLFD) for Trucks. A target ATL was synthesized by analogy based on data from other models (see Table 8-4). From the NHTS data, it is possible to derive peak/off-peak ATL ratios and external/internal ATL ratios, as shown in Table 8-3.

Table 8-3: Average Trip Length Ratios per Trip Type

	I-I Trips (min)	I-I Trips (miles)	I-E Trips (min)	I-E Trips (miles)	Pk/OP Ratio	NHTS Trips	Wtd Avg	I-E/I-I Ratio
Peak								
HBW	26.81	10.44			1.49	556814		
HBS	14.28	4.65	25.62	8.92	1.21	350301		
HBO	14.98	4.94			1.15	901238		
NHB	17.52	6.07			1.31	546227		
							18.26	1.40
Off-Peak								
HBW	18.04	8.68				341216		
HBS	11.83	4.38	20.11	7.74		744491		
HBO	13.07	5.28				1147049		
NHB	13.36	5.31				1014480		
							13.40	1.50
				Wtd Avg Pk/OP ratio:			1.36	

Next, relationships were obtained from other areas to estimate a target truck ATL. Ratios of the Truck ATL to the Work (HBW) and Other (HBO) ATL were established from other models, as shown in Table 8-4.

Table 8-4: Average Trip Length Ratios for Trucks from Other Models

Area	Year	HBW (min)	HBO (min)	HTK (min)	HTK/ HBW	HTK/ HBO	Notes
Charlotte, NC	2001	26.4	15.9	27.1	1.024	1.706	HBW, HBO weighted est avg by income; HTK is estimated
Prince William Co, VA	2005	28.0	12.5	29.1	1.037	2.330	HTK = TRK est; other values est
Baltimore, MD	2000	20.8	12.2	24.5	1.181	2.007	TRK is est; others are obs
Sioux Falls, SD	2008	15.0	10.7	10.6	0.701	0.987	all are est; HTK is TRK
Hampton Roads, VA	2009	20.7	14.8	22.5	1.091	1.519	Dominion Blvd study estimate
Averages		22.2	13.2	22.7	1.025	1.721	
Hampton Roads	2009 NHTS	23.5	13.9		**24.09**	**23.92**	
					Avg:	**24.0**	(assume this is for the off-peak)

Combining the data in Table 8-3 and Table 8-4 produces the target ATLs shown in Table 8-5.

Table 8-5: Synthesized Truck Average Trip Length

	Internal (min)	External (min)
Peak	32.7	45.9
Offpeak	24.0	36.0

For example, the peak Internal value was calculated as the off-peak Internal value (24.0), multiplied by the peak/off-peak ratio (1.36).

As part of the trip distribution model, an estimate of the peak/off-peak split was made, based on data from other areas (See Table 8-4). A split of 32% peak / 68% off-peak was implemented within the trip distribution step.

A common way of developing friction factors (F factors) is to initially assume that the F's for all time periods is 1, apply the distribution model, and examine the resulting estimated ATL and TLFD. Comparing the estimated and target ATLs suggests specific changes to the assumed F's for testing in the next run. This process continues in iterative fashion until the estimated and target ATLs are sufficiently close and other trip distribution measures are reasonable, including the share of intrazonal trips, error in the attraction estimates by zone, and the number of gravity model iterations required. This was done separately by trip type: internal peak, internal off-peak, external peak, and external off-peak.

Figure 8-3 shows the resulting F factor curves (the peak and off-peak External F's are the same curve). A gamma function was used to represent the F factors, because this has been shown to produce appropriate values and is simpler to calibrate. The gamma function is as follows:

$$F = A \times t^{B} \times e^{Gt}$$

where:
F = F factor (dimensionless)
t = highway travel time, minutes
A,B,G = calibrated coefficients

Table 8-6 lists the parameters for the curves in Figure 8-3.

Figure 8-3: Truck F Factors

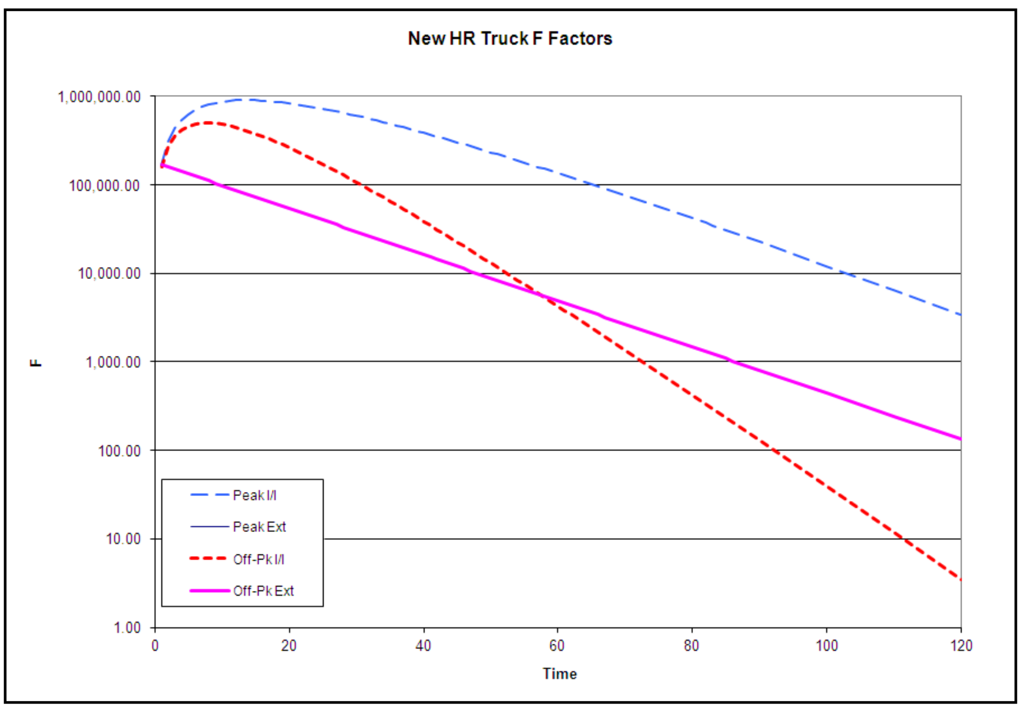


Table 8-6: Truck F Factor Gamma Coefficients

Trip Type	A	B	G
Internal Peak	180,000	1.000	-0.073
Internal Off-Peak	180,000	0.993	-0.130

F factor values are estimated by minute for travel times from 1 to 120 minutes. Over 120 minutes, the F factor is defined as zero so that no trips are estimated. F values are expressed to a precision of two places to the right of the decimal point. The gravity model is set to iterate until the root-mean-square error (RMSE) on zonal attractions for all purposes is 1 or lower, or until 40 iterations have been performed, whichever occurs first.

Table 8-7 shows the final ATL comparisons. The internal trips are shown to match the target values very well. However, after considerable testing, it was concluded that the target External ATLs shown in Table 8-5 are probably not accurate. Those ATLs are based on relationships from other areas, which have a different geography than the Hampton Roads region. In Hampton Roads, most of the external trips go to/from the Richmond area and there is a very long distance from the Richmond-area external stations to downtown Norfolk, the naval bases, and the ports. Model testing disclosed that if the External F's were adjusted to try to match the synthesized ATLs, the gravity model would not converge sufficiently on the attractions. That is, the gravity model's estimate of attractions by zone did not match the generation model's estimate of attractions by zone very well. As a result, the final estimated External ATLs are much higher than the values shown in Table 8-5.

Table 8-7: Truck ATL Comparisons

	Target (min)	Estimated (min)
Internal		
Peak	32.7	32.0
Offpeak	24.0	23.3

8.3 Time of Day

As with the other trip purposes, the Truck time of day (ToD) model is split into two parts. The first part, described above, splits the daily trips into peak and off-peak and is applied as part of the trip distribution model. The basic split is 32% peak, 68% off-peak. The second part is applied after the trip distribution model and splits the peak trips into AM and PM peak period trips and splits the off-peak trips into MD and NT period trips.

The detailed splits use a simple set of percentages to split the 2-period trip tables into four periods. Since Truck trips are estimated in O/D format, this is a straightforward calculation without the need for matrix transposition. The detailed split percentages were initially based on a consensus of heavy truck ToD models from Washington, Baltimore, and Atlanta. These percentages were subsequently modified in response to a comparison of estimated vs. counted trips by link from the assignment phase. Table 8-8 shows the final detailed ToD splits. This says, for example, that the AM peak trips are 50% of the peak total.

Table 8-8: Truck Detailed Time of Day Splits

Period	Percentage
AM (6:00 am to 9:00 am)	50
PM (3:00 pm to 6:00 pm)	50
MD (9:00 am to 3:00 pm)	80
NT (6:00 pm to 6:00 am)	20

8.4 Traffic Assignment

Trucks are assigned simultaneously with the auto classes with associated values of time and toll rates as described earlier in this report. Specific facilities have been identified with truck prohibitions that are respected in the assignment phase of the model. Locations identified in 2009 as part of Model V1 have been carried forward into V2 of the Model.

Known Restrictions due to Political Decisions			
Jurisdiction	**Route Name**	**Location**	**Time of Restriction**
Chesapeake/Virginia Beach	Elbow Road	Butts Station Road to Indian River Road	all times
Chesapeake	George Washington Hwy	Cedar Road to I-64	all times
Norfolk	Hampton Boulevard	Redgate Avenue and International Terminal Blvd	4 pm to 6 am
Norfolk	Colley Avenue	Colley Bay and Front Street	all times
Norfolk	Granby Street	East Ocean View Avenue and Main Street	4 pm to 6 am
Norfolk	Church Street	Granby St and Brambleton Avenue	4 pm to 6 am
Norfolk	Jamestown Cresent	Hampton Boulevard and Colley Bay	all times
Suffolk	Nansemond Pkwy	Wilroy Road and Chesapeake CL	all times
Suffolk	Pughsville Road	Shoulders Hill Road and Chesapeake CL	all times
Suffolk	Town Point Road	Respass Beach Road and Portsmouth CL	all times
York	Richneck Road	Newport News CL to Fort Eustis Blvd	all times
Restrictions due to Bridge Limits			
Jurisdiction	**Route Name**	**Crossing**	
Chesapeake	22ND STREET	SEABOARD AV & NS RAILWAY	
Chesapeake	BELLS MILL ROAD	MILL CREEK	
Chesapeake	FENTRESS AIRFLD RD	POCATY CREEK	
Chesapeake	GEO. WASHINGTON HW	DISMAL SWAMP CANAL	
Chesapeake	GEO. WASHINGTON HW	YADKINS RD & NS RAILWAY	
Chesapeake	LAKE DRUMMOND CAWY	LEAD DITCH	
Chesapeake	MILITARY HIGHWAY	SOUTH BR ELIZABETH RIVER	
Chesapeake	MOUNT PLEASANT ROAD	CHESAPEAKE & ALBEMARLE CANAL	
Chesapeake	ROUTE 0017	DEEP CREEK	
Isle of Wight	Carrsville Highway	Rte. 632 & CSX Railway	
Newport News	WASHINGTON AVE.	NNS & DD (PRIVATE) RWY	
Suffolk	LAKE PRINCE DRIVE	LAKE PRINCE	
Suffolk	TURLINGTON RD.	BR.KILBY CREEK-SPILLWAY	
York	MERRIMAC TRAIL	QUEENS CREEK	
Other Restrictions			
Jurisdiction	**Route Name**	**Location**	
York	Battle Rd	Old York-Hampton to GW Memorial Hwy	
Williamsburg	John Tyler	VA 199 to Jamestown Rd	
Newport News	Eastwood	Warwick to Colony	
York/James City/Williamsburg	Colonial National Historical Parkway (all)		
Newport News	41st St	Roanoke to Chestnut	
Norfolk	Robin Hood	Sewells Point to Azalea Garden	
Isle of Wight (Smithfield Town)	Main St	VA 10 Bypass to Church	

Figure 8-4: Location of Truck Prohibitions (Source: 2009 Model)

9 Feedback

9.1 Structure

Traditional four-step travel demand models apply trip generation, trip distribution, mode choice, and trip assignment steps in a sequential and independent fashion. While the individual steps are validated to observed data, it isolates the decisions regarding origin-destination, mode and route. Therefore, there is a discrepancy between the input travel times used for trip distribution and mode choice with the travel times that result from trip assignment. This discrepancy is significant for large model regions such as Hampton Roads, which have measurable congestion during some portions of the day.

The state-of-the practice approach is to feed the travel times from the trip assignment step back into the trip distribution step and repeat the application of mode choice and trip assignment using the updated results. This process can be repeated until the travel times used to determine trip patterns during the distribution process and the resulting congested travel times from the trip assignment are approximately equivalent. This consistency is determined using predetermined criteria called "convergence criteria." When this criterion is met, the iterative model application process is terminated.

9.2 Convergence

The convergence criteria used for highway assignments is based on the difference in feedback volumes between iterations. Convergence is achieved for each of the four time periods when both the difference in VMT between the current iteration and the previous iteration is less than 5% for each of the four time periods, and the difference in feedback volumes between current iteration and the previous iteration is less than 5% for 95% of the links with volumes greater than 5,000. The Method of Successive Averages (MSA) is used in the Hampton Roads model to calculate the feedback highway volume between successive iterations of the model chain. The following is the generic formula for calculating the feedback volume.

Feedback Volume = (1-(1/Iter#)) * Feedback Volume + (1/Iter#) * FDBK_1,

where:

FDBK_1 = loaded volume in the current iteration;

Feedback Volume = Feedback volume to be input to the next iteration

Iter# = speed feedback iteration number.

Thus, for every iteration, the feedback volume is calculated as follows:

Iteration 1: Feedback Volume = FDBK_1

Iteration 2: Feedback Volume = 1/2 * Feedback Volume + 1/3 * FDBK_1

Iteration 4: Feedback Volume = 3/4 * Feedback Volume + 1/4 * FDBK_1

... and so on.

Table 9-1: Feedback Convergence Criterion

Model Period	Criteria
Peak	Percent change in VMT for the last two iterations <5%, and percentage of links with volume > 5000 have volume difference less than 5% (with respect to previous iteration.) for both AM and PM peak
Off-Peak	Percent change in VMT for the last two iterations <5%, and percentage of links with volume > 5000 have volume difference less than 5% (with respect to previous iteration.) for both Midday and Night

10 VALIDATION

Model calibration refers to the development of model parameters and coefficients. Model validation refers to the process of testing a model's ability to replicate base year conditions and its predictive capabilities. The validation to base year conditions is called static validation and is performed by comparing simulated results to the observed data not used to develop or calibrate the model. Testing the model's predictive capabilities is called dynamic validation and involves testing the model's sensitivity to changes in data inputs and parameters and testing the reasonableness of future forecasts.

10.1 Static Validation

10.1.1 Trip Generation

The calculated trip rates from NHTS that are used in the model were compared against national averages and best practice trip rates from NCHRP 716. The overall HBW and combined HBOther combined trip rates compare well with the national averages from NCHRP 716. NHB trip rates are not comparable given the different methodology applied for NHB travel in the HRTPO Model.

Table 10-1: Trip Rate Comparison

Trip Purpose	Model	NHCRP
HBW	1.53	1.4
HBO + HBOREC	3.53	5.1
HBSHOP	1.88	

Source: NCHRP 716, Appendix C

The distribution of trips by purpose compares well for the Home Based Other and Shopping categories. The HRTPO model has a higher HBW share of travel and lower NHB as compared to NCHRP national averages. AirSage data was used to verity the percent distribution of trips, which was more inline with the Model having a higher percentage of HBW as compared to NCHRP.

Table 10-2: Distribution of Trips by Purpose

Trip Purpose	Model	NHCRP	AirSage
HBW	18.29	11	20
HBO	34.22	54	47
HBSH	20.25		
NHB	27.24	35	33
Total	100	100	100

Source: NCHRP 716, Page 84

10.1.2 Trip Distribution

The following series of tables compare the modeled distribution of trips by purpose to the AirSage Cell Phone OD data. The data has been aggregated to the jurisdiction to allow for an easy comparison between the modeled and observed data. Rather than comparing the entire regional flows, the tables or organized by origin and the resulting distribution to each jurisdiction as columns. The matrices are numbered by the district numbers presented earlier in the report.

HBW	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	40.1%	10.5%	6.7%	0.7%	41.8%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norfolk City	4.9%	87.3%	2.9%	0.1%	4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Portsmouth	19.8%	30.4%	42.2%	1.3%	6.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suffolk	8.1%	16.3%	16.5%	49.9%	5.8%	0.6%	1.5%	0.4%	0.0%	0.1%	0.1%	0.1%	0.0%	0.5%	0.2%
VA Beach	12.7%	23.5%	3.0%	0.1%	60.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Isle of Wight	5.4%	15.4%	9.3%	4.5%	8.0%	41.3%	10.1%	2.5%	0.1%	0.2%	0.2%	0.5%	0.0%	1.6%	0.8%
Newport News	1.2%	2.3%	0.9%	0.2%	0.9%	0.1%	84.2%	3.6%	0.2%	1.3%	1.4%	3.4%	0.2%	0.0%	0.0%
Hampton City	1.7%	3.9%	1.3%	0.3%	2.1%	0.2%	16.3%	71.1%	0.3%	0.5%	0.5%	1.7%	0.1%	0.0%	0.0%
Poquoson	3.7%	30.0%	3.0%	0.4%	2.9%	0.3%	21.6%	15.3%	7.8%	2.1%	2.2%	10.3%	0.4%	0.0%	0.0%
Williamsburg	0.4%	1.3%	0.3%	0.0%	0.3%	0.0%	2.1%	0.5%	0.0%	43.5%	41.4%	10.1%	0.1%	0.0%	0.0%
James City	0.8%	2.9%	0.8%	0.1%	0.6%	0.0%	4.0%	0.9%	0.1%	31.9%	44.6%	13.0%	0.2%	0.0%	0.0%
York	2.5%	18.1%	2.0%	0.3%	1.9%	0.2%	22.4%	9.7%	1.3%	11.2%	8.1%	21.6%	0.8%	0.0%	0.0%
Gloucester	2.4%	5.5%	3.6%	0.6%	1.0%	0.3%	12.8%	3.3%	0.3%	7.5%	6.3%	13.3%	43.2%	0.0%	0.0%
Franklin	8.4%	13.1%	4.6%	2.5%	7.0%	0.9%	0.8%	0.2%	0.0%	0.1%	0.1%	0.1%	0.0%	53.2%	9.1%
Southampton	13.6%	19.0%	9.6%	2.5%	7.5%	1.3%	1.5%	0.4%	0.0%	0.1%	0.1%	0.2%	0.0%	12.8%	31.4%

Figure 10-1: HBW Model Jurisdiction to Jurisdiction Distribution

HBW	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	45.1%	17.2%	8.9%	4.6%	19.8%	0.5%	2.0%	1.4%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%
Norfolk City	14.9%	38.7%	6.6%	2.9%	30.3%	0.4%	2.6%	2.7%	0.1%	0.0%	0.1%	0.4%	0.0%	0.0%	0.1%
Portsmouth	21.2%	17.8%	28.7%	10.0%	12.0%	1.6%	4.7%	3.0%	0.1%	0.0%	0.1%	0.3%	0.0%	0.3%	0.2%
Suffolk	13.1%	9.6%	11.7%	42.7%	4.9%	5.0%	5.9%	3.5%	0.1%	0.1%	0.2%	0.5%	0.0%	1.5%	1.1%
VA Beach	10.4%	17.9%	2.7%	0.9%	65.6%	0.1%	1.2%	0.9%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
Isle of Wight	4.2%	3.9%	5.3%	14.5%	1.3%	40.6%	14.5%	6.2%	0.1%	0.1%	1.0%	0.7%	0.1%	4.2%	3.1%
Newport News	2.1%	3.2%	1.9%	2.1%	2.1%	1.9%	45.5%	22.3%	1.1%	1.2%	4.6%	9.9%	1.9%	0.1%	0.1%
Hampton City	2.2%	5.1%	1.9%	1.8%	2.8%	1.1%	32.3%	41.8%	1.2%	0.5%	1.8%	6.9%	0.6%	0.0%	0.0%
Poquoson	0.4%	4.1%	1.3%	1.5%	0.6%	0.4%	38.9%	29.2%	7.8%	0.5%	1.9%	12.3%	1.1%	0.0%	0.0%
Williamsburg	0.4%	0.6%	0.3%	0.4%	0.4%	0.1%	16.1%	4.9%	0.3%	9.5%	47.4%	17.2%	2.5%	0.0%	0.0%
James City	0.4%	0.5%	0.2%	0.2%	0.4%	0.6%	16.1%	4.3%	0.2%	11.6%	48.5%	14.7%	2.2%	0.0%	0.0%
York	0.4%	2.1%	0.5%	0.7%	0.7%	0.3%	33.1%	16.8%	1.4%	3.6%	12.6%	23.9%	3.8%	0.0%	0.0%
Gloucester	0.3%	0.5%	0.1%	0.1%	0.4%	0.2%	18.3%	4.2%	0.3%	1.6%	5.5%	10.0%	58.5%	0.0%	0.0%
Franklin	2.0%	2.0%	3.3%	15.7%	1.1%	16.2%	2.8%	1.0%	0.0%	0.0%	0.0%	0.2%	0.0%	5.8%	49.9%
Southampton	1.3%	1.6%	1.9%	8.2%	0.6%	6.8%	2.1%	0.5%	0.0%	0.0%	0.2%	0.1%	0.0%	29.6%	47.1%

Figure 10-2: HBW AirSage Jurisdiction to Jurisdiction Distributions

HBO	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	67.1%	10.9%	8.7%	2.3%	10.3%	0.1%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Norfolk City	3.9%	82.3%	2.0%	0.1%	11.4%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Portsmouth	15.8%	13.0%	62.7%	4.0%	3.6%	0.2%	0.3%	0.2%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%
Suffolk	9.5%	7.4%	6.9%	66.3%	4.2%	2.5%	1.1%	0.8%	0.0%	0.1%	0.2%	0.2%	0.1%	0.3%	0.5%
VA Beach	4.5%	7.5%	0.4%	0.1%	87.3%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Isle of Wight	3.1%	6.4%	2.0%	6.6%	4.1%	66.9%	4.1%	2.7%	0.1%	0.3%	0.5%	0.5%	0.1%	1.1%	1.4%
Newport News	0.4%	1.2%	0.3%	0.3%	0.7%	0.4%	74.9%	12.4%	0.3%	0.8%	1.5%	6.6%	0.3%	0.0%	0.0%
Hampton City	0.4%	2.0%	0.2%	0.2%	0.9%	0.3%	17.4%	74.7%	0.4%	0.3%	0.4%	2.6%	0.1%	0.0%	0.0%
Poquoson	0.7%	2.1%	0.4%	0.4%	1.3%	0.3%	10.9%	12.1%	48.4%	0.8%	1.2%	21.0%	0.3%	0.0%	0.1%
Williamsburg	0.1%	0.4%	0.1%	0.1%	0.2%	0.1%	1.0%	0.3%	0.0%	52.4%	31.5%	13.7%	0.1%	0.0%	0.0%
James City	0.2%	0.6%	0.1%	0.1%	0.2%	0.1%	1.5%	0.5%	0.0%	15.6%	73.9%	6.9%	0.2%	0.0%	0.0%
York	0.4%	1.2%	0.2%	0.2%	0.7%	0.2%	22.8%	9.3%	3.2%	7.3%	7.2%	45.9%	1.2%	0.0%	0.0%
Gloucester	0.3%	1.1%	0.3%	0.4%	0.2%	0.3%	3.7%	1.4%	0.2%	2.1%	2.9%	4.2%	82.9%	0.0%	0.0%
Franklin	1.0%	1.7%	0.6%	2.1%	1.4%	2.8%	0.3%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	76.2%	13.3%
Southampton	2.6%	4.2%	1.7%	2.8%	2.8%	2.6%	0.9%	0.6%	0.0%	0.1%	0.1%	0.2%	0.0%	8.6%	72.8%

Figure 10-3: HBO (Combined) Model Jurisdiction to Jurisdiction Distributions

HBO	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	66.5%	8.1%	7.0%	3.8%	11.9%	0.4%	0.9%	0.8%	0.0%	0.0%	0.2%	0.2%	0.0%	0.1%	0.1%
Norfolk City	8.9%	62.3%	3.9%	1.6%	18.6%	0.2%	1.6%	2.0%	0.1%	0.0%	0.2%	0.4%	0.1%	0.1%	0.1%
Portsmouth	17.5%	8.8%	54.7%	7.7%	6.3%	0.8%	1.9%	1.4%	0.0%	0.0%	0.2%	0.2%	0.1%	0.1%	0.2%
Suffolk	8.5%	3.3%	7.1%	69.4%	2.8%	3.4%	2.0%	1.3%	0.0%	0.0%	0.2%	0.2%	0.0%	0.8%	0.8%
VA Beach	6.3%	8.8%	1.3%	0.6%	81.2%	0.1%	0.6%	0.6%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%
Isle of Wight	2.2%	1.3%	1.8%	8.2%	1.1%	69.4%	5.6%	3.2%	0.1%	0.1%	0.7%	0.5%	0.1%	2.2%	3.6%
Newport News	1.1%	1.7%	0.9%	1.0%	1.4%	1.3%	65.8%	14.0%	0.7%	0.5%	2.5%	7.7%	1.3%	0.0%	0.1%
Hampton City	1.2%	2.8%	0.9%	0.9%	1.9%	0.9%	18.6%	65.9%	1.0%	0.2%	1.0%	4.1%	0.4%	0.0%	0.0%
Poquoson	0.4%	1.1%	0.3%	0.3%	0.8%	0.3%	14.0%	14.6%	51.6%	0.3%	1.4%	14.4%	0.6%	0.0%	0.0%
Williamsburg	0.6%	0.8%	0.2%	0.3%	1.1%	0.3%	8.0%	2.2%	0.2%	35.8%	34.9%	13.7%	1.8%	0.0%	0.0%
James City	0.5%	0.5%	0.2%	0.2%	0.8%	0.4%	6.8%	2.1%	0.2%	5.6%	72.1%	9.2%	1.2%	0.0%	0.0%
York	0.5%	1.1%	0.3%	0.3%	1.0%	0.3%	20.8%	8.6%	1.9%	2.2%	9.0%	51.0%	2.9%	0.0%	0.0%
Gloucester	0.2%	0.4%	0.2%	0.1%	0.4%	0.1%	5.6%	1.4%	0.2%	0.5%	2.0%	4.8%	84.2%	0.0%	0.0%
Franklin	1.7%	1.1%	0.7%	6.9%	0.7%	8.1%	0.9%	0.3%	0.0%	0.0%	0.1%	0.0%	0.0%	53.8%	25.6%
Southampton	0.9%	0.6%	0.6%	3.0%	0.7%	5.6%	0.6%	0.2%	0.0%	0.0%	0.1%	0.1%	0.0%	10.8%	76.7%

Figure 10-4: HBO AirSage Model Jurisdiction to Jurisdiction Distributions

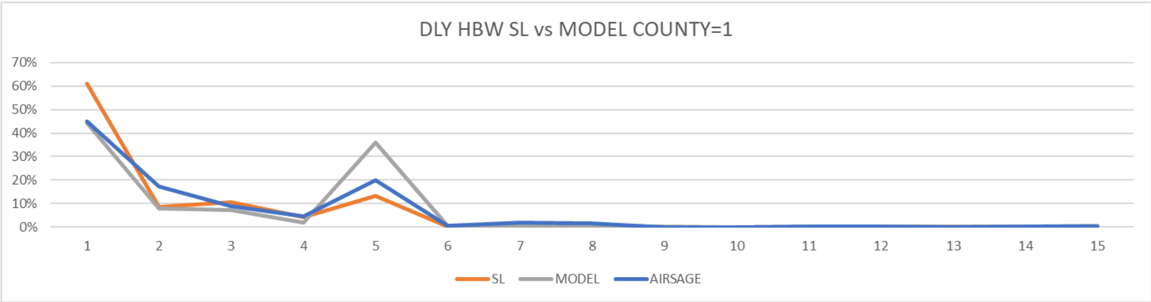
NHB	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	62.0%	14.4%	9.6%	2.2%	11.4%	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norfolk City	5.4%	75.6%	3.0%	0.2%	15.5%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Portsmouth	17.7%	17.4%	54.2%	4.6%	5.3%	0.2%	0.3%	0.2%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
Suffolk	10.9%	12.1%	7.9%	58.2%	5.3%	2.2%	1.2%	0.7%	0.0%	0.1%	0.2%	0.2%	0.0%	0.7%	0.3%
VA Beach	6.6%	10.9%	0.9%	0.1%	81.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Isle of Wight	5.0%	11.0%	3.4%	8.4%	5.7%	54.0%	5.2%	2.8%	0.1%	0.2%	0.5%	0.6%	0.1%	2.0%	0.9%
Newport News	0.9%	3.3%	0.6%	0.5%	1.2%	0.5%	70.6%	12.5%	0.3%	0.7%	2.0%	6.4%	0.3%	0.0%	0.0%
Hampton City	0.9%	5.0%	0.6%	0.5%	1.9%	0.6%	20.2%	66.6%	0.4%	0.2%	0.6%	2.4%	0.1%	0.0%	0.0%
Poquoson	1.6%	5.9%	0.9%	0.7%	2.5%	0.5%	18.5%	20.4%	31.7%	0.7%	1.7%	14.5%	0.4%	0.0%	0.0%
Williamsburg	0.2%	0.5%	0.1%	0.1%	0.2%	0.0%	1.2%	0.3%	0.0%	44.2%	32.7%	20.4%	0.1%	0.0%	0.0%
James City	0.2%	0.8%	0.2%	0.1%	0.2%	0.1%	1.9%	0.4%	0.0%	13.2%	71.5%	11.2%	0.1%	0.0%	0.0%
York	0.9%	3.1%	0.5%	0.4%	1.2%	0.3%	26.4%	11.7%	2.2%	5.8%	8.1%	38.3%	1.1%	0.0%	0.0%
Gloucester	0.7%	1.8%	0.8%	0.8%	0.4%	0.5%	7.4%	2.4%	0.2%	2.1%	4.7%	6.7%	71.4%	0.0%	0.0%
Franklin	1.2%	2.0%	0.6%	1.9%	1.8%	1.5%	0.3%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	84.3%	6.0%
Southampton	5.1%	8.3%	2.6%	4.3%	5.6%	3.3%	1.2%	0.7%	0.0%	0.1%	0.3%	0.3%	0.0%	14.4%	54.0%

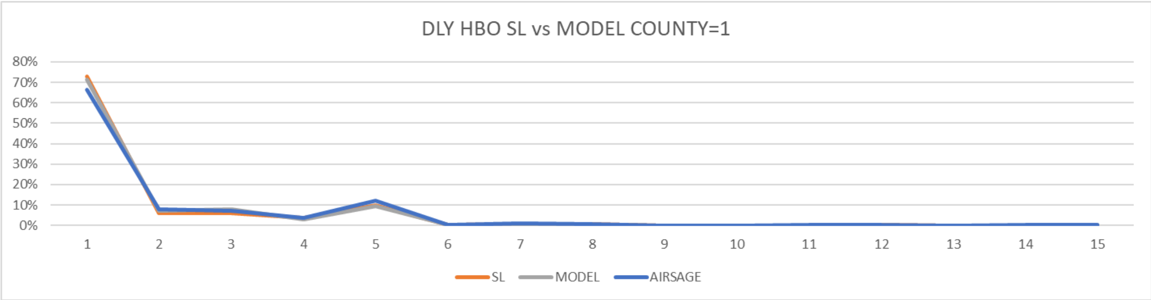
Figure 10-5: NHB Model Jurisdiction to Jurisdiction Distributions

NHB	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	57.5%	9.9%	6.8%	5.2%	16.5%	0.7%	1.2%	1.1%	0.0%	0.0%	0.2%	0.3%	0.1%	0.1%	0.2%
Norfolk City	12.3%	49.3%	4.8%	2.7%	24.3%	0.5%	2.1%	2.7%	0.1%	0.1%	0.3%	0.5%	0.2%	0.1%	0.1%
Portsmouth	20.9%	12.8%	38.7%	9.8%	10.2%	1.5%	2.5%	2.1%	0.1%	0.0%	0.3%	0.5%	0.2%	0.2%	0.3%
Suffolk	10.4%	4.3%	6.6%	61.6%	4.1%	5.4%	2.3%	1.8%	0.1%	0.1%	0.3%	0.4%	0.1%	1.3%	1.3%
VA Beach	8.8%	11.1%	1.5%	1.0%	75.0%	0.2%	0.8%	0.8%	0.0%	0.1%	0.2%	0.3%	0.1%	0.0%	0.1%
Isle of Wight	2.7%	1.7%	1.8%	11.1%	1.5%	60.5%	6.5%	3.7%	0.1%	0.1%	0.8%	0.6%	0.1%	3.2%	5.6%
Newport News	2.2%	2.5%	1.3%	2.0%	2.6%	2.4%	52.0%	16.7%	1.0%	0.8%	3.7%	9.8%	2.7%	0.1%	0.2%
Hampton City	2.2%	4.3%	1.3%	1.7%	3.3%	1.6%	21.9%	53.5%	1.3%	0.4%	1.5%	6.0%	0.9%	0.0%	0.1%
Poquoson	1.0%	1.8%	0.3%	0.5%	0.7%	0.4%	19.7%	20.7%	33.4%	0.5%	1.8%	17.8%	1.3%	0.0%	0.0%
Williamsburg	0.6%	0.8%	0.2%	0.3%	1.8%	0.3%	7.9%	2.7%	0.2%	25.4%	38.3%	18.9%	2.4%	0.0%	0.0%
James City	0.6%	0.6%	0.2%	0.4%	1.2%	0.8%	7.9%	2.6%	0.2%	8.7%	61.1%	13.7%	1.9%	0.0%	0.1%
York	0.8%	1.2%	0.3%	0.5%	1.5%	0.4%	21.6%	8.3%	1.7%	4.6%	14.9%	38.7%	5.4%	0.0%	0.0%
Gloucester	0.3%	0.5%	0.2%	0.1%	0.5%	0.1%	6.8%	1.8%	0.2%	0.7%	2.5%	6.8%	79.6%	0.0%	0.0%
Franklin	2.0%	1.1%	1.0%	9.9%	1.0%	11.8%	0.6%	0.3%	0.0%	0.0%	0.1%	0.1%	0.0%	36.0%	36.2%
Southampton	1.4%	0.8%	0.5%	3.4%	1.0%	7.7%	0.6%	0.3%	0.0%	0.0%	0.1%	0.1%	0.0%	12.7%	71.2%

Figure 10-6: NHB AirSage Jurisdiction to Jurisdiction Distributions

Similar comparisons were made that included the Streetlight location based OD data that includes a definition of purpose as well. Following is an example output generated comparing the distribution of trips from Chesapeake to each jurisdiction from the model to Streetlight and AirSage.





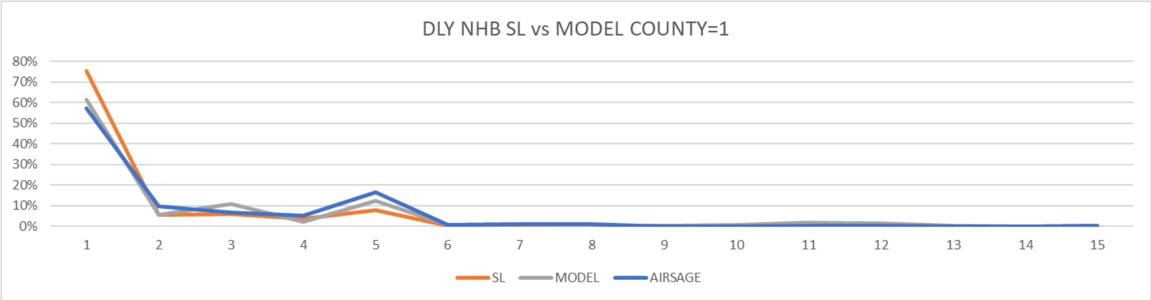


Figure 10-7: Jurisdiction Distribution Patterns

Using the above information, the HBW K-factors were estimated to improve the overall model validation. Similar graphics for each jurisdiction are provided as an Appendix to this Report. The K-factors are input to the peak period distribution model via a script as part of the model stream. The factors are applied at the jurisdiction level and applied to all zones within the jurisdiction. The k-factors were developed based on improving the distribution of model to observed trips based on the Streetlight peak period LBS trip purpose jurisdiction to jurisdiction flows. The factors were used to improve the intra jurisdiction and crossings of the James and Elizabeth Rivers.

	Chesapeake	Norfolk City	Portsmouth	Suffolk	VA Beach	Isle of Wight	Newport News	Hampton City	Poquoson	Williamsburg	James City	York	Gloucester	Franklin	Southampton
Chesapeake	1	0.5	0.5	1	5	1	1	1	1	1	1	1	1	1	1
Norfolk City	1	2.5	1	1	0.5	1	1	1	1	1	1	1	1	1	1
Portsmouth	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Suffolk	0.5	0.5	1	5	1	1	1	1	1	1	1	1	1	1	1
VA Beach	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isle of Wight	0.5	0.5	1	1	1	5	1	1	1	1	1	1	1	1	1
Newport News	1	0.25	1	1	1	1	5	1	1	1	1	1	1	1	1
Hampton City	1	0.15	1	1	1	1	1	5	1	1	1	1	1	1	1
Poquoson	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Williamsburg	1	1	1	1	1	1	1	1	1	1	2.5	1	1	1	1
James City	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
York	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gloucester	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Franklin	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Southampton	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 10-8: Peak Period HBW K-Factors (Jurisdiction to Jurisdiction)

10.1.3 Mode Choice

The process of calibration of mode choice model involved adjusting the mode specific constants iteratively until the modeled trips match the calibration targets. The mode choice is run by trip purpose, time of day, and vehicle ownership. The mode choice coefficients and alternative specific constants in the top level after including nest coefficients are reported in Table 10-3, Table 10-4 and Table 10-5.

Table 10-3 Mode Choice Model Coefficients

Class	IVTT	OVTT	Cost	Transfer	C_DA	C_HOV2	C_HOV3+
HBW0PK	-0.025	-0.0625	-0.0015	-0.05	-99.00	-6.30	-6.40
HBW1PK	-0.025	-0.0625	-0.0015	-0.05	0.00	-3.00	-4.60
HBO0PK	-0.025	-0.0625	-0.0015	-0.05	-3.30	-0.50	-0.65
HBO1PK	-0.025	-0.0625	-0.0015	-0.05	0.00	-0.37	-0.88
HBW0OP	-0.025	-0.0625	-0.0015	-0.05	-99.00	-4.10	-4.60
HBW1OP	-0.025	-0.0625	-0.0015	-0.05	0.00	-2.75	-6.00
HBO0OP	-0.025	-0.0625	-0.0015	-0.05	-2.40	-0.75	-1.30
HBO1OP	-0.025	-0.0625	-0.0015	-0.05	0.00	-0.61	-1.15

Table 10-4 Mode Choice Model Coefficients

Class	C_WKTRN	C_DRTRN	C_FPWLK	C_MSDA	C_MSSR2	C_MSSR3
HBW0PK	-3.00	-99.00	-99.00	-99.00	-99.00	-99.00
HBW1PK	-3.90	-5.94	-6.70	-99.00	-99.00	-99.00
HBO0PK	-4.30	-99.00	0.00	-99.00	-99.00	-99.00
HBO1PK	-3.67	-3.98	0.00	-99.00	-99.00	-99.00
HBW0OP	-2.85	-99.00	0.00	-99.00	-99.00	-99.00
HBW1OP	-3.65	-6.70	0.00	-99.00	-99.00	-99.00
HBO0OP	-4.90	-99.00	0.00	-99.00	-99.00	-99.00
HBO1OP	-4.50	-4.90	0.00	-99.00	-99.00	-99.00

Table 10-5 Mode Choice Model Coefficients

Class	OP_COST	HOV3_OCC
HBW0PK	10.5	3.5
HBW1PK	10.5	3.5
HBO0PK	10.5	3.5
HBO1PK	10.5	3.5
HBW0OP	10.5	3.5
HBW1OP	10.5	3.5
HBO0OP	10.5	3.5
HBO1OP	10.5	3.5

The utility function coefficients were calibrated in light of FTA guidance. As shown in Table 10-6, the new mode choice coefficients are in keeping with FTA recommendations.

Table 10-6 Mode Choice Utility Function Coefficients and FTA Guidance

Utility function Variable	Model Coefficient	FTA Lower Bound	FTA Upper Bound
In-vehicle time	-0.025	-0.03	-0.02
Ratio of Out-of-vehicle time coefficient to In-vehicle time coefficient	2.5	2	3
Value of Time ($/Hour)	10	6	15

Table 10-7 shows the in-vehicle time and out-of-vehicle time coefficients and their ratio used in mode choice. It also presents the factors used in the transit path building. The transit-path building factors shown in Table 10-7 include weights applied to in-vehicle time and out-of-vehicle time. According to Table 10-7, the model uses the same ratios in the mode choice and transit path-building.

Table 10-7 Transit-Related Coefficients in Mode Choice and Transit-Path Building

Utility function Variable	Mode Choice Coefficient	Transit Path Building Factor
In-vehicle time	-0.025	1
Out-of-vehicle time	-0.0625	2.5
Ratio of Out-of-vehicle time coefficient to In-vehicle time coefficient	2.5	2.5

The calibrated mode specific constants for all purposes and time periods in the mode choice model are shown in Table 10-8.

Table 10-9 shows the mode specific constants expressed as equivalent minutes of in-vehicle time (compared to the drive alone mode). Note that the high values of 3,960 minutes' penalty for some sub-modes is an asserted value (based on the experience) to prevent illogical trips, e.g., drive alone trips for 0-car households.

Table 10-8 Mode Choice Model Constants

Class	C_DA	C_HOV2	C_HOV3+	C_WKTRN	C_DRTRN	C_FPWLK
HBW0PK	-99.00	-6.30	-6.40	-3.00	-99.00	-99.00
HBW1PK	0.00	-3.00	-4.60	-3.90	-5.94	-6.70
HBO0PK	-3.30	-0.50	-0.65	-4.30	-99.00	0.00
HBO1PK	0.00	-0.37	-0.88	-3.67	-3.98	0.00
HBW0OP	-99.00	-4.10	-4.60	-2.85	-99.00	0.00
HBW1OP	0.00	-2.75	-6.00	-3.65	-6.70	0.00
HBO0OP	-2.40	-0.75	-1.30	-4.90	-99.00	0.00
HBO1OP	0.00	-0.61	-1.15	-4.50	-4.90	0.00

Table 10-9 Mode Choice Model Constants in Equivalent IVTT Minutes

Class	C_DA	C_HOV2	C_HOV3+	C_WKTRN	C_DRTRN	C_SLG
HBW0PK	3,960	252	256	120	3,960	3,960
HBW1PK	0	120	184	156	237.6	268
HBO0PK	132	20	26	172	3,960	0
HBO1PK	0	14.8	35.2	146.8	159.2	0
HBW0OP	3,960	164	184	114	3,960	0

HBW1OP	0	110	240	146	268	0
HBO0OP	96	30	52	196	3,960	0
HBO1OP	0	24.4	46	180	196	0

The mode choice base year validation indicates it works very well in replicating the observed mode shares. Table 10-10 and Table 10-11 present modeled target and model mode shares for the household trips. Comparison between modeled mode shares and target mode shares confirms that the mode choice performs very well.

Table 10-10 Target Mode Shares by Trip Purpose and Time Period (NHTS 2015)

Mode	Peak			Off-Peak		
	HBW	HBO	NHB	HBW	HBO	NHB
Drive Alone	89.5%	41.9%	59.9%	89.0%	49.3%	56.5%
Shared Ride 2	7.1%	35.3%	25.6%	9.3%	31.5%	27.7%
Shared Ride 3+	2.9%	22.1%	13.6%	1.8%	19.0%	15.4%
Transit	0.5%	0.7%	0.9%	0.0%	0.2%	0.3%

Table 10-11 Mode Share by Trip Purpose and Time Period (Model 2015)

Mode	Peak			Off-Peak		
	HBW	HBO	NHB	HBW	HBO	NHB
Drive Alone	89.1%	42.2%	60.0%	87.1%	48.9%	56.5%
Shared Ride 2	6.8%	34.7%	25.6%	9.6%	31.5%	27.7%
Shared Ride 3+	2.6%	22.4%	13.5%	2.2%	19.0%	15.7%
Walk to Transit	1.4%	0.7%	0.9%	1.2%	0.5%	0.3%

It should be mentioned that NHTS sample size for transit trips is very small and the shares might not represent the real world. The calibration/validation, therefore, was done based on other models, overall highway traffic loading error, and daily transit ridership.

10.1.4 Highway Assignment

The results of the highway assignment are based upon the daily volumes reported by the model and compared against the 2017 AWDT coded in the network. Several metrics are calculated including:

- Model Vehicle Miles of Travel vs Count Vehicle Miles Traveled
    a. Facility Type
    b. Area Type
    c. Jurisdiction
- Model vs Count
    a. % RMSE by Volume Group
- Scatter Plot: Count vs Model
- Estimate of Jurisdiction VMT vs Model

Based upon the VDOT Travel Demand Modeling Standards, a set of criteria were defined to assess the validation of the model. The criteria were as follows:

Type of Check	Check
VMT by link group (facility type, geographic subregion, etc.)	FHWA functional classification Freeways/Expressways: ±7% Principal Arterials: ±10% Minor Arterials: ±15% Collectors: ±20%
R^2 between modeled volumes and counts on links	Large Region: 0.90 Small Region: 0.92
Percent root mean square error	See Table 10.5
Cordon line and screenline volume checks	< 54,000: ± 10 percent ≥ 54,000 and < 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent
Cutline volume checks	< 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent
Speed checks	Reasonableness checks only

Figure 10-9: VDOT Validation Criteria (Source: VDOT Travel Demand Modeling Policies and Procedures Manual – Recommended Practices Quick Reference)

The following tables summarize the count vs model VMT by facility type (Table 10-12), area type (Table 10-13) and jurisdiction (Table 10-14). Within each table, the criteria and target value are shown for reference. With the exception of the CBD which has very few count locations and a few jurisdictions, the model meets the criteria.

Table 10-12: Model vs Count VMT by Facility Type

Facility Type		Count VMT	Model VMT	Count/Model	N	Criteria
1	Interstate	7,124,081	7,357615	1.03	158	+/- 7%
2	Minor Freeway	1,164,317	1,149,918	0.99	40	+/- 7%
3	PA / Highway	1,564,267	1,568,188	1.00	221	+/- 10%
4	MA / Highway	455,065	470,303	1.01	119	+/- 10%
5	Min Art / Highway	2,158,089	2,050,549	0.95	676	+/- 15%
6	Major Collector	216,244	232,364	1.06	156	+/- 15%
7	Minor Collector	493,110	440,837	0.89	510	+/- 20%
8	Local	14,632	10,704	0.73	11	+/- 20%
TOTAL		13,189,805	13,280,478	1.01	1,891	

Table 10-13: Model vs Count VMT by Area Type

Area Type		Count VMT	Model VMT	Count/Model	N	Criteria
1	CBD	6,758	4,584	0.68	6	
2	Urban	2,097,467	1,993,045	0.95	375	
3	Dense Suburban	2,130,383	2,220,715	1.04	393	+/- 10%
4	Suburban	3,016,660	2,901,388	0.96	412	
5	Rural	5,938,536	6,160,746	1.03	705	

TOTAL	13,189,805	13,280,478	1.01	1,891	

Table 10-14: Model vs Count VMT by Jurisdiction

Jurisdiction		Count VMT	Model VMT	Count/Model	N	Criteria
1	Chesapeake	2,220,216	2,350,715	1.06	228	+/- 10%
2	Norfolk City	1,652,534	1,684,583	1.02	301	
3	Portsmouth	397,155	423,569	1.07	167	
4	Suffolk	1,033,596	1,098,661	1.05	140	
5	VA Beach	2,520,944	2,281,694	0.91	323	
6	Isle of Wight	219,687	211,893	0.96	72	
7	Newport News	1,446,302	1,499,690	1.04	147	
8	Hampton City	1,690,788	1,667,474	0.99	168	
9	Poquoson	21,223	21,145	1.00	13	
10	Williamsburg	60,643	46,582	0.77	38	
11	James City	1,000,192	1,026,780	1.02	72	
12	York	637,516	686,457	1.08	78	
13	Gloucester	139,955	138,165	0.95	44	
14	Franklin	23,474	14,766	0.63	39	
15	Southampton	125,579	128,304	1.02	61	
TOTAL		13,189,805	13,280,478	1.01	1,891	

Percent RMSE by volume group is a critical validation criterion and was applied to the HRTPO model. The % RMSE Guidance is shown as well. The model follows the guidance with the exception of a few volume groups.

Table 10-15: %RMSE by Volume Group

Volume Group	%RMSE	N	Criteria
1- 5,000	103.5%	528	100%
5,000- 10,000	57.4%	375	45%
10,000- 15,000	44.1%	271	35%
15,000- 20,000	29.4%	142	30%
20,000- 30,000	30.8%	221	27%
30,000- 50,000	24.3%	251	25%
50,000- 60,000	22.1%	40	20%
60,000-500,000	15.2%	63	19%
1-500,000	36.3%	1891	40%

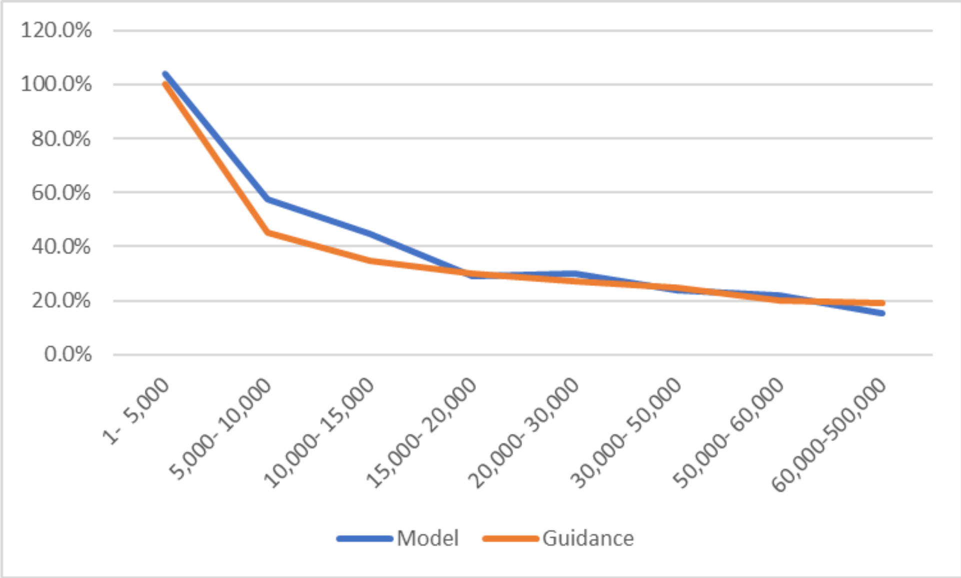


Figure 10-10: Percent RMSE by Volume Group (Model vs Count)

The overall R-squared was calculated based on the model vs count flows across the entire model area and for all facility types. The resulting R-squared was 0.8833 which is very close to the guidance value of 0.90 as recommended by VDOT for large areas.

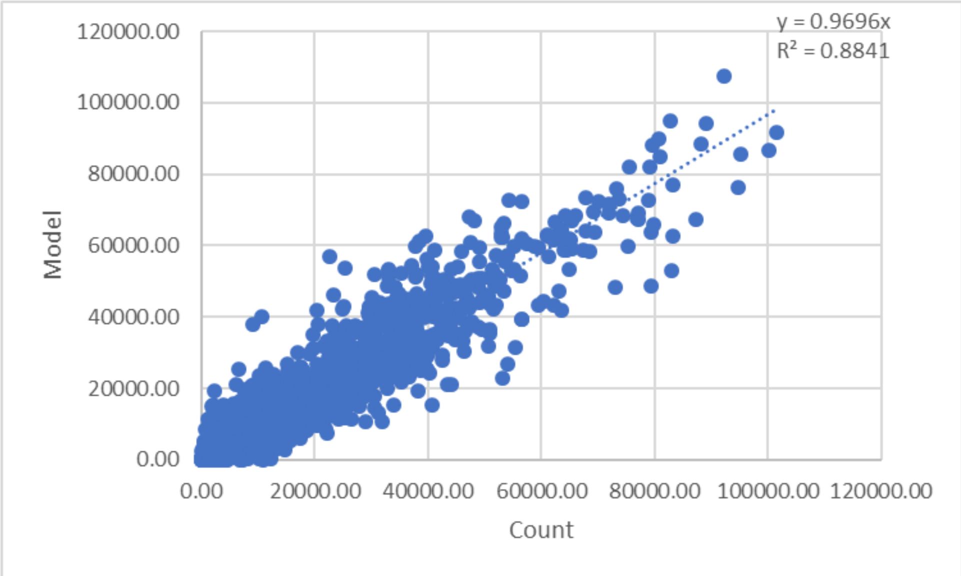


Figure 10-11: Model vs Count Scatterplot

The above comparisons are based only on links with counts. A broader comparison was made using jurisdiction wide estimates of VMT on all facilities was provided by VDOT to compare against the model volumes on all links for 2017. Because of differences in the network density of the model versus roadways included in the jurisdiction estimates, the comparison was limited to interstates through minor arterials. Figure 10-12 shows over the 15 jurisdictions, the model very closely follows the estimated VMT on all links. The variation between Major and Minor Arterials maybe attributed to differences in how links are classified in the model as compared to the VDOT reporting scheme.

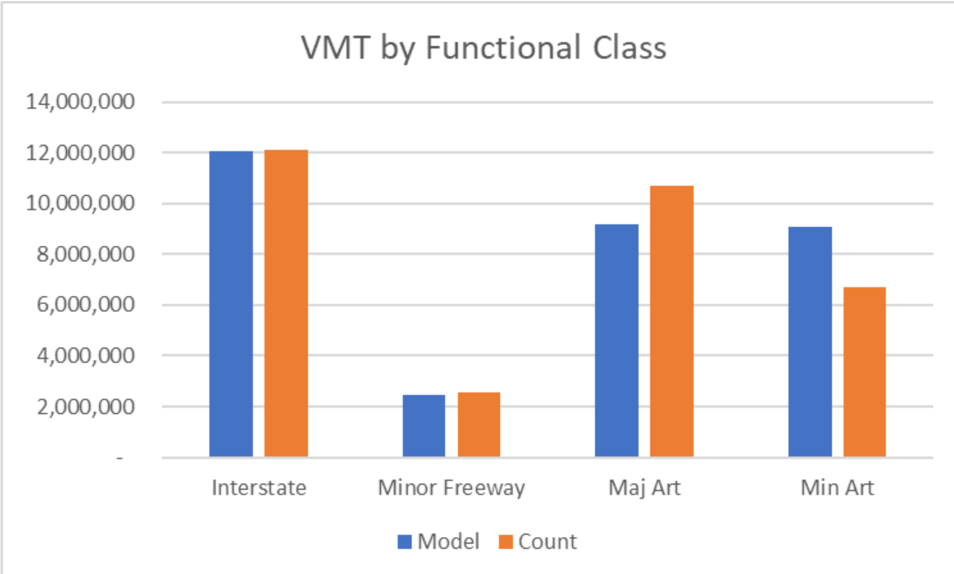


Figure 10-12: HRTPO Model Area - Model vs Count VMT by Facility Type

Figure 10-13 is a similar comparison, but is focused on the total observed vs model VMT by jurisdiction. Overall, the model is within 10% across the entire model area including all facility types. Most jurisdictions are within +/- 10% with the exception of a few jurisdictions.

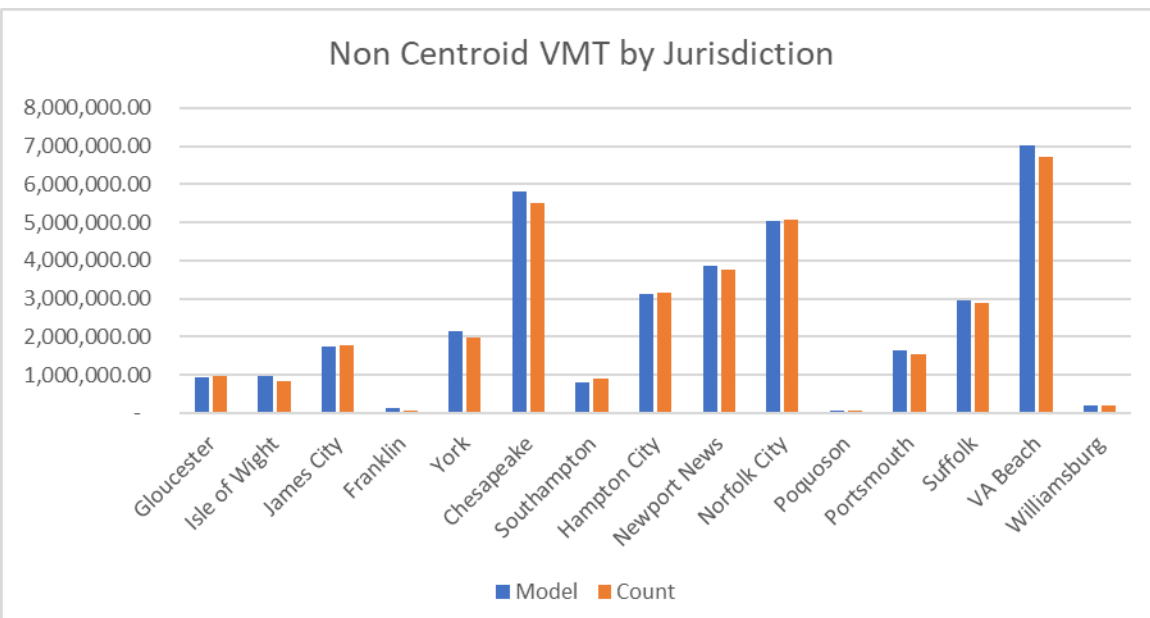


Figure 10-13: HRTPO Model Area - Model vs Count VMT by Jurisdiction

The final comparison of the assigned volumes versus count is on the bridges and tunnels throughout the HRTPO region. Table 10-16 provides a comparison of the 2017 count vs model volumes on each bridge or tunnel by river including the James and Elizabeth crossings. The model is very close to count on each James River Crossing and is within 15% when all Elizabeth River crossings are considered.

Table 10-16: James and Elizabeth River Crossings

		Count	Model
James River	James River Bridge	31,203	32,625
	Monitor Merrimac Memorial Bridge, I-664	70,751	71,998
	Hampton Roads Bridge Tunnel, I-64	92,437	96,697
Elizabeth River	US 58 Midtown Tunnel	34,087	48,223
	Berkley Bridge	102,476	139,726
	Downtown Tunnel	89,686	83,286
	Campostella Road	55,371	31,614
	Military Highway US 40	38,498	61,110
	I-64 High Rise	94,404	109,391

10.1.5 Transit Assignment

Transit ridership for the model area in 2015 was used for model calibration. According to the data, the daily observed ridership is 58,612 and the model produces 57,665 transit ridership, which is very close to the observed ridership. Table 10-17 reports the total model ridership and observed ridership by service. Which shows agreement between the model and reality.

Table 10-17 Observed and Model Transit Ridership by Service (2015)

Service	Observed Ridership	Model Ridership
Southside	32,794	28,714
Peninsula	14,891	17,112
VB Wave	4	304
Peninsula Commuter	467	358
Max	1,736	1,158
LRT/Ferry	5,541	5,488
Suffolk	243	1,186
WATA	2,935	3,345
Total	58,612	57,665

10.2 Dynamic Validation

Dynamic Validation is intended to understand whether the calibrated model parameters and relationships are maintained when tested under changes in model inputs. For purposes of this validation, 2045 land use was input to the model along with an E+C network to evaluate the growth in VMT as compared to the land use changes. In addition a network scenario for 2017 was evaluated by testing the I-64 HOT project.

10.2.1 Mode Choice

A limited number of sensitivity analyses were conducted as a mean of dynamic validation of the model's response properties. Although the model replicates the target mode shares, it should be tested to see how the model reacts to changes in variables. In other words, the elasticity of the model should be verified. The elasticity of the transit demand to transit level of service and fare was tested. According to a general rule of thumb for transit, elasticity of transit demand should be between 30% and 70%. Since the Hampton Roads model area is not large and the transit trips consist a small portion of daily trips, the consultant team expected to see the elasticity of the model near the lower bound or 30%. Four scenarios were designed and run as follows:

1- Transit fares were doubled for each transit mode.
2- Transit fares were decreased by 50 percent for each transit mode.
3- Transit headways were doubled for each transit mode.
4- Transit headways were decreased by 50 percent for each transit mode.

Two scenarios (2 and 4) make transit more attractive while the other two should shift people to auto trips. Arc elasticity for transit trips was calculated as the following equation:

$$Elasticity = 100 \times \frac{\Delta D / Average\ (D_1, D_2)}{\Delta X / Average\ (X_1, X_2)}$$

Where:

D_1: is the transit demand in the base scenario

D_2: is the transit demand in the sensitivity scenario

X_1: is the transit attribute in the base scenario, and

X_2: is the transit attribute in the sensitivity scenario

The calculated elasticities are reported in Table 10-18. According to Table 10-18, the transit system is more sensitive to transit level of service than fare. For example, scenario 4 which equal to 100 percent increase in the frequency shows the transit demand significantly goes up. According to this sensitivity analysis, transit users in the model do not have other options for their trip as the change in fare does not drastically affect them. On the other hand, change in transit headway or frequency is very important to them as decrease in frequency generates more walk paths in transit skimming or increase in frequency brings some walk paths to transit. The sensitivity analysis results look reasonable and confirm that the mode choice works properly.

Table 10-18 Transit Demand Arc Elasticity

Sensitivity Scenario	Daily Transit Trips	Difference with the Base (Daily)	Arc Elasticity for the Entire System (%)
Scenario 1	42,501	-7,309	-22.01
Scenario 2	53,985	4,175	12.57
Scenario 3	26,264	-23,546	-70.92
Scenario 4	76,060	26,250	79.05

10.2.2 Land Use Change

The HRTPO Model was run using the 2045 land use data as developed by HRTPO. Table 10-19 below compares the regional total households, population and employment between 2017 and 2045. The region is expected to increase by 108,925 households which represents a 17% increase. In terms of employment, there are 75,549 new jobs expected to be added by 2045.

Table 10-19 2017 vs 2045 Land Use Inputs

Variable	2017	2045
Total Households	631,173	740,098
Total Population	1,737,381	2,016,710
Average Household Size	2.75	2.72
Total Employment	1,029,012	1,104,561

Table 10-20 reports the number of person trips by trip purpose between the two years. In total 1,106,068 trips were added to the region which is consistent with the total number of added households and average household trip rate that has decreased between 2017 and 2045 based on decreasing household size.

Table 10-20: 2017 vs 2045 Person Trips by Purpose

Trip Purpose	2017	2045
HBW	1,306,927	1,512,305
HBO	2,445,458	2,811,921
NHB	1,946,376	2,252,793
HBShop	1,447,040	1,674,822
Total	7,147,818	8,253,886

Table 10-21 provides a comparison of the system wide VMT by area type for 2017 and 2045. VMT increases are a function of trip growth from both internal and external travel as well as changes in travel patterns based on additional projects and congestion in the system. The VMT increases by 17.5% between 2017 and 2045 which is consistent with the increase in households.

Table 10-21 2017 vs 2045 VMT

Area Type	2017	2045
1-CBD	41,951	54,444
2-OBD	7,161,819	8,044,419
3-Urban	6,774,442	6,786,995
4-Sub Urban	8,325,354	10,435,713
5-Rural	17,788,878	21,775,382
Total	40,094,461	47,098,998

10.2.3 Network Change

The HRTPO Model was run for 2017 with the only change being a network project. The project in question was Segment 1 of the I-64 Express Lane from I-64 to I-264. It is an 8.4 mile reversible two express lane project which is highlighted in the map below (Figure 10-14). The project opened after 2017 but as an evaluation of the network sensitivity, the 2017 model was run with the project open.

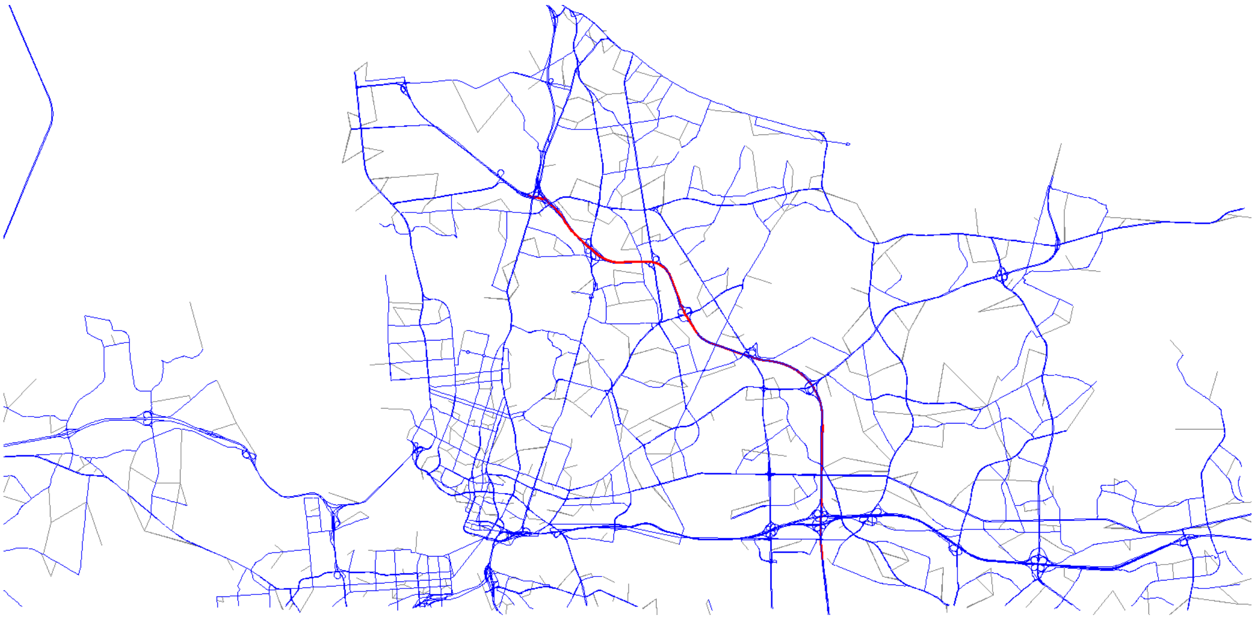


Figure 10-14 I-64 Express Lane Project, Segment 1

The maps below show the 2017 and 2017 + HOT scenario volumes on I-64 through the project location. Traffic on the supporting roadways does not change significantly. The traffic on the corridor does re-distribute between the general purpose and managed lanes as the project does have an impact to utilization during the peak periods when it is now tolled.

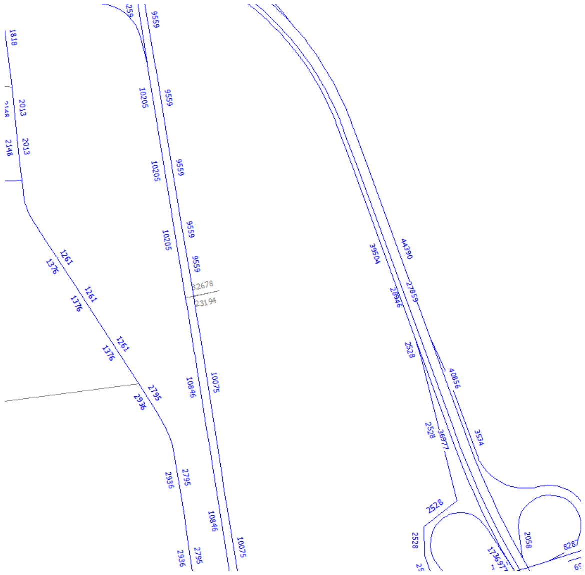


Figure 10-15 2017 Daily Volume

Figure 10-16 2017 + HOT Daily Volume

Overall, VMT in the entire HRTPO Region increases under the HOT scenario by approximately 80,000 miles per day:

- 2017: 40,092,443
- 2017 HOT: 40,163,048

As expected, the majority of the change occurs in Norfolk, the location of the project with an increase of 45,367 daily vehicle miles traveled with the majority of that change being on the interstate links. Overall VHT is changed with an increase of less than 2000 hours representing a change of less than 1%.

11 Connected and Autonomous Vehicle

The Hampton Roads Travel Demand Model was enhanced to include a framework for addressing connected and autonomous vehicles (CAVs). A framework similar to what RSG developed for the Michigan statewide travel demand model and Charlottesville Travel Demand Model can be implemented in trip-based models such as the Hampton Roads model. The framework should initially support exploratory model analysis (EMA) and scenario planning, and later support forecasting as data on CAV use becomes available. Scenario planning is a structured way to think about future using a limited number of scenarios such as best case, worst case, most likely, etc., and EMA considers varied input assumptions across a wide range of future scenarios along key dimensions of uncertainty to explore potential outcomes, find critical input assumptions, and identify robust future policy directions in the face of deep uncertainty.

There are several uncertainties in both transportation demand and supply in modeling CAVs. The main demand uncertainties are market penetration, level of carsharing and ridesharing as a substitute for private vehicle use, zero occupant vehicle (ZOV) trips, parking location and behavior changes, decrease in disutility of travel time, and induced trip-making. On the supply side, several assumptions can be made for CAV capacity and speed, which makes their modeling more challenging. Moreover, this new mobility needs specific infrastructure such as smart signals and dedicated lanes to fully realize some of this potential, and some of this infrastructure is costly. The last but not the least, CAV fleet size and depot locations of transportation network companies that offer mobility as a service are not clear in advance, which adds further complexity to the model.

Although little data currently exists for estimating CAV impacts, it is already generally agreed that CAVs could drastically alter travel patterns in ways that can either alleviate or exacerbate congestion. The Hampton Roads model should allow users to design a wide range of CAV scenarios. Creating these scenarios will involve asserting assumptions about the fundamental parameters of behavioral change. The assumptions will be speculative until higher levels of autonomous vehicle functionality become real and data begins to become available on how travelers respond. Even without CAV data, however, incorporating fundamental parameters into the model framework is not premature for two reasons. First, an understanding of the range of possible futures and importance of different factors or robustness of policies from EMA can be valuable in itself. Second, real data on the travel behavior of at least early adopters of CAV technology will become available during the lifespan of the model.

A framework for modeling CAVs can largely be thought of as an overlay on conventional mode travel models with the ability to adjust existing components and the addition of a few new components specifically related to the new phenomenon of zero occupant vehicle (ZOV) trips. The framework should address both privately owned CAVs (pCAVs) and shared CAVs (sCAVs). The user should be able to specify assumptions about how each dimension of travel may change for various market segments (e.g., induced trip-making and decreased sensitivity to travel time for households with their own pCAV).

11.1 CAV Modeling framework

The general framework to model CAV in the HRTPO model is shown in Figure 11-1. Different parts of the model such as auto and truck trips were shown separately to make the process clear. New features to each step of the model are briefly explained in the following sections.

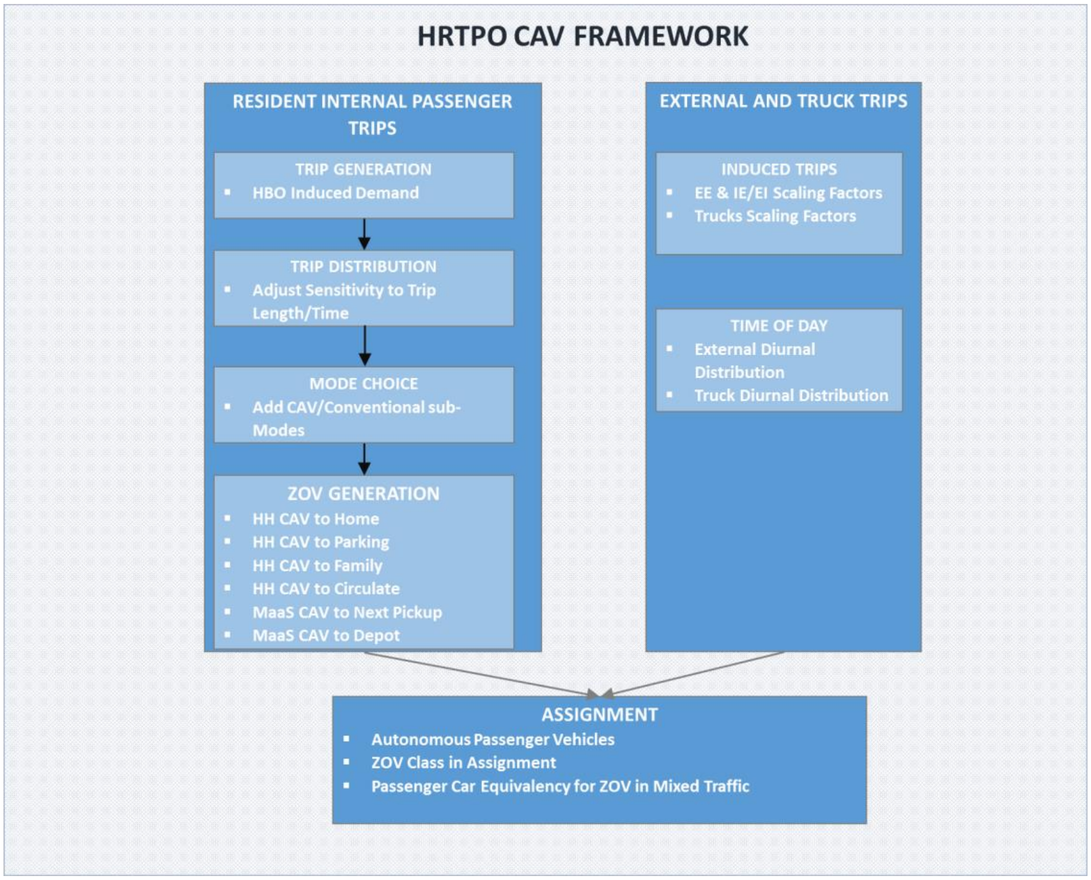


Figure 11-1: HRTPO Model CAV Framework

A CAV framework such as this should allow the MPO to rapidly adjust travel assumptions as soon as substantial data on CAV use becomes available or explore the range of possible futures and the commonalities and differences between them. It should be noted that this framework is an option for the user in the HRTPO model. In fact, this option is not active by default and the model produces the trip tables without CAV as described in previous sections of this report; however, there is a key in the user interface called "Run the Model with CAV?" which turns on this option if it is checked. This key is unchecked by default. There is another parameter file associated with CAV scenarios called "CAVParams.txt" in the "Inputs" folder. This file includes most of the keys and parameters used to run a scenario with CAV mode and the keys can be changed/modified by the user.

11.2 Trip Generation

Given expected induced demand because of CAVs, trip generation rates can be scaled-up with special emphasis on households for whom CAVs will reduce barriers to mobility—households with disabled person(s), households with seniors, and households with children—but also on the population in general. Increasing evidence suggests that MaaS with conventional vehicles is already inducing trip-making even among drivers. Moreover, a recent study emulating CAV ownership by providing study participants with a chauffeur for two weeks found travelers increased trip-making by over 80%. While the study sample was small and novelty may have inflated this finding, even so, studies such as these begin to present evidence of potential for significant increases in trip-making at least among households that own their own CAVs.

As explained above, adding CAV to the model increases daily non-work trips in different ways. For instance, it makes travel easier and sometime possible for seniors, children, and disabled people who may not otherwise be able travel alone. It may also allow households with no or few vehicles to make trips they otherwise would not through the use of shared CAV services. Others may be willing to make more trips since they can use their travel time for other activities and need not be sober. Although forecasting these trips is very complicated, scaling up the trip rates to represent these induced demands is a simple, effective and helpful approach assuming if different scaling factors are considered as separate scenarios. The following parameters found in “CAVParams.txt” can be used for the induced demand due to CAV. Although it is expected to have increase in the trips because of CAV, any reduce in trips due to CAV can be also tested with negative values for these parameters.

Table 11-1: Keys used to Define CAV Shares and Induced Demand due to CAV

Key	Description	Existing Value
CAVPen	Share of CAV in household vehicles	0.5
HBSH_TFAC	Change in HBSR and HBSH trips due to CAV	0.2
HBO_TFAC	Change in HBO trips due to CAV	0.3

11.3 Trip Distribution

CAVs can also be expected to have an impact on trip distribution but not as much mode choice or trip generation. The most likely effect is that passengers may be willing to travel farther because in-vehicle travel time can be easily used for working, relaxing, sleeping, and other activities. The traveler’s sensitivity to travel time, therefore, can be factored down as people can perform many of their personal or business activities while they are on their way to their destination. This effect is presumed to be primarily relevant for only CAV trips and the market segments who own their own CAVs since it is assumed that shared CAV services will still be priced by time/distance and this can be assumed to generally maintain traveler’s sensitivity to travel time/distance. Table 11-2 reports the travel time disutility factors that are used in the trip distribution. These keys exist in “CAVParams.txt” file.

Table 11-2: Keys Used to Define Travel Time Disutility Factor Due to CAV

Key	Description	Existing Value
PkHBW_TimeFac	Travel Time Disutility Factor for HBW in Peak Period	0.8
OpHBW_TimeFac	Travel Time Disutility Factor for HBW in Off-Peak Period	0.8
PkHBO_TimeFac	Travel Time Disutility Factor for HBO in Peak Period	0.8

OpHBO_TimeFac	Travel Time Disutility Factor for HBO in Off-Peak Period	0.8

11.4 Mode choice

Because CAV and MaaS are substantially different from and will be a substitute for other transportation modes, traditional mode choice models must be expanded to reflect the increased choice set for travelers. Within CAV modes, the distribution of trips taken in pCAVs and sCAVs is critical to the operational characteristics of CAVs. To include these additional choices in our models, these new modes were added to the model through two adaptations of the existing nesting structure. First, MAAS was added as an upper level mode, in competition with private auto, transit, and fringe to walk. Second, all auto modes (including MaaS) were subdivided into conventional auto and CAV sub-modes. The one exception to this is that drive-access to transit and fringe to walk are not subdivided as they are too small to support more detailed modeling (although this may be important in large metro areas with rail transit). The resulting nesting structure is shown in Figure 11-2.

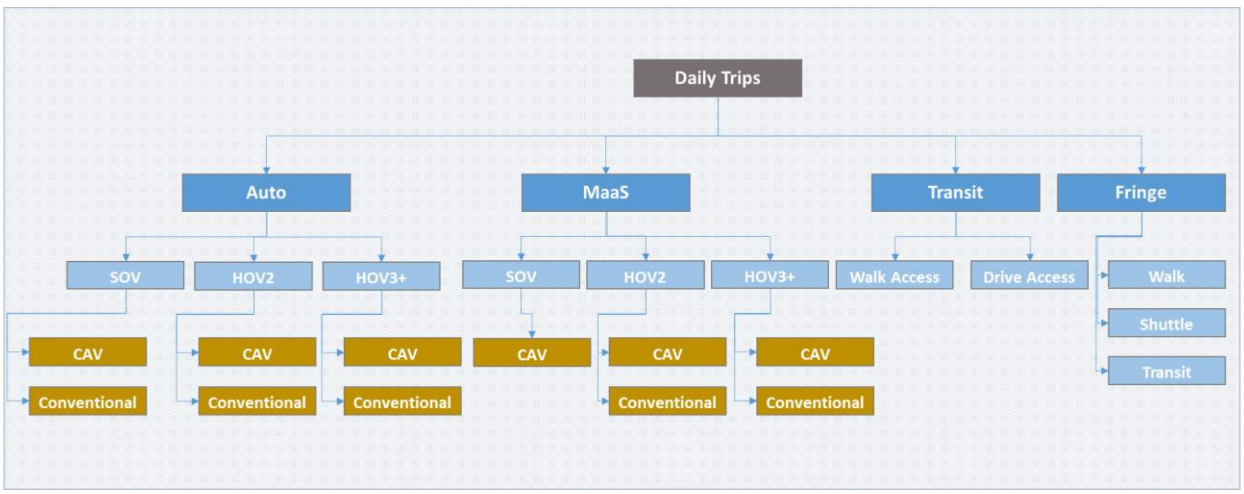


Figure 11-2: HRTPO Model Mode Choice with CAV

The user will assert the shares of these new modes (or all modes) to create different scenarios. These shares can be asserted separately by the trip purpose and time period (peak vs off-peak).

Another key uncertainty is the occupancy of MAAS HOV3+ vehicles (both sCAV and conventional). Rather than represent this with a formal, pseudo-behavioral nested choice, a simple occupancy factor is used to convert HOV3+ person trips to vehicle trips. Given the importance of this factor different scenarios should be created and analyzed to provide a better sense how these factors affect mode shares, VMT and other possible future outcomes.

“Mode_Shares.DBF” and “CAV_CONV_SPLIT.DBF” in “Inputs” folder can be used to determine the shares for any combination of modes and also to split trips between CAV and Conventional for each trip purpose and time period. The split between CAV and conventional modes must be specified by the user for any CAV scenario but the cells in the mode share file can be blank. If the model finds a predetermined share for any mode, it adds a shadow price to the utility function for those modes and updates them accordingly in an iteration process to generate desired mode shares. The final shadow prices by trip purpose and time period are separately stored in the "Calibration Constants" folder. Shadow prices are updated for 10 iterations unless the maximum difference between the model and predetermined mode shares is less than 5 percent. Since, there is no data for MAAS to calibrate the utility function for this mode, the model will have MAAS trips if MAAS share(s) are specified in "Mode_Shares.DBF" file. In fact, if the target mode share file has null value or blank cell for any mode, the model will not have any trip for that mode in the final trip table. As a result, the summation of shares over all modes for each combination of purpose and time period in the "Mode_Shares.DBF" file must be equal to one if this option is selected by the user.

Non-HOME-BASED trips

Since the new methodology to estimate NHB trips conditional on HB trips has been implemented for HRTPO travel demand model, the impacted home-based (HB) trips by CAV will also affect NHB trips. In fact, it is assumed that the relationships between HB and NHB trips will remain the same. HB CAV and conventional trips for any upper level mode (SOV, HOV2, and HOV3+) are added to each other to be used in NHB trip generation. Then, the resulted trips are split between CAV and conventional based on user defined shares which exist in "CAV_CONV_SPLIT.DBF" file. This procedure is repeated over all house income groups to generate NHB trips by household income group with all CAV and conventional modes.

The vehicle occupancy factor was defined to convert HB and NHB HOV3+ person trips to vehicle trips by purpose and mode (MaaS, CAV, and Conventional). The vehicle occupancy factors can be found in "cavparams.dbf" in Parameter folder as shown in Table 11-3. The vehicle occupancy factor for conventional vehicles are read from the model configuration file.

Table 11-3: HOV3+ Vehicle Occupancy Factor by Mode and Purpose for CAV Scenario

Key	Description	Existing Value
HBW_CAV_PK_Occ	HBW CAV HOV3 Occupancy Factor for PK Period	3.42
HBO_CAV_PK_Occ	HBO CAV HOV3 Occupancy Factor for PK Period	3.42
NHB_CAV_PK_Occ	NHB CAV HOV3 Occupancy Factor for PK Period	3.42
HBW_CAV_OP_Occ	HBW CAV HOV3 Occupancy Factor for OP Period	3.42
HBO_CAV_OP_Occ	HBO CAV HOV3 Occupancy Factor for OP Period	3.42
NHB_CAV_OP_Occ	NHB CAV HOV3 Occupancy Factor for OP Period	3.42
HBW_MS_CAV_PK_Occ	HBW CAV MaaS HOV3 Occupancy Factor for PK Period	3.42
HBO_MS_CAV_PK_Occ	HBO CAV MaaS HOV3 Occupancy Factor for PK Period	3.42
NHB_MS_CAV_PK_Occ	NHB CAV MaaS HOV3 Occupancy Factor for PK Period	3.42
HBW_MS_CAV_OP_Occ	HBW CAV MaaS HOV3 Occupancy Factor for OP Period	3.42
HBO_MS_CAV_OP_Occ	HBO CAV MaaS HOV3 Occupancy Factor for OP Period	3.42
NHB_MS_CAV_OP_Occ	NHB CAV MaaS HOV3 Occupancy Factor for OP Period	3.42

11.5 Auto External Trips

Long-distance travelers may choose to use traveling hours for sleeping and, as a result, shift long-distance trips to nighttime hours. This temporal shift in long distance travel may help offset induced trip-making which may be significant for this market segment since CAVs would substantially decrease the cost of long-distance travel, for instance, by obviating the need to pay for a hotel on route to a destination. Parameters "AUTO_EE" and "AUTO_EXT " are representing the induced demand of E-E and I-E/E-I trips because of CAV technology. Parameters "EE_CAV" and "EX_CAV" represent share of CAV in E-E and I-E/E-I trips, respectively. All parameters which are shown in Table 11-4 can be found in "CAVParams.txt" file in "Inputs" folder. Although the same values for the induced demand and CAV share can be used for EI\IE and E-E trips, the model is capable of treating them differently because E-E trips and their diurnal distributions seem to be affected by this technology more than EI/IE trips.

Table 11-4: External Trip Parameters Used in CAV Scenarios

Key	Description	Existing Value
AUTO_EE	Relative change in E-E auto trips	0.25
AUTO_EXT	Relative change in I-E/E-I auto trips	0.5
EE_CAV	CAV share in E-E auto trips	0.4
EX_CAV	CAV share in I-E/E-I auto trips	0.3

11.6 Truck trips

While time-of-day shifts may be the primary impact on truck travel patterns, there is considerable uncertainty in how truck traffic will be impacted more generally. Therefore, in addition to varying the truck diurnal distributions, the user will simply have the ability to scale truck trips up (or down, perhaps to represent the use of aerial drones for delivery) to reflect this uncertainty and explore possible future scenarios. Table 11-5 shows the parameters that truck model needs to run a CAV scenario including internal and external scaling factors for trucks, time of day split factors, and share of truck CAVs.

Table 11-5: Truck Trip Parameters Used in CAV Scenarios

Key	Description	Existing Value
TRK_II	Relative change in internal truck trips by CAV	0.5
TRK_EXT	Relative change in I-E/E-I truck trips by CAV	0.5
TRK_EE	Relative change in E-E truck trips by CAV	0.5
PK_TRK	Share of peak period in truck trips due to CAV	0.25
OP_TRK	Share of off-peak period in truck trips due to CAV	0.75
TRK_CAV	Share of CAV in truck trips	0.3

11.7 Time-of-day

Time-of-Day (TOD) or diurnal distributions of travel for residents may also be impacted by vehicle automation, but significant shifts in long distance passenger and truck traffic should be anticipated. Trucks may shift their trips to overnight to avoid daytime congestion. In this model, it is assumed diurnal distribution for short trips remains the same, but passengers may take advantage of the ability to sleep overnight on longer distance trips. Therefore, the user will be able to specify new diurnal distributions separately for autos and trucks for internal-internal, internal-external trips, external-internal trips, and through trips. There are three files in the model which include TOD factors for CAV scenario as follows:

1- Pk_offpk_FAC_CAV.DBF: This file includes split factors between peak and off-peak for auto external trips (I-E/E-I and E-E). This file is in “Calibration Constants” directory.

2- PK_TOD_FAC_CAV.DBF: This file includes split factors between AM and PM periods out of peak period trips for the following segments: HBW, HBO, NHB, Auto I-E/E-I, Auto E-E, Truck I-E/E-I, and Truck E-E. This file is in “Calibration Constants” directory. These factors are only applied to CAV trip tables.

3- OP_TOD_FAC_CAV.DBF: This file includes split factors between MD and NT periods out of off-peak period trips for the following segments: HBW, HBO, NHB, Auto I-E/E-I, Auto E-E, Truck I-E/E-I, and Truck E-E. This file is in “Calibration Constants” directory. These factors are only applied to CAV trip tables.

It should be mentioned that the TOD factors for conventional trips are defined in the original TOD files (PK_TOD_FAC.DBF and OP_TOD_FAC.DBF). Moreover, the overall split between peak and off-peak truck trips is determined by the factors explained in the Section 0.

11.8 Zero-Occupant Vehicle Trips

The introduction of CAVs into the vehicle fleet will result in a new type of trip: zero-occupant vehicle trips (ZOVs). CAVs could generate a significant number of ZOV trips as vehicles travel to pick up and drop off passengers or simply avoid parking costs. The resulting increase in VMT could be the largest impact of CAVs and substantially exacerbate congestion if unregulated. Further, ZOV deadheading would occur most frequently during peak periods and in areas where parking is at a premium — precisely when and where urban systems are already stressed. For these reasons, the handling of ZOV trips is a critical facet of any CAV modeling framework.

The characteristics of ZOVs will depend on whether a CAV is privately owned (pZOV) or operated as a MAAS (sZOV), since sCAVs can simply pick up the nearest passenger, whereas pCAVs must travel to pick up very specific people, such as family members who may be far away. ZOV trips also differ based on their purpose, with sCAVs presumably focused on passenger pick-up/drop-off while pCAVs may also be used significantly for parking cost avoidance.

For pCAVs, car-sharing among members of the same household may result in ZOV trips (Type 1) if a pCAV drops one household member off at some destination and subsequently travels to some other location to pick up another member of the same household. To incorporate within-household pCAV car-sharing ZOV trips into our trip-based framework, the zonal origins and destinations of an assumed percentage of household person trips were inverted and fed into a gravity model. The HBW and HBO are the trip purposes considered as a source for this type of ZOV trips. The percentage of household person trips for this type of ZOV trips varies by purpose, time period, and zone and can be changed by the user. “ZOV_TYPE1.DBF” which is in “Inputs” folder is the file containing the percentage of household contributing in this type of ZOV trips in each zone by the purpose and time period (peak and off-peak). The user, therefore, can choose different shares by purpose and time period.

The gravity model applied to distribute ZOV type 1 trips between origins and destinations uses a gamma function as the impedance function and the gamma function takes trip length from the skim into account which is shown in the equation below:

$f(d_{ij}) = a d_{ij}^{-b} \mathrm{Exp}(-c \times d_{ij})$

Where:

$f(d_{ij})$: is the friction factor generated by the gamma function,

d_{ij}: is the trip length from TAZ *i* to TAZ *j* based on the congested network, and

a, b, and c: are the parameters

The parameters used in the gamma function are stored in "ZOV_Gamma.DBF" in the "Calibration Constants" folder and can be modified by the user.

Table 11-6: Gamma Function Parameters used for ZOV Type 1 Trip Distribution

Parameter	Time Period	Existing Value
a	Peak	1
b	Peak	0.05
c	Peak	0.5
a	Off-Peak	1
b	Off-Peak	0.05
c	Off-Peak	0.5

The output of gravity model is in production-attraction (PA) format and needs to be converted to origin-destination (OD) format. This PA to OD conversion is conducted based on conventional conversion factors.

Additionally, pCAVs may return to their home location after dropping an occupant off to avoid paid parking (Type 2). These ZOV trips were included in our framework by inverting the trip origins and destinations of an assumed percentage of HBW and HBO trips to TAZs with paid parking. The percentage of household person trips contributed to this type of ZOV trips may vary by zone, purpose, and time period and is stored in "ZOV_TYPE2.DBF" in "Inputs" folder. The output of this procedure is in OD format but needs to be divided to time-of-day periods.

Alternately, pCAVs may travel to some other remote (non-home) location to avoid paid parking (Type 3). These trips were incorporated into our framework by creating HBW, HBO, and NHB trips between TAZs with paid parking and nearby TAZ with non-paid parking as a function of long duration activities at zones with paid parking. Similar to ZOV Type 2, the percentage of household person trips contributed to ZOV Type 3 trips may vary by zone, purpose, and time period and is stored in "ZOV_TYPE3.DBF" in "Inputs" folder. The gravity model is also applied to distribute ZOV Type 3 trips between origins and destinations with the parameters shown in Table 11-7.

Table 11-7: Gamma Function Parameters used for ZOV Type 3 Trip Distribution

Parameter	Time Period	Existing Value
a	Peak	1
b	Peak	0.05
c	Peak	0.5
a	Off-Peak	1
b	Off-Peak	0.5
c	Off-Peak	0.5

The resulted trip table is in OD format but needs to be divided to time-of-day (TOD) periods. The TOD factors by purpose are in “PK_TOD_Fac_CAV.DBF” and “OP_TOD_Fac_CAV.DBF” in “Calibration Constants” directory, that are used for CAV trips TOD split in general. This TOD split for ZOV trips in OD format is only conducted for ZOV Type 2 and 3 trips.

Finally, pCAVs may circulate after dropping off an occupant for a short-duration activity in lieu of parking (Type 4). Circulating trips were modelled by assuming some percentage of only HBO trips resulted in the generation of additional VMT. This VMT was then apportioned to the network within a buffer of the zone dividing by the length of each segment to convert the VMT into vehicle volumes which were preloaded on the network prior to assignment. There are some details for this type of ZOV trips which should be mentioned as follows:

1- Similar to ZOV Type 2 and 3, the percentage of household person trips resulted in generation of ZOV Type 4 trips is a parameter that can be modified by the user and is stored in “ZOV_Type4.DBF” in “Inputs” folder.

2- The percentage of household trips contributed to ZOV Type 4 trips varies by TAZ and time period.

3- With the assumption of 12 minutes circulation with 20 mph speed, each vehicle is traveling about 4 miles in average. This travel distance is considered when VMT is converted to vehicle volume. This average drive distance is a parameter called “ZOV_T4_Dist” in “CAVParams.txt” file and can be updated by the user.

4- All non-freeway and non-connector links within the buffer area with the radius of 0.3 mile around each zone centroid are considered for the circulation. Since the model network does not cover all roads and streets in the reality, another factor which represents the share of network roads to real roads is also taken into account. This factor which is currently equal to 0.4 and the buffer radius exist in the model user interface and can be modified by the user.

5- Since the calculation of ZOV Type 4 trips is in peak and off-peak periods, the resulted trips in each of them should be divided to the corresponding time periods (AM and PM for peak and MD and NT for off-peak). The factors used to split ZOV Type 4 trips to time periods are the same as the ones used for HBO CAV trips and can be found in “PK_TOD_Fac_CAV.DBF” and “OP_TOD_Fac_CAV.DBF” files in “Calibration Constants” folder

6- The final output of this process is stored in separate fields in the loaded network and will be considered as preloads in the assignment. The fields are as follows:

   a. Z4VHBO_AM1

b. Z4VHBO_AM2
c. Z4VHBO_AM3
d. Z4VHBO_AM4
e. Z4VHBO_PM1
f. Z4VHBO_PM2
g. Z4VHBO_PM3
h. Z4VHBO_PM4
i. Z4VHBO_MD1
j. Z4VHBO_MD2
k. Z4VHBO_MD3
l. Z4VHBO_MD4
m. Z4VHBO_NT1
n. Z4VHBO_NT2
o. Z4VHBO_NT3
p. Z4VHBO_NT4

To get ZOV Type 4 volumes, Cube must run a Python code which generates a buffer around each zone centroid and find the non-freeway and non-connector links in the buffer and their length for each zone. The output of the Python code is read by the model for the rest of the procedure as explained above. The user has this option to skip this type of ZOV trips in case his/her machine does not have required Python libraries. There is a key in the user interface which that controls running this specific type of ZOV trips.

Zero-occupant vehicle trips will also occur for sCAVs. After dropping off a passenger, sCAVs will often need to dead-head to a different location to pick up the next passenger (Type 5). Dead-heading was incorporated into our modeling framework by inverting all passenger origins and destinations of MAAS CAV trips and feeding into a gravity model. The sCAV passenger (SOV & HOV) destinations become the corresponding ZOV origins, and the passenger (SOV & HOV) origins are the corresponding ZOV destinations. Table 11-8 reports the gamma function parameters used to distribute ZOV Type 5 trips. The resulted trip table is in PA format and similar to ZOV Type 1, the PA to OD conversion is conducted by using conventional conversion factors.

Table 11-8: Gamma Function Parameters used for ZOV Type 5 Trip Distribution

Parameter	Time Period	Existing Value
a	Peak	1
b	Peak	0.05
c	Peak	0.5
a	Off-Peak	1
b	Off-Peak	0.05
c	Off-Peak	0.5

Additionally, sCAVs will need to return to centralized depots intermittently, either to re-charge or when demand is low (Type 6). These trips can be modeled in our framework by first asserting that some TAZs contain depots with set capacities, generating trips based on assumptions regarding vehicle charging requirements and/or variation in demand between periods and employing a gravity model between sCAV origins and destinations and TAZs containing sCAV depots. In fact, it is assumed that improvements in battery technology will make variations in passenger demand throughout the day the primary driver of these trips. Hence, the number of these trips from depots will be estimated as a function of the passenger demand in the current period minus the passenger demand in the previous period, and the number of these trips to depots will be estimated as a function of the passenger demand in the current period minus the passenger demand in the subsequent period. A gravity model will be used to connect the depots to sCAV passenger (SOV & HOV) origins/destinations. “Depots.DBF” in “Inputs” folder includes the depot capacity for each TAZ and Table 11-9 reports the gamma function parameters used to distribute ZOV Type 6 trips. Since the trips from/to depots are estimated and distributed separately, the resulted trip table is in OD format. Moreover, the analysis is conducted by time period. The time-of-day split, therefore, is not needed for this type of ZOV trips.

Table 11-9: Gamma Function Parameters used for ZOV Type 6 Trip Distribution

Parameter	Time Period	Existing Value
A	Peak	1
b	Peak	0.05
c	Peak	0.5
A	Off-Peak	1
b	Off-Peak	0.05
c	Off-Peak	0.5

There are also two more parameters used for this type of ZOV trips which can be modified by the user. These parameters which exist in the “CAVParams.dbf” file, are reported in Table 11-10.

Table 11-10: Other Parameters used for ZOV Type 6

Parameter	Description	Existing Value
PkMSWait	Vehicle-Wait Time for MAAS Mode in PK Period	10
OPMSWait	Vehicle-Wait Time for MAAS Mode in OP Period	10

As mentioned above, the user will assert the percentages of pCAV on different trip purposes to areas with paid parking in which the passenger will use different strategies. Since each trip purpose contributes to different types of ZOV, the user must notice that the summation of shares over ZOV Types 2, 3, and 4 does not exceed one. Table 11-11 presents the shares in each ZOV type, selected by the user for each trip purpose. The share of trips which pay for the parking, therefore, must be equal or greater than zero with respect to the percentages asserted by the user for all ZOV types. In addition to the exclusivity of the parking strategies, the user should consider that some HB trips will not opt to send the car away because they have additional subsequent stops on the tour for which they desire it.

Table 11-11: Parameters for Private CAV Parking Avoidance

Trip Purpose	Pay for Parking	Send Car Home to Park (Type 2)	Send Car to Park Somewhere Else (Type 3)	Circulate to Avoid Parking (Type 4)
HBW	1-a-b	a%	b%	
HBO	1-c-d-e	c%	d%	e%
NHB	1-f		f%	

11.9 Assignment

Vehicles are assigned by period using multi-class equilibrium with generalized costs. The new HRTPO model has several classes in the assignment varying by trip purpose, mode, household income group, and toll/non-toll path. More vehicle classes are in the assignment of a CAV scenario because ZOV trips by purpose and household income are assigned as separate classes. CAV and conventional trips for each combination of trip purpose, mode, and household income are combined to save assignment runtime; otherwise, the model will crash due to too many assignment vehicle classes.

One of the most widely touted benefits of CAVs is their ability to reduce crash rates and provide improved safety to travelers. However, this benefit would likely come at the cost of increased consumption of capacity by CAVs in mixed traffic. CAVs would reduce crash rates by driving more conservatively than humans, leaving more space between vehicles, and thereby reducing throughput. This effect can easily be incorporated in static user equilibrium assignment models through the use of passenger car equivalency (PCE) factors. While the traditional use of PCEs was to reflect trucks' consumption of more roadway space / capacity, the same technique can be applied for CAVs. "ZOV_PCE" which can be found in "CAVParams.txt" file is the factor that can be modified by the user. CAV values of time exist in "VOT_PK_Toll_CAV.DBF" and "VOT_PK_Toll_CAV.DBF" in the "Calibration Constants" folder and can be updated by the user. The same scaling factors as conventional modes are used for CAV trips in the toll choice model.

Several runs were conducted to test the model with CAV scenario and analyze the model responses. The tests were different in terms of private CAV shares in ZOV types or impact of CAV on trip generation. It was expected to see significant increase in the person trips and VMT and the model confirmed it with the increase in person trip between 6 and 21 percent and increase in VMT between 29 and 64 percent.

11.10 Summary

Trip-based travel demand models can be enhanced to capture many of the dimensions of uncertainty about CAVs. Adding a MAAS and CAV sub-modes, and including ZOV trip components can provide decision-makers with a more focused picture of what widespread CAV adoption may entail for transportation systems. Again, it should be noted that the framework implemented in the HRTPO model initially supports exploratory model analysis (EMA) and scenario planning, and later supports forecasting as data on CAV use becomes available.

As explained in detail, this framework includes many parameters and the user might need to modify some of them depending on the scenario. These parameters are stored in different files as follows:

1- CAVParams.txt: This file includes most of required network and script keys to run a CAV scenario. The definition for each key can be also found in this file.

2- CAV_CONV_SPLIT.DBF: This file includes the split between CAV and Conventional for all available auto modes by trip purpose, time period, and auto sufficiency group.

3- Mode_SHARES.DBF: This file includes mode shares by purpose and time period in case user wants to run a scenario with specific mode shares. If the file has any value for any mode and purpose, the model changes utilities to generate mode shares as specified; otherwise, mode shares are calculated based on the original approach.

4- ZOV_Gamma.DBF: This file includes the gamma function parameters used to distribute ZOV trips by ZOV type, trip purpose, and time period.

5- ZOV_Type1.DBF: This file includes percentage of private CAV trips sharing the same vehicle for their trips by purpose and time period

6- ZOV_Type2.DBF: This file includes percentage of private CAV trips going back home without any occupancy to avoid parking by purpose and time period

7- ZOV_Type3.DBF: This file includes percentage of private CAV trips going somewhere else without any occupancy to avoid parking by purpose and time period

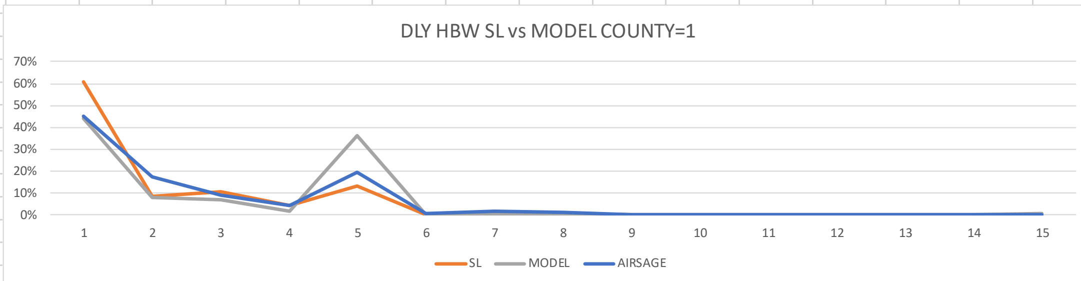
8- ZOV_Type4.DBF: This file includes percentage of private CAV trips circulating around without any occupancy to avoid parking by purpose and time period

9- ZOV_Type6.DBF: This file includes depot capacities for shared CAV vehicles by TAZ

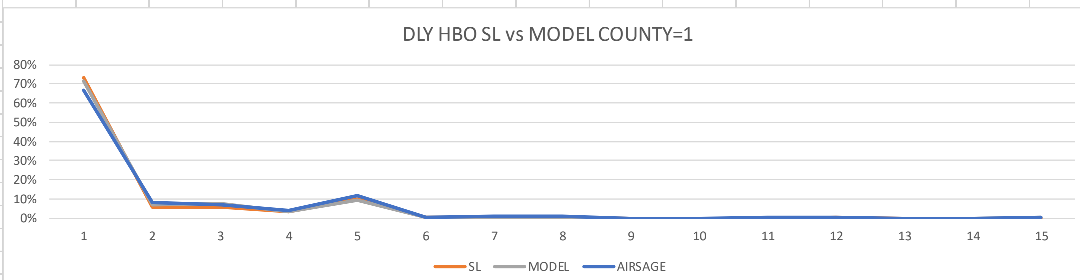
All of these files have the values currently based on reasonable assumptions, however, the user can change any parameter to create a new scenario. It should be also noted that the parameters can affect the trip table drastically, which might lead to model crash due to the extremely congested condition.

APPENDIX A: JURISDICTION DISTRIBUTION PATTERNS

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	1	61%	8%	11%	4%	13%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	1	45%	17%	9%	5%	20%	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	1	44%	8%	7%	2%	36%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	1	73%	6%	6%	4%	10%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	1	66%	8%	7%	4%	12%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	1	71%	7%	8%	3%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	1	76%	5%	6%	4%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	1	57%	10%	7%	5%	17%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	1	61%	6%	11%	2%	13%	1%	1%	0%	0%	1%	2%	2%	0%	0%	0%

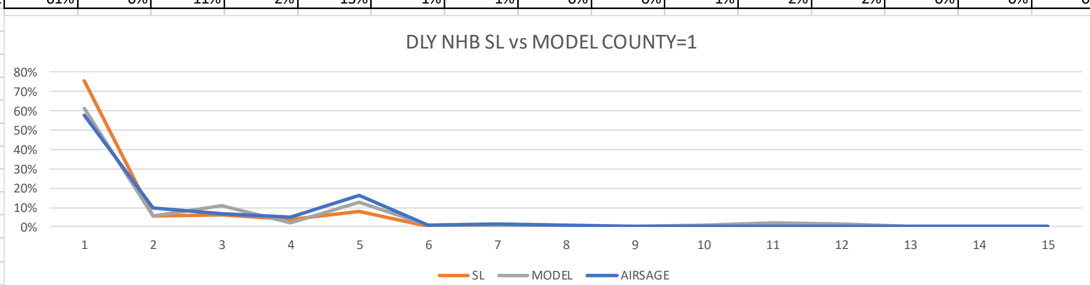
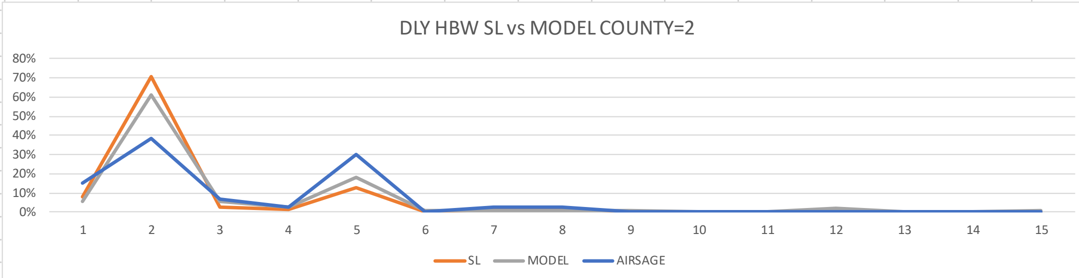
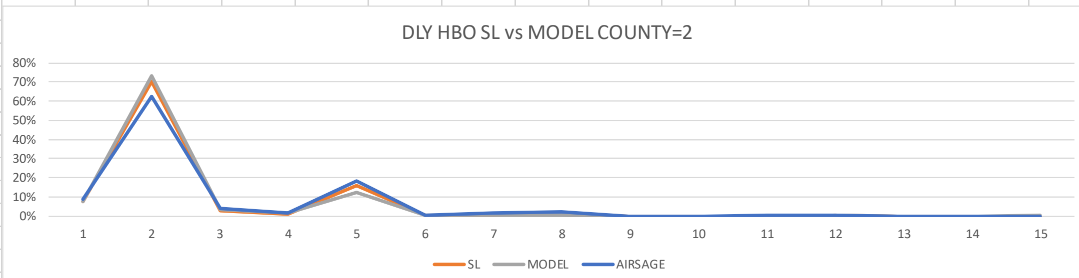


Figure A-0-1: Chesapeake Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	2	8%	71%	3%	2%	13%	0%	1%	2%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	2	15%	39%	7%	3%	30%	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%
MODEL	2	6%	61%	5%	2%	18%	1%	1%	1%	1%	0%	0%	2%	0%	0%	1%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	2	8%	70%	2%	1%	16%	0%	1%	2%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	2	9%	62%	4%	2%	19%	0%	2%	2%	0%	0%	0%	0%	0%	0%	0%
MODEL	2	7%	73%	3%	1%	12%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	2	8%	70%	3%	1%	15%	0%	1%	2%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	2	12%	49%	5%	3%	24%	0%	2%	3%	0%	0%	0%	1%	0%	0%	0%
MODEL	2	5%	78%	1%	0%	13%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%

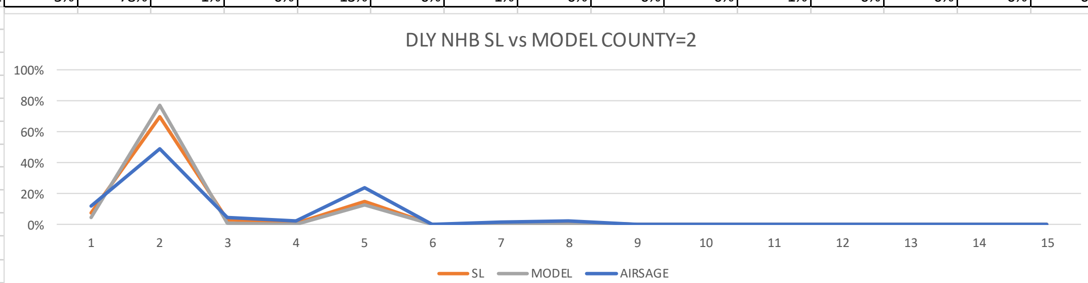
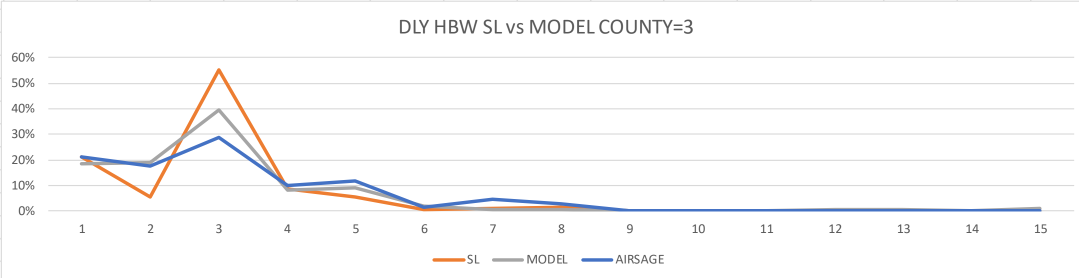
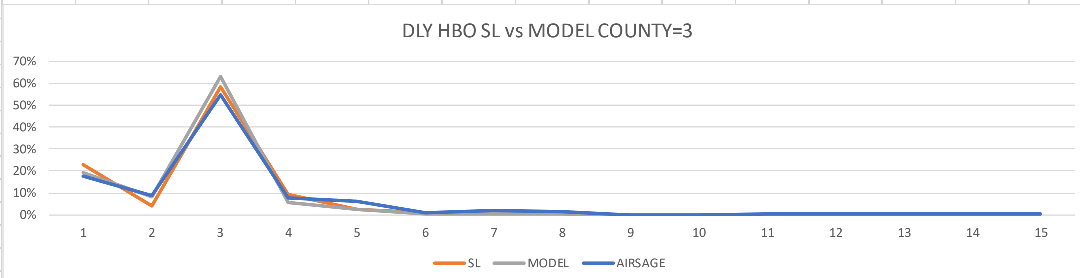


Figure A-0-2: Norfolk Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	3	21%	6%	55%	8%	6%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	3	21%	18%	29%	10%	12%	2%	5%	3%	0%	0%	0%	0%	0%	0%	0%
MODEL	3	18%	19%	40%	8%	9%	2%	1%	1%	0%	0%	0%	1%	1%	0%	1%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	3	23%	4%	58%	9%	3%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	3	17%	9%	55%	8%	6%	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	3	19%	8%	63%	5%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	3	19%	5%	63%	6%	3%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	3	21%	13%	39%	10%	10%	1%	2%	2%	0%	0%	0%	0%	0%	0%	0%
MODEL	3	26%	4%	54%	4%	6%	1%	1%	1%	0%	0%	1%	1%	0%	0%	0%

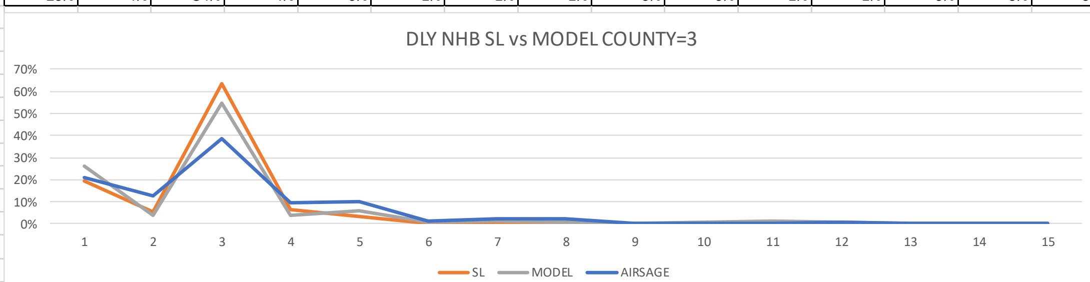
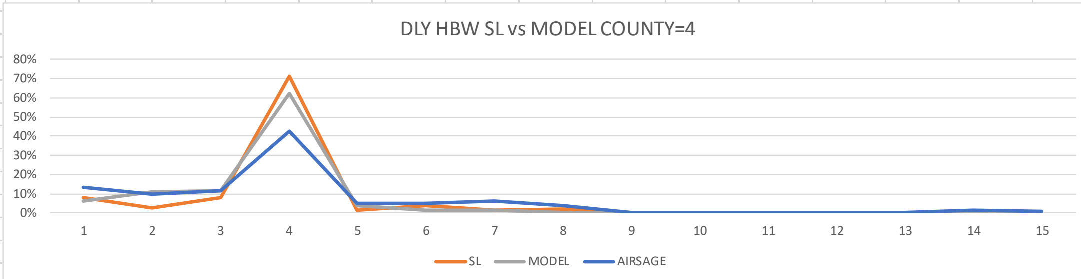
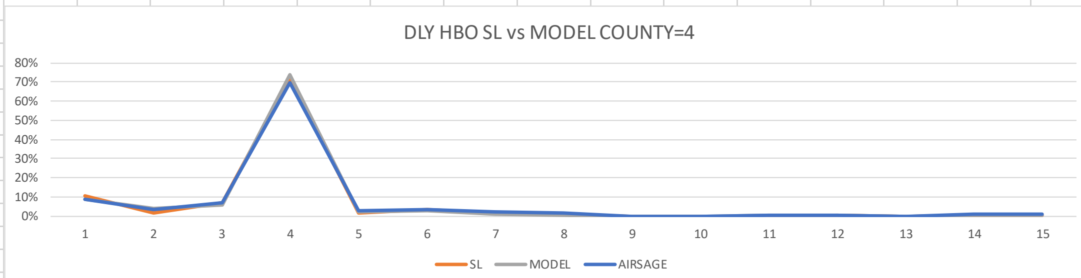


Figure A-0-3: Portsmouth Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	4	8%	3%	8%	71%	2%	4%	1%	2%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	4	13%	10%	12%	43%	5%	5%	6%	4%	0%	0%	0%	1%	0%	1%	1%
MODEL	4	6%	11%	11%	62%	4%	1%	1%	0%	0%	0%	0%	0%	0%	0%	1%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	4	10%	2%	7%	72%	1%	4%	1%	1%	0%	0%	0%	0%	0%	1%	1%
AIRSAGE	4	9%	3%	7%	69%	3%	3%	2%	1%	0%	0%	0%	0%	0%	1%	1%
MODEL	4	8%	4%	6%	74%	2%	3%	1%	1%	0%	0%	0%	0%	0%	0%	1%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	4	9%	2%	6%	74%	1%	4%	1%	1%	0%	0%	0%	0%	0%	1%	1%
AIRSAGE	4	10%	4%	7%	62%	4%	5%	2%	2%	0%	0%	0%	0%	0%	1%	1%
MODEL	4	7%	1%	5%	75%	5%	1%	1%	1%	0%	1%	1%	1%	0%	0%	0%

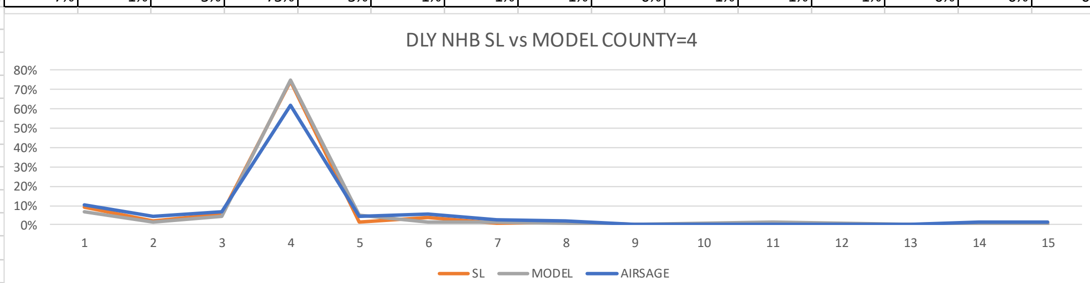
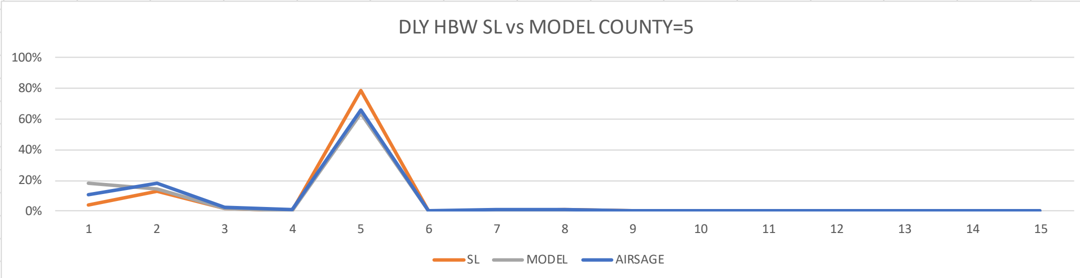
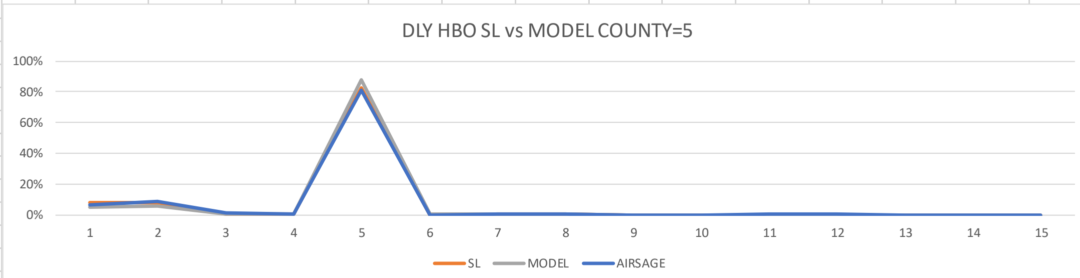


Figure A-0-4: Suffolk Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	5	4%	13%	2%	1%	79%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	5	10%	18%	3%	1%	66%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	5	18%	14%	2%	1%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	5	8%	8%	1%	0%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	5	6%	9%	1%	1%	81%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	5	5%	6%	1%	0%	88%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	5	7%	7%	1%	0%	85%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AIRSAGE	5	9%	11%	1%	1%	75%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
MODEL	5	6%	8%	1%	1%	80%	0%	1%	0%	0%	1%	1%	1%	0%	0%	0%

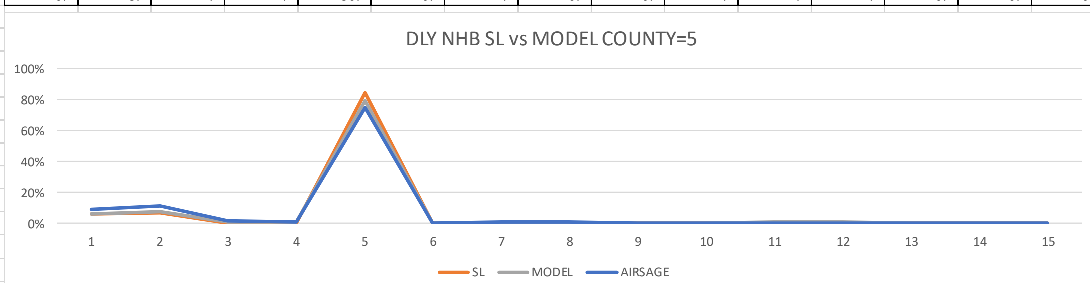
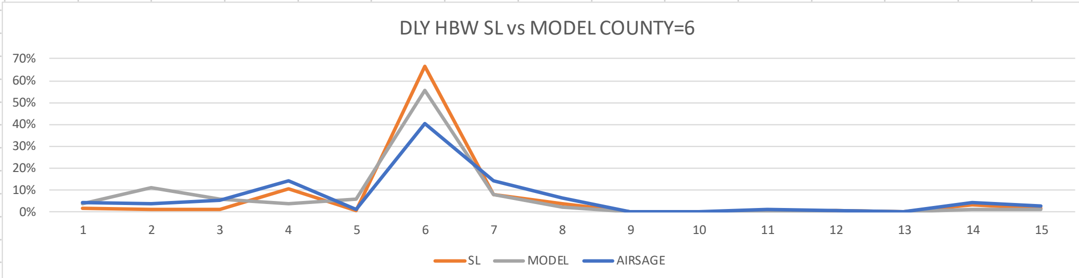
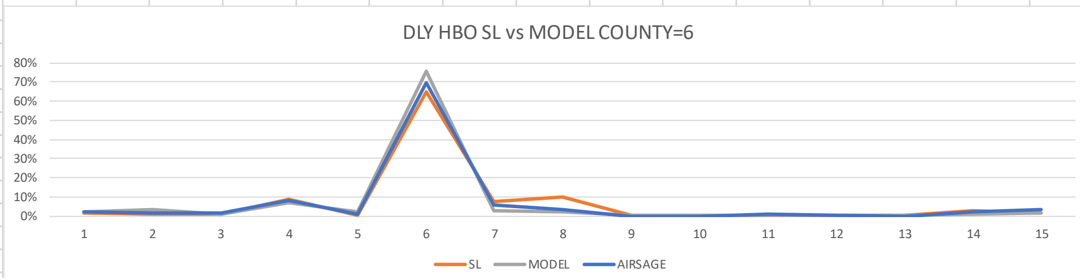


Figure A-0-5: Virginia Beach Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	6	2%	1%	1%	11%	1%	66%	8%	4%	0%	0%	0%	1%	0%	3%	2%
AIRSAGE	6	4%	4%	5%	15%	1%	41%	14%	6%	0%	0%	1%	1%	0%	4%	3%
MODEL	6	4%	11%	6%	4%	6%	55%	8%	2%	0%	0%	0%	1%	0%	1%	1%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	6	1%	1%	1%	9%	0%	65%	8%	10%	0%	0%	0%	1%	0%	3%	1%
AIRSAGE	6	2%	1%	2%	8%	1%	69%	6%	3%	0%	0%	1%	1%	0%	2%	4%
MODEL	6	2%	3%	1%	7%	2%	76%	3%	2%	0%	0%	0%	0%	0%	1%	2%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	6	1%	1%	1%	9%	0%	74%	5%	3%	0%	0%	0%	0%	0%	3%	2%
AIRSAGE	6	3%	2%	2%	11%	1%	61%	7%	4%	0%	0%	1%	1%	0%	3%	6%
MODEL	6	5%	2%	2%	4%	6%	70%	3%	2%	0%	1%	2%	2%	0%	1%	0%

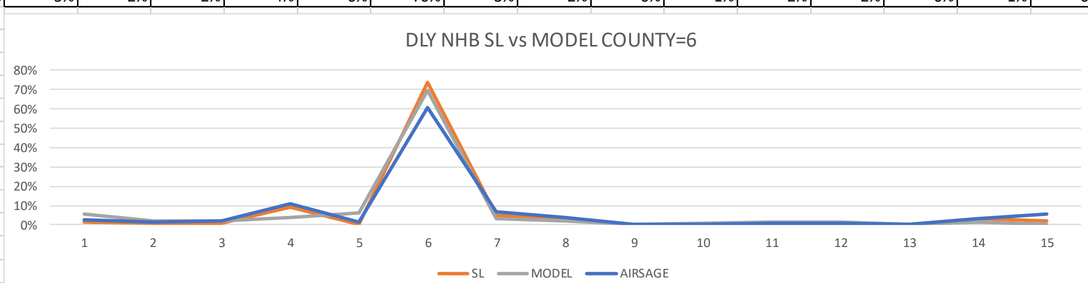
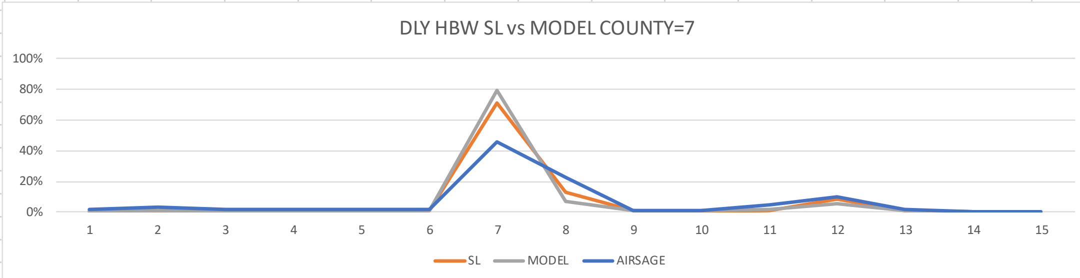
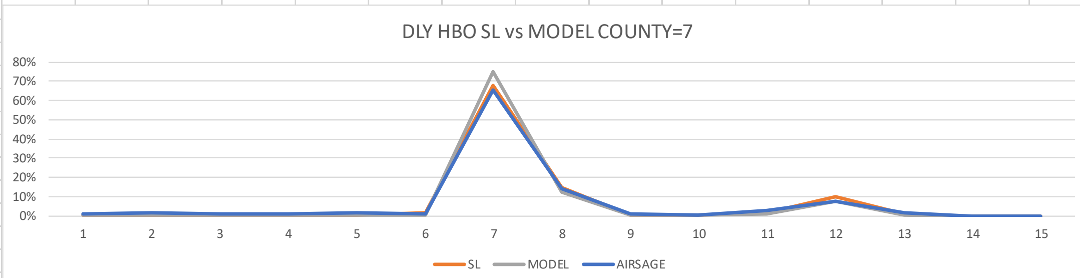


Figure A-0-6: Isle of Wight Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	7	1%	1%	0%	1%	1%	1%	71%	13%	1%	0%	1%	9%	1%	0%	0%
AIRSAGE	7	2%	3%	2%	2%	2%	2%	46%	22%	1%	1%	5%	10%	2%	0%	0%
MODEL	7	1%	1%	0%	0%	0%	1%	79%	7%	1%	1%	1%	6%	1%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	7	0%	1%	0%	0%	0%	1%	68%	15%	1%	0%	1%	10%	1%	0%	0%
AIRSAGE	7	1%	2%	1%	1%	1%	1%	66%	14%	1%	0%	3%	8%	1%	0%	0%
MODEL	7	0%	1%	0%	0%	0%	1%	75%	12%	1%	0%	1%	8%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	7	0%	1%	0%	0%	0%	1%	68%	18%	1%	0%	1%	9%	1%	0%	0%
AIRSAGE	7	2%	3%	1%	2%	3%	2%	52%	17%	1%	1%	4%	10%	3%	0%	0%
MODEL	7	1%	1%	1%	1%	1%	0%	64%	25%	0%	0%	1%	4%	0%	0%	0%

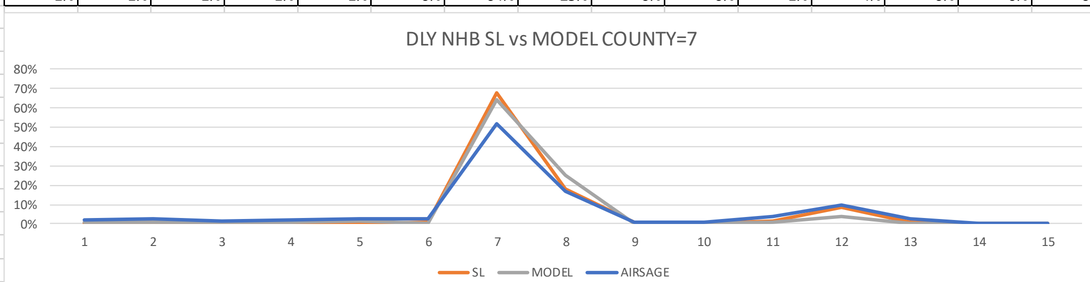
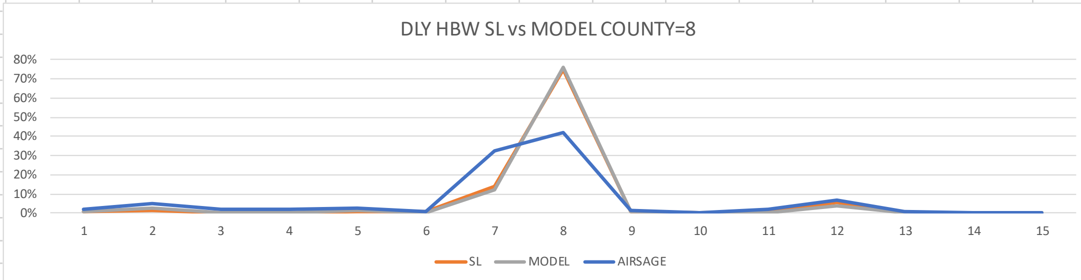
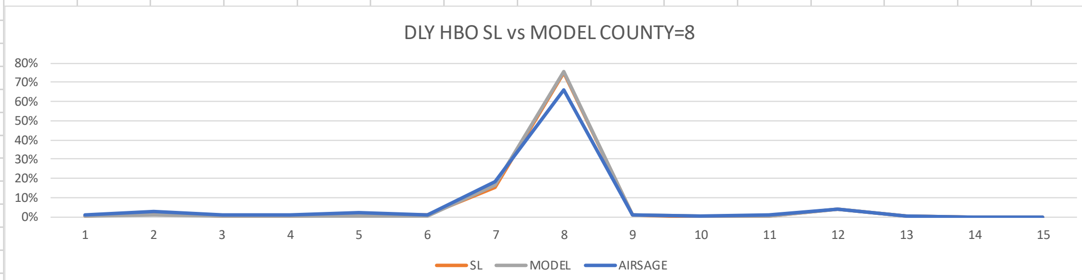


Figure A-0-7: Newport News Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	8	1%	1%	0%	0%	1%	1%	14%	75%	1%	0%	1%	6%	0%	0%	0%
AIRSAGE	8	2%	5%	2%	2%	3%	1%	32%	42%	1%	0%	2%	7%	1%	0%	0%
MODEL	8	1%	2%	1%	0%	1%	1%	12%	76%	1%	0%	1%	4%	1%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	8	1%	2%	0%	0%	1%	1%	15%	75%	1%	0%	0%	4%	0%	0%	0%
AIRSAGE	8	1%	3%	1%	1%	2%	1%	19%	66%	1%	0%	1%	4%	0%	0%	0%
MODEL	8	0%	1%	0%	0%	0%	1%	16%	76%	1%	0%	0%	4%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	8	0%	1%	0%	0%	1%	1%	13%	77%	1%	0%	0%	4%	0%	0%	0%
AIRSAGE	8	2%	4%	1%	2%	3%	2%	22%	53%	1%	0%	2%	6%	1%	0%	0%
MODEL	8	1%	1%	1%	0%	1%	0%	34%	59%	0%	0%	1%	2%	0%	0%	0%

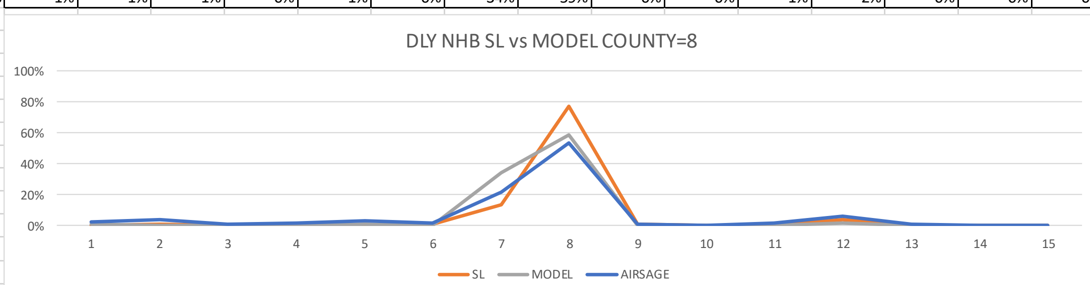
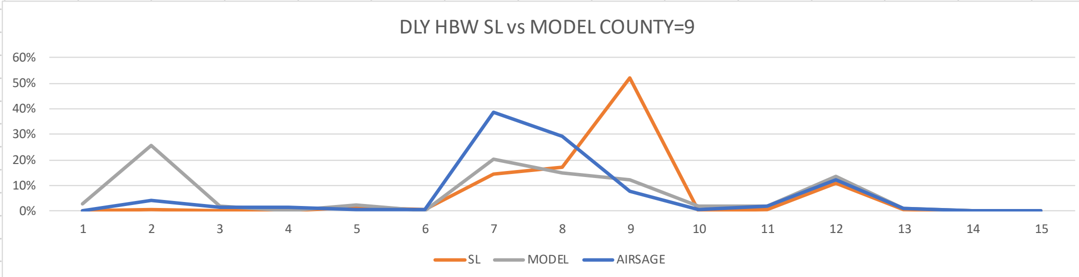
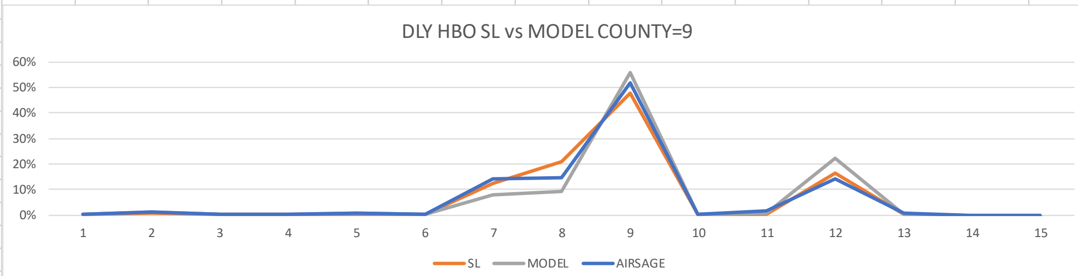


Figure A-0-8: Hampton City Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	9	0%	1%	0%	0%	1%	1%	15%	17%	52%	0%	1%	11%	1%	0%	0%
AIRSAGE	9	0%	4%	1%	1%	1%	0%	39%	29%	8%	1%	2%	12%	1%	0%	0%
MODEL	9	3%	26%	2%	0%	2%	0%	20%	15%	12%	2%	2%	14%	1%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	9	0%	1%	0%	0%	0%	0%	12%	21%	48%	0%	1%	16%	0%	0%	0%
AIRSAGE	9	0%	1%	0%	0%	1%	0%	14%	15%	52%	0%	1%	14%	1%	0%	0%
MODEL	9	0%	1%	0%	0%	1%	0%	8%	9%	56%	0%	1%	22%	0%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	9	0%	1%	0%	0%	0%	0%	15%	23%	40%	0%	1%	20%	1%	0%	0%
AIRSAGE	9	1%	2%	0%	0%	1%	0%	20%	21%	33%	0%	2%	18%	1%	0%	0%
MODEL	9	7%	2%	2%	2%	9%	1%	6%	6%	41%	1%	3%	20%	1%	0%	0%

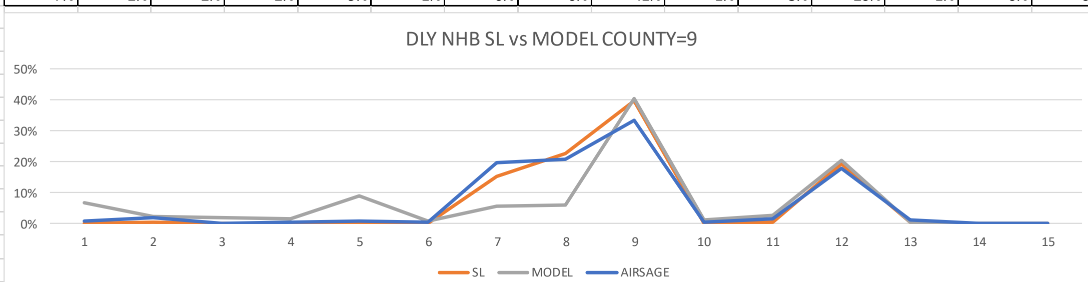
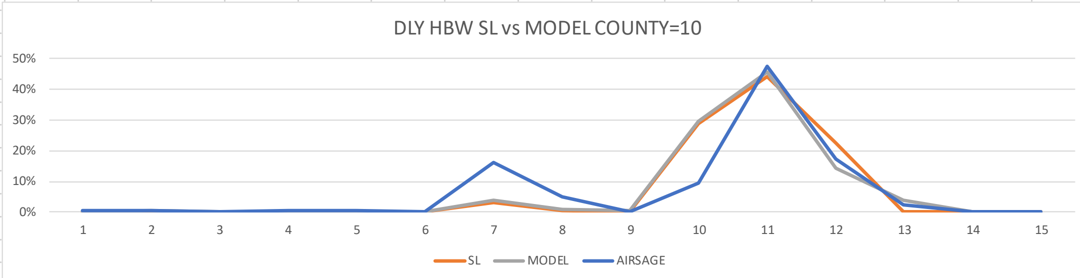
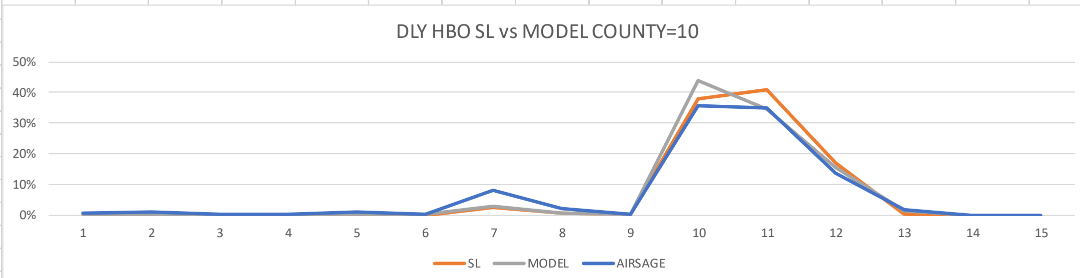


Figure A-0-9: Poquoson Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	10	0%	0%	0%	0%	0%	0%	3%	1%	0%	29%	44%	22%	0%	0%	0%
AIRSAGE	10	0%	1%	0%	0%	0%	0%	16%	5%	0%	10%	47%	17%	2%	0%	0%
MODEL	10	0%	0%	0%	0%	0%	0%	4%	1%	0%	30%	46%	14%	4%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	10	0%	0%	0%	0%	0%	0%	2%	1%	0%	38%	41%	17%	0%	0%	0%
AIRSAGE	10	1%	1%	0%	0%	1%	0%	8%	2%	0%	36%	35%	14%	2%	0%	0%
MODEL	10	0%	0%	0%	0%	0%	0%	3%	1%	0%	44%	35%	16%	1%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	10	0%	0%	0%	0%	0%	0%	2%	0%	0%	42%	35%	19%	0%	0%	0%
AIRSAGE	10	1%	1%	0%	0%	2%	0%	8%	3%	0%	25%	38%	19%	2%	0%	0%
MODEL	10	5%	2%	1%	1%	7%	1%	2%	1%	0%	40%	26%	13%	0%	0%	0%

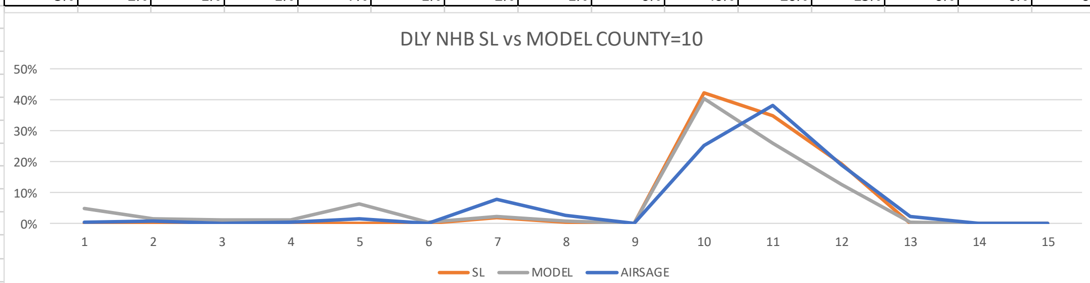
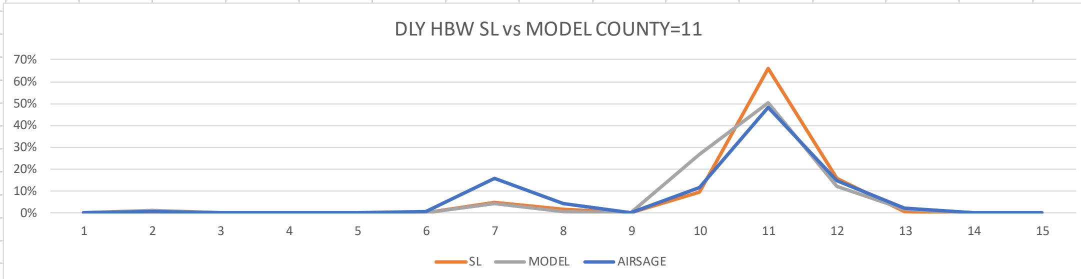
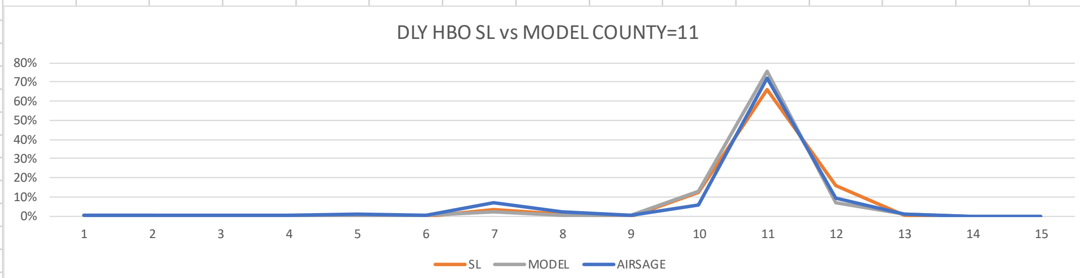


Figure A-0-10: Williamsburg Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	11	0%	0%	0%	0%	0%	0%	5%	2%	0%	10%	66%	16%	1%	0%	0%
AIRSAGE	11	0%	1%	0%	0%	0%	1%	16%	4%	0%	12%	49%	15%	2%	0%	0%
MODEL	11	0%	2%	0%	0%	0%	0%	4%	1%	0%	27%	51%	12%	2%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	11	0%	0%	0%	0%	0%	0%	3%	1%	0%	12%	66%	16%	0%	0%	0%
AIRSAGE	11	1%	1%	0%	0%	1%	0%	7%	2%	0%	6%	72%	9%	1%	0%	0%
MODEL	11	0%	0%	0%	0%	0%	0%	2%	1%	0%	13%	76%	7%	1%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	11	0%	0%	0%	0%	0%	0%	3%	1%	0%	14%	64%	18%	0%	0%	0%
AIRSAGE	11	1%	1%	0%	0%	1%	1%	8%	3%	0%	9%	61%	14%	2%	0%	0%
MODEL	11	6%	2%	2%	1%	8%	1%	3%	1%	0%	14%	53%	8%	1%	0%	0%

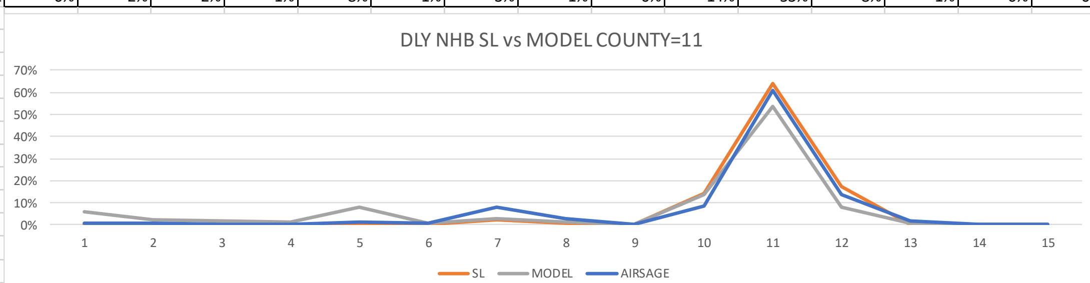
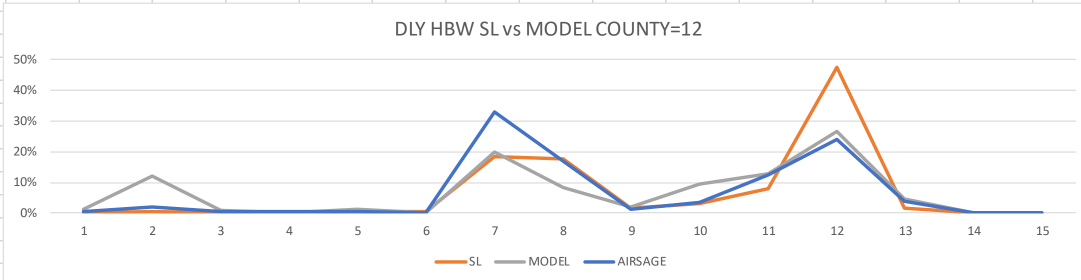
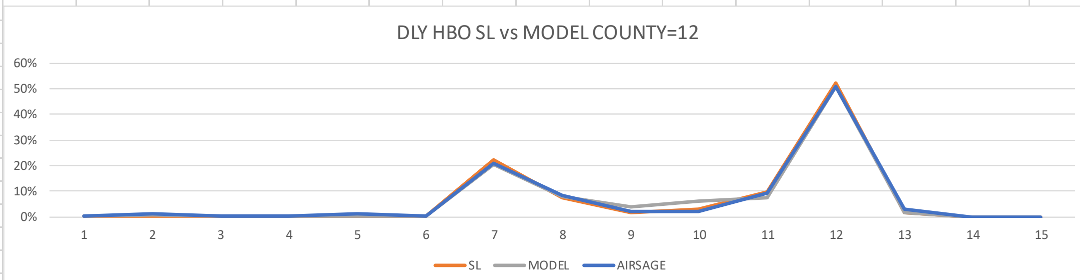


Figure A-0-11: James City Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	12	0%	1%	0%	0%	0%	0%	19%	18%	2%	3%	8%	47%	2%	0%	0%
AIRSAGE	12	0%	2%	1%	1%	1%	0%	33%	17%	1%	4%	13%	24%	4%	0%	0%
MODEL	12	1%	12%	1%	0%	1%	0%	20%	8%	2%	10%	13%	27%	5%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	12	0%	0%	0%	0%	0%	0%	22%	7%	2%	3%	10%	52%	2%	0%	0%
AIRSAGE	12	1%	1%	0%	0%	1%	0%	21%	9%	2%	2%	9%	51%	3%	0%	0%
MODEL	12	0%	1%	0%	0%	0%	0%	20%	8%	4%	6%	8%	51%	2%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	12	0%	0%	0%	0%	0%	0%	14%	8%	1%	6%	13%	55%	2%	0%	0%
AIRSAGE	12	1%	1%	0%	1%	1%	0%	22%	8%	2%	5%	15%	39%	5%	0%	0%
MODEL	12	6%	2%	2%	1%	7%	1%	12%	4%	3%	8%	9%	44%	1%	0%	0%

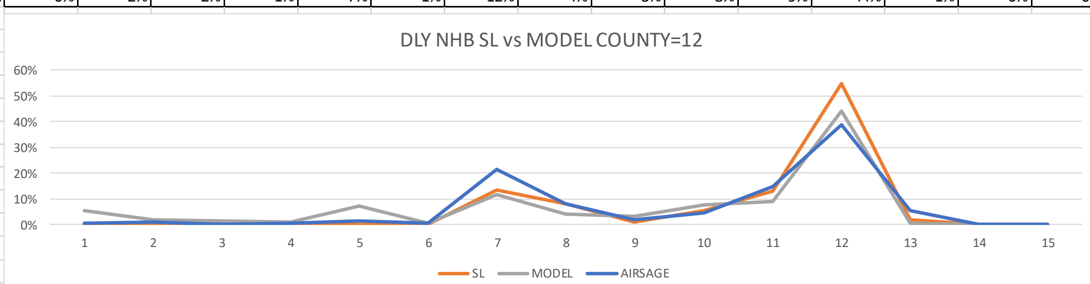
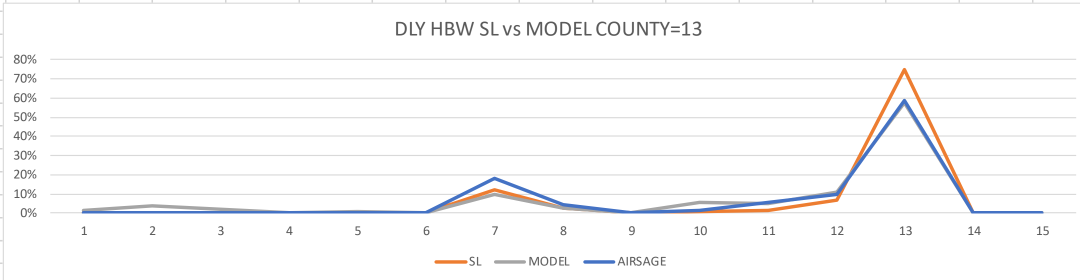
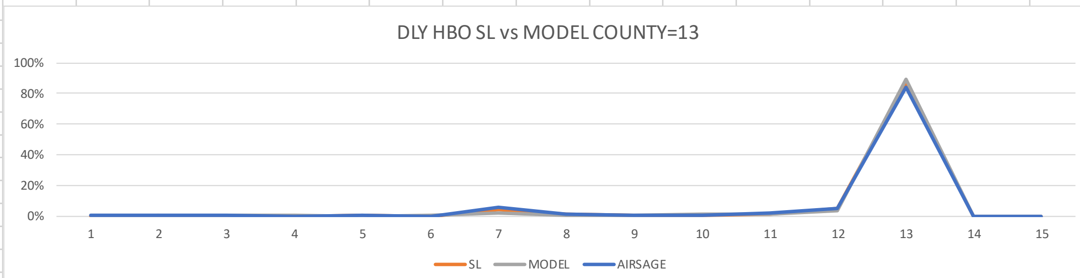


Figure A-0-12: York Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	13	0%	0%	0%	0%	0%	0%	12%	3%	0%	1%	2%	7%	75%	0%	0%
AIRSAGE	13	0%	1%	0%	0%	0%	0%	18%	4%	0%	2%	6%	10%	58%	0%	0%
MODEL	13	1%	4%	2%	0%	1%	0%	10%	3%	0%	6%	5%	11%	58%	0%	0%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	13	0%	0%	0%	0%	0%	0%	4%	1%	0%	0%	1%	5%	87%	0%	0%
AIRSAGE	13	0%	0%	0%	0%	0%	0%	6%	1%	0%	1%	2%	5%	84%	0%	0%
MODEL	13	0%	1%	0%	0%	0%	0%	2%	1%	0%	1%	2%	3%	90%	0%	0%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	13	0%	0%	0%	0%	0%	0%	3%	1%	0%	0%	1%	5%	89%	0%	0%
AIRSAGE	13	0%	1%	0%	0%	0%	0%	7%	2%	0%	1%	2%	7%	80%	0%	0%
MODEL	13	3%	1%	1%	1%	4%	0%	1%	1%	0%	1%	1%	2%	84%	0%	0%

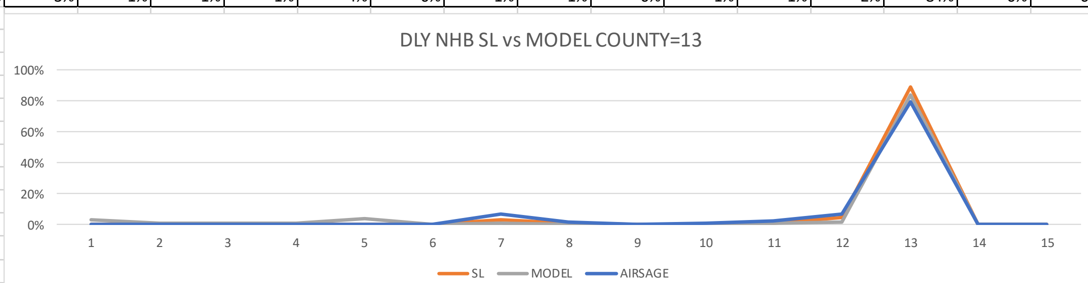
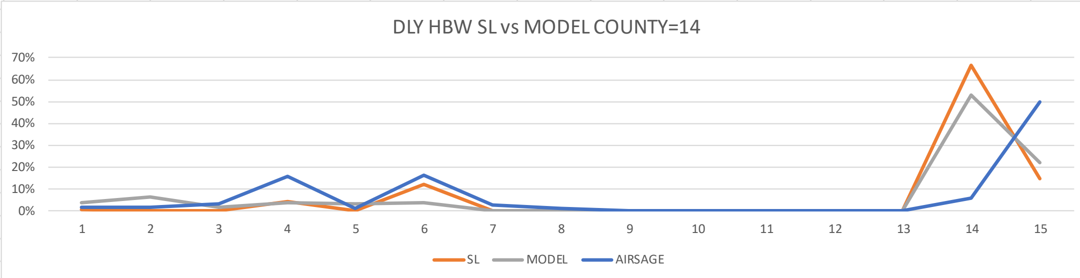
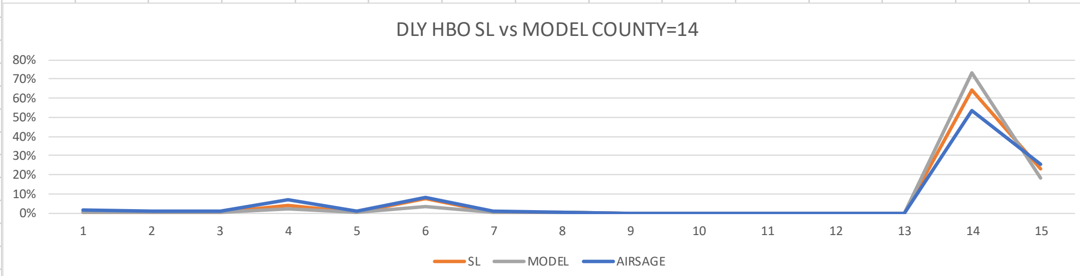


Figure A-0-13: Gloucester Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	14	1%	0%	0%	4%	0%	12%	0%	0%	0%	0%	0%	0%	0%	66%	15%
AIRSAGE	14	2%	2%	3%	16%	1%	16%	3%	1%	0%	0%	0%	0%	0%	6%	50%
MODEL	14	4%	7%	2%	4%	4%	4%	0%	0%	0%	0%	0%	0%	0%	53%	22%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	14	0%	0%	0%	4%	0%	8%	0%	0%	0%	0%	0%	0%	0%	65%	23%
AIRSAGE	14	2%	1%	1%	7%	1%	8%	1%	0%	0%	0%	0%	0%	0%	54%	26%
MODEL	14	1%	1%	0%	2%	1%	4%	0%	0%	0%	0%	0%	0%	0%	73%	18%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	14	0%	0%	0%	4%	0%	8%	0%	0%	0%	0%	0%	0%	0%	63%	24%
AIRSAGE	14	2%	1%	1%	10%	1%	12%	1%	0%	0%	0%	0%	0%	0%	36%	36%
MODEL	14	2%	1%	1%	1%	3%	3%	1%	0%	0%	0%	1%	1%	0%	82%	5%

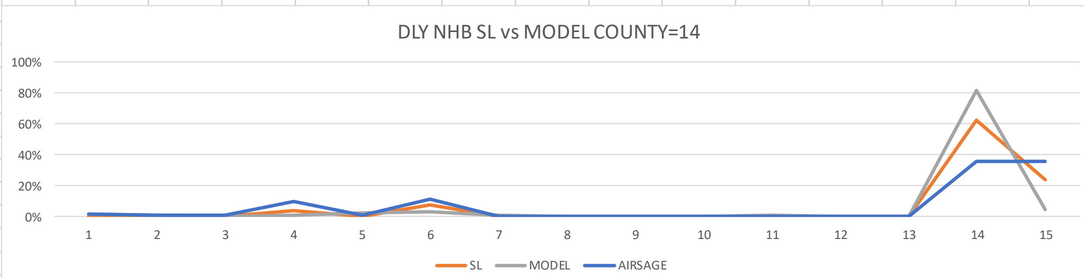
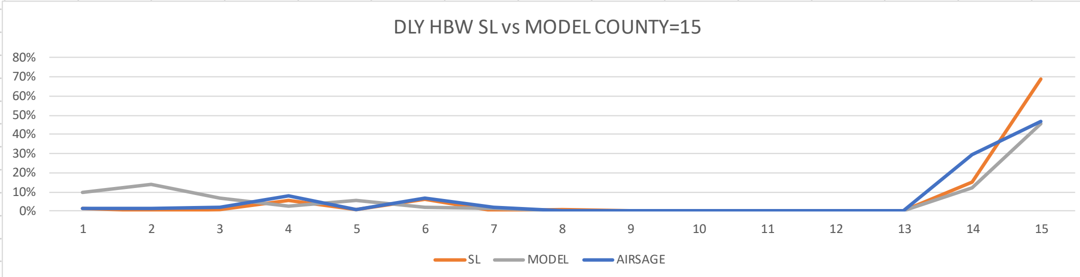
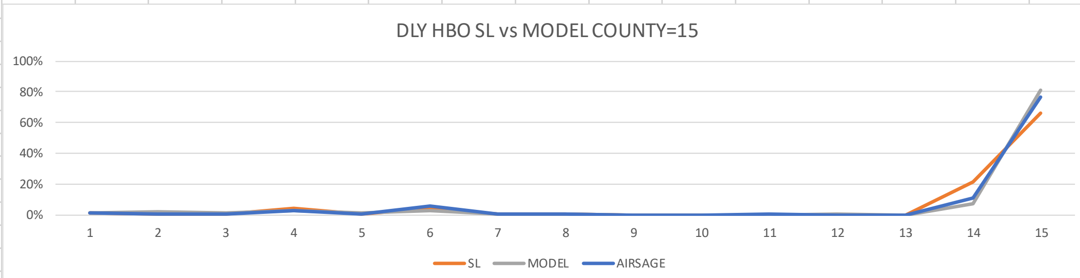


Figure A-0-14: Franklin Distribution

DLY HBW SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	15	1%	1%	1%	5%	1%	6%	0%	1%	0%	0%	0%	0%	0%	15%	69%
AIRSAGE	15	1%	2%	2%	8%	1%	7%	2%	1%	0%	0%	0%	0%	0%	30%	47%
MODEL	15	10%	14%	7%	2%	6%	2%	1%	0%	0%	0%	0%	0%	0%	12%	46%



DLY HBO SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	15	1%	1%	1%	5%	0%	4%	0%	0%	0%	0%	0%	0%	0%	21%	66%
AIRSAGE	15	1%	1%	1%	3%	1%	6%	1%	0%	0%	0%	0%	0%	0%	11%	77%
MODEL	15	1%	2%	1%	2%	1%	2%	0%	0%	0%	0%	0%	0%	0%	7%	81%



DLY NHB SL vs MODE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SL	15	1%	0%	0%	5%	0%	4%	0%	0%	0%	0%	0%	0%	0%	21%	68%
AIRSAGE	15	1%	1%	1%	3%	1%	8%	1%	0%	0%	0%	0%	0%	0%	13%	71%
MODEL	15	2%	1%	1%	1%	3%	1%	1%	0%	0%	0%	1%	1%	0%	3%	86%

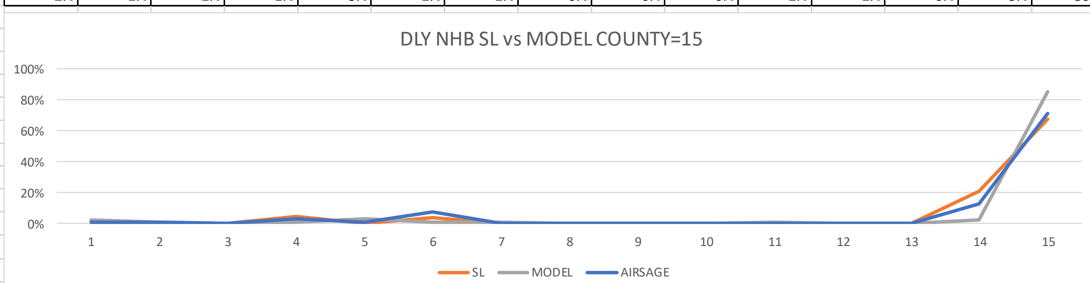


Figure A-0-15: Southampton Distribution