NVTA MODEL DEVELOPMENT

Calibration and Validation

Prepared by

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NVTA's TransAction

Transportation Action Plan for Northern Virginia

NOVEMBER 2021 (DRAFT)
JANUARY 2022 (REVISED)

NVTA Model Development

Calibration and Validation

Prepared for

Northern Virginia
Transportation Authority

November 2021 Draft and January 2022 Revised

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EXECUTIVE SUMMARY

The Northern Virginia Transportation Authority (NVTA) is undertaking the TransAction Update and Six Year Program, including

- Developing and updating the long-range, multimodal Transportation Plan for Northern Virginia, TransAction.
- Prioritizing and funding regional transportation projects in the Six Year Program for the next three updates: FY2022-2027, FY2024-2029, and FY2026-2031.

To support the NVTA program, we developed a modeling strategy that will balance tradeoffs between functionality and efficiency, ensure consistency with the TransAction performance measures and consider the ability to build in-house modeling capabilities to improve upon the existing model system.

Model Functionality Enhancements

Some of the key enhancements in this modeling strategy include:

- Integration of the COG/TPB model with a DTALite tool, which is an open-source, queue-based mesoscopic simulation package that provides a simpler, user-friendly, and more economical solution to conducting mesoscopic modeling at a large regional scale.
- New capability to model emerging travel behavior of transportation network company (TNC) travel
- New capability to conduct scenario analysis of travel via connected and automated vehicles (CAVs)
- Updating representation of travel behavior (trip rates and mode choices) reflecting the latest Regional Travel Survey (RTS 2017/8)
- New dynamic traffic assignment model to better represent and simulate traffic congestion
- A robust scenario management system with flexibility for users and customized features.
- A Modeling Dashboard that facilitates comparisons between scenarios and allows model users to quickly visualize information, with a variety of portable summary reports with a wealth of information about each scenario.
- Enhanced postprocessing utilities that will empower users with analytical capabilities to gain insights from the model results, with specialized module for easy use, such as highway assignment only run and select link analysis.

Calibration and Validation

The objective of the macroscopic model calibration and validation is to make the macroscopic model better replicate observed data for the base year and produce more reasonable results in the study area, i.e., the Northern Virginia region. The focus is on the model components that have been refined, especially trip productions, mode choice, and traffic assignments. The data used for calibration and validation include:

- 2017/2018 Regional Travel Survey
- AAWDT and VMT from VDOT and COG/TPB
- Transit boardings from COG/TPB and transit agencies

Trip rates per household by trip purposes were compared reasonably well between those estimated from the model and those derived from the 2017/2018 Regional Travel Survey. Modal shares (transit, TNC and auto) by trip purposes in the whole region demonstrate the close match between the estimated and observed. The modal shares were also summarized by sub-regions, including DC, urban areas in Maryland (MD Urban) and Virginia (VA Urban), suburban areas in Maryland (MD Suburban) and in Virginia (VA Suburban). The estimated HBW modal shares are reasonably consistent with those observed for sub-regions, including those in urban and suburban areas in Virginia.

The screenlines and cutlines, as defined by the COG/TPB, are used as part of traffic assignment validation. Out of the 35 screenlines and cutlines, the NVTA model performance was improved to a better category for 7 screenlines and cutlines, 4 with a worse category and 24 within the same category. Notably, the improved screenline and cutlines include those for Potomac River, central Fairfax County, and west Fairfax County.

The HPMS VMT data were used for validation against the model estimates of VMT by jurisdictions, especially those in Northern Virginia. For the NVTA jurisdiction as a whole, the relative deviation is 0.1%. At the jurisdictional level for Northern Virginia, relative deviations are all within 3%, except for Alexandria. For the TPB planning area as a whole, the model VMT estimate is slightly lower than that for the HPMS VMT, -2.6%.

Transit assignment validation includes the comparisons of daily boardings by transit submodes between the estimated and observed. For the model domain, the estimated daily boardings closely match with the observed, with all within 5% deviations, except for MARC. For Northern Virginia, the estimated daily boardings are reasonably close to the observed.

The DTA model calibration and validation leveraged the RITIS speed data to identify the locations and extents of congestion at a high level of spatial and temporal detail, with focus on key corridors in Northern Virginia. The 11 priority corridors in Northern Virginia were further segmented into priority corridor segments. For priority corridor segments by direction, the speed and congestion duration (average and distance-weighted) were summarized for AM and PM peak periods. VMT-weighted speed and congestion duration were computed for these priority corridor segments in AM and PM peak periods. The DTALite model estimates of speed were compared with the RITIS speed at the corridor segment level, in terms of descriptive statistics including Mean Absolute Error, Mean Absolute Percentage Error, and Root-Mean Squared Error. These performance measures appear to be reasonable overall. The estimated volume profiles by time of day were reasonably consistent with those observed ones for select locations where continuous counts were available.

1.0 MODELING FRAMEWORK

The NVTA is undertaking the TransAction Update and Six Year Program, including

- Developing and updating the long-range, multimodal Transportation Plan for Northern Virginia, TransAction.
- Prioritizing and funding regional transportation projects in the Six Year Program for the next three updates: FY2022-2027, FY2024-2029, and FY2026-2031.

NVTA Model Framework

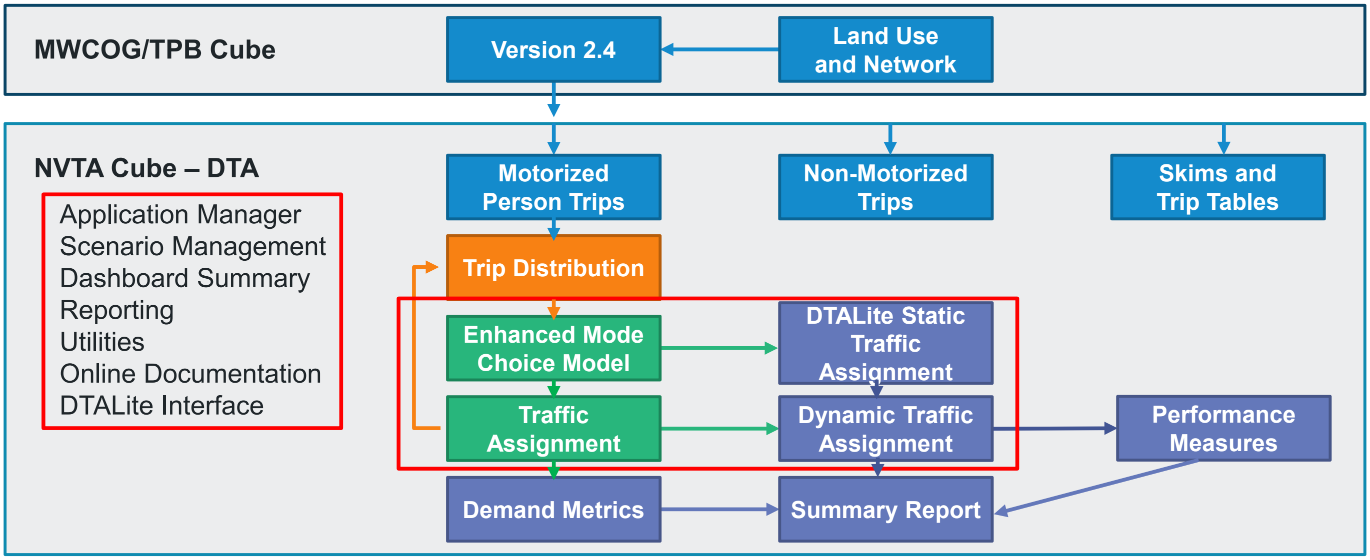
- *Integrated modeling system of macroscopic and mesoscopic tools*
- *Enhanced model functionality to model new and emerging travel behavior*
- *User-Friendly Interface*

To support the NVTA program, a modeling strategy has been developed that balances functionality and efficiency, while ensuring consistency with the TransAction performance measures to improve upon the existing model system.

1.1 Model Framework

The modeling system framework, as shown in Figure 1, is built on the existing COG/TPB model and includes enhanced model functionality and usability that will support the goal of building in-house modeling capacity. The COG/TPB model Version 2.4 represents the latest planning assumptions in terms of the fiscally constrained long range plan (CLRP), *the 2020 Amendment to the Visualize 2045*, and officially adopted land use forecasts (Round 9.1a). The new Round 9.2 cooperative forecasts are being reviewed by the COG/TPB, and once it is adopted for Air Quality Conformity analysis, they will be incorporated into the model.

Figure 1 NVTA Modeling System Framework



This model framework leverages the strengths of the region's existing tools and other proven solutions. By integrating an enhanced version of the COG/TPB model with a Dynamic Traffic Assignment (DTA), the new model system will better represent the effects of congestion on travel patterns, be more cost efficient to use, analyze the benefits of a wide variety of projects, and account for a range of future uncertainties such as new modes, technologies, and pricing strategies. Some of the key enhancements in this modeling strategy include:

- Integration of the COG/TPB model with the DTALite model. DTALite is an open-source, queue-based mesoscopic simulation package that provides a simpler, user-friendly, and more economical solution to conducting mesoscopic modeling at a large regional scale.
- Enhancement of the mode choice model with added capabilities to model emerging and new transportation technologies such as TNCs and CAVs, with new attributes and different sensitivities to auto in-vehicle travel time, parking costs, fare, waiting time, and terminal times. TNC data for model development were derived from the 2017/2018 Regional Travel Survey (RTS).

To support NVTA's in-house modeling capabilities, the model approach also includes development of a user-friendly interface with a dashboard system with key features that include:

- A robust scenario management system with flexibility for users and customized features.
- A Modeling Dashboard that facilitates comparisons between scenarios and allows model users to quickly visualize information, with a variety of portable summary reports with a wealth of information about each scenario.
- Enhanced postprocessing utilities that will empower users with analytical capabilities to gain insights from the model results, with specialized modules for easy use, such as highway assignment only run and select link analysis.

1.2 Macroscopic Model Functionality Enhancements

Model functionality enhancements were made for both the macroscopic and mesoscopic model elements. The macroscopic model functionality enhancements are described below, while the mesoscopic model is discussed in Section 1.3.

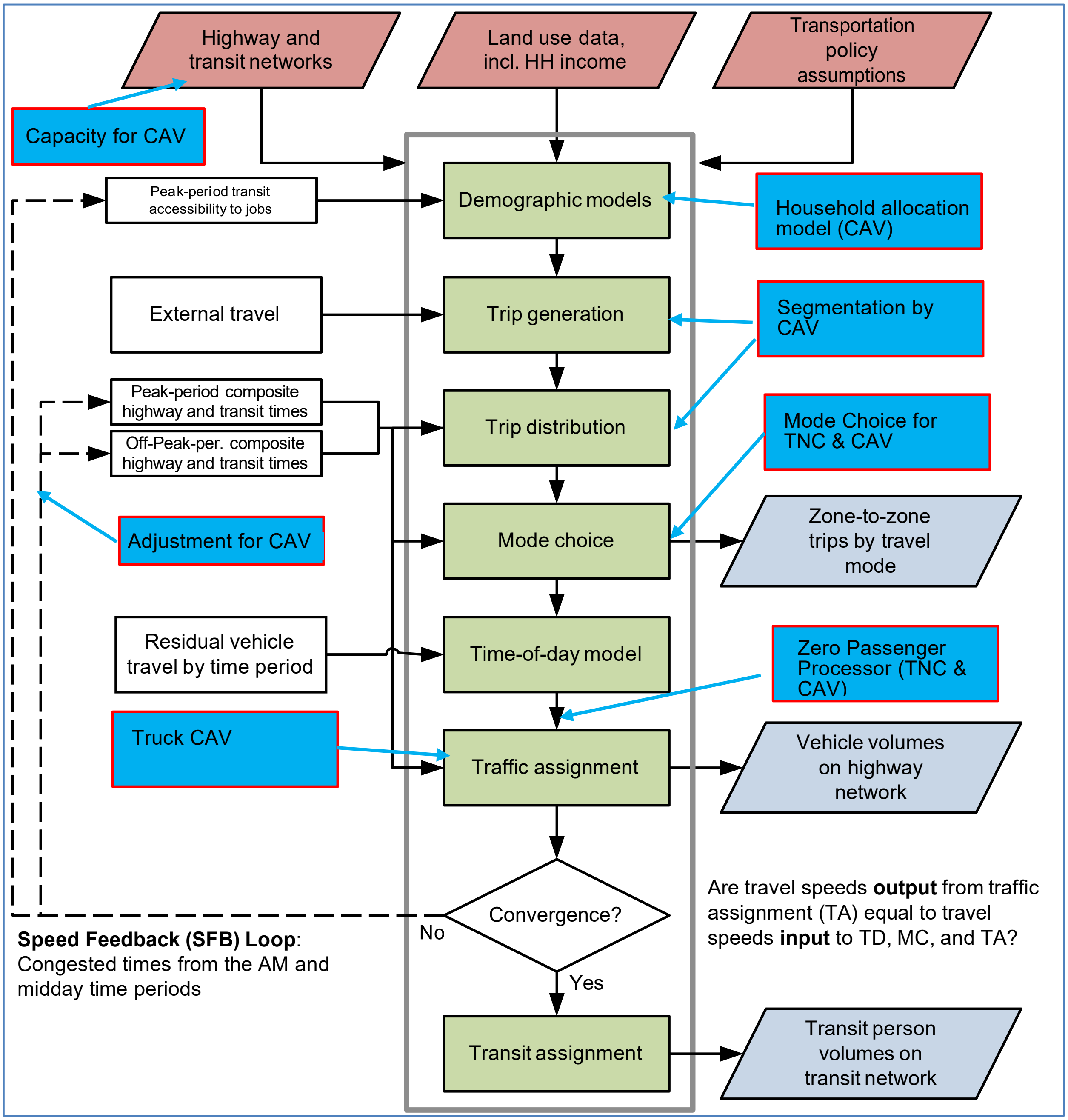
Functionality Enhancements

- *New capability to model emerging and new travel options (TNC and CAV)*
- *Updating representation of travel behavior (trip rates and mode choices) reflecting the latest Regional Travel Survey (2017/8)*

1.2.1 Enhanced Elements

The COG/TPB model Version 2.4 model structure is the basis and has been adapted to include additional model functionalities, as highlighted in blue boxes in the flowchart in Figure 2.

Figure 2 COG/TPB Model Structure with enhancements highlighted in blue



Source: Adapted from COG/TPB. 2021. USER'S GUIDE For the COG/TPB Gen2/Version 2.4 Travel Demand Forecasting Model.

1.2.2 Household Allocation Model

The household allocation model is a new model component that adds further household segmentations to the zonal-level household file to allocate CAV ownership to households based on income levels and other characteristics.

The Household Allocation model uses an assumption of the percentage of households in the region who own CAVs. The model allocates CAV ownership to households based on household income levels.

The output from the Household Allocation model is a zonal-level household file segmented by household income, household vehicle, household size, and CAV ownership. The file is used as an input into the trip production estimation.

Based on current research on the costs of owning a CAV compared to conventional vehicles, higher income households are more likely to own a CAV. Table 1 shows how CAV ownership is distributed by income level at different levels of CAV market penetration. With no fully automated vehicles on the road, all values are equal to zero.

Table 1. Percentage of Households within each Income Category that own CAVs by regional CAV ownership levels

Table Header	Percentage of Households that own CAVs								
Household Income	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
<=50k	2%	5%	7%	10%	12%	16%	24%	43%	66%
50k-100k	11%	21%	33%	44%	55%	70%	94%	100%	100%
100k-150k	17%	33%	51%	67%	84%	100%	100%	100%	100%
>150k	19%	37%	56%	75%	93%	100%	100%	100%	100%

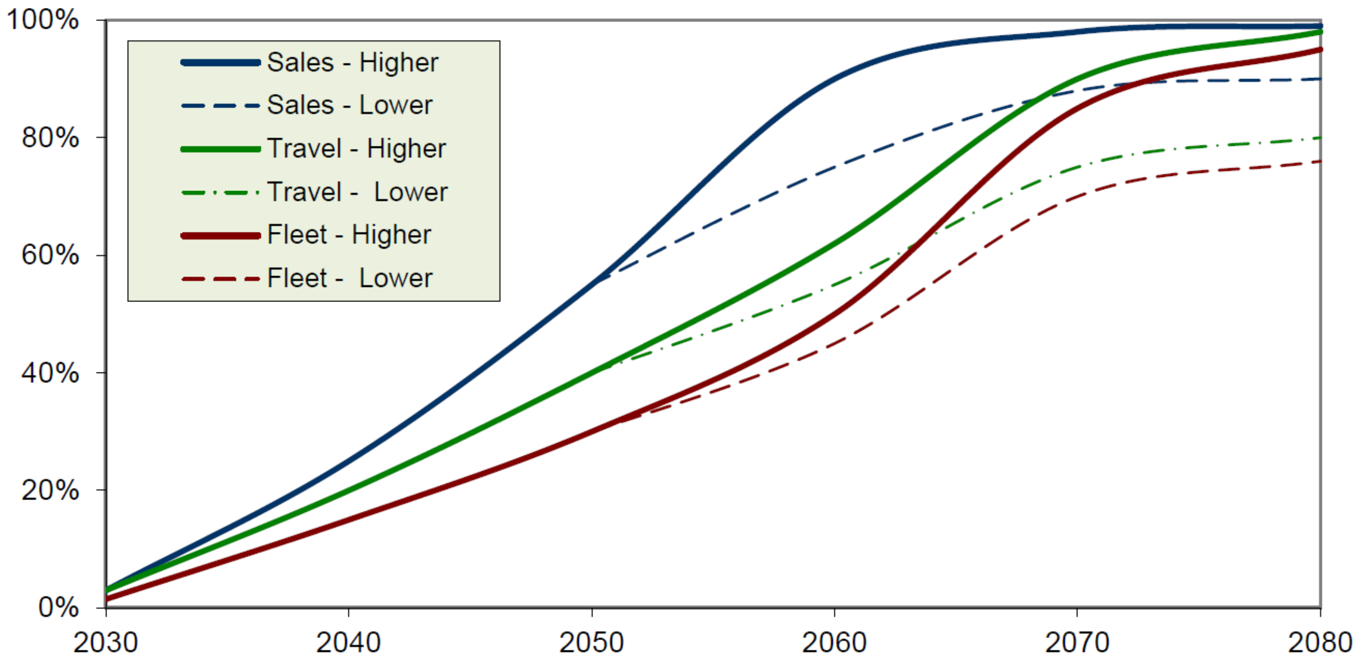
Source: Adapted from Cambridge Systematics,2020, Houston SMART Study Travel Demand Model Calibration, Validation and Sensitivity Testing, prepared for TxDOT.

Adoption of the CAVs is expected to follow an S-curve development pattern historically exhibited for new technologies, with a gradual slow adoption in the early stages of development, testing, approval, and commercial release, and then accelerated pace of adoption for the stages of product improvement, market expansion, differentiation, and maturation, eventually reaching a plateau as the market saturates.

CAV adoption rates are important assumptions for evaluating the impacts of CAV on travel. Figure 3 shows predictions of autonomous vehicle sales, fleet, and travel over a fifty-year horizon, based on the historical adoption of previous vehicle related technologies. As shown, for the current planning horizon of 2045, the AV sales are projected to take approximately 40% of the market sales, 20% of the overall vehicle fleet, and 30% of vehicle travel. By the 2060s, AV sales are expected to reach market saturation with 80-100% new sales, but still only accounting for 50-80% of travel. This prediction is consistent with some predictions in the industry but less optimistic than others who forecast a steeper curve.

Households utilizing shared-CAVs (SCAVs) will have an experience that is very similar to those currently utilizing TNCs and will be part of mode choice options taking into account their level of service characteristics.

Figure 3 Autonomous Vehicle Sales, Fleet and Travel Projections



Source: T. Litman, "Autonomous Vehicle Implementation Predictions," 28, Exhibit 20, 2021. https://www.vtpi.org/avip.pdf

1.2.3 Trip Generation

Trip production rates were updated using those derived from the 2017/2018 Regional Travel Survey. The trip production rates in the COG/TPB Version 2.4 were based on the 2007/2008 Household Travel Survey. As shown in Table 2, the updated 2017/2018 trip production rates per household have some differences from those based on 2007/8. In particular, home-based work (HBW) and home-based shopping (HBS) trip production rates are lower while HBO and NHO show moderate increases. Overall, trip production rates declined slightly, by 1.4 percent.

Table 2. Trip production rates per household

	HBW	HBS	HBO	NHW	NHO	Total
2017/18	1.41	1.21	3.29	0.88	1.48	8.28
2007/08	1.63	1.36	3.13	0.87	1.41	8.40
Difference	-0.22	-0.15	0.16	0.01	0.07	-0.12
Difference %	-13%	-11%	5%	1%	5%	-1.4%

Source: Observed trip rates were derived from the 2017/2018 Regional Travel Survey.

The model also assumes slightly higher trip generation rates for CAV owning households (approximately 2.5% more) since it will allow for non-driving population groups such as children and the elderly to travel more easily[1]. For the home-based trip purposes, in addition to the existing segmentations, the trip generation model is

[1] Cambridge Systematics,2020, Houston SMART Study Travel Demand Model Calibration, Validation and Sensitivity Testing, prepared for TxDOT.

segmented by CAV ownership and non-CAV ownership. These segmentations are retained for use in trip distribution and mode choice.

1.2.4 Trip Distribution

For non-CAV households, the trip distribution process retains the existing procedures in the COG/TPB Version 2.4 model. For scenarios with the CAV presence, trip distribution includes the additional new household segments of CAV ownership only. CAVs will likely lead people to be less sensitive to distance as part of the trip destination choice. For CAV ownership segmentations, trip distribution parameters, including value of time, are adjusted such that average trip lengths for each trip purpose are, on average, 18 percent higher than for non-CAV ownership households[2].

1.2.5 Mode Choice Model

Several changes were made to the Mode Choice component to account for TNCs and CAVs.

- The mode choice models were segmented by CAV and Non-CAV ownership.
- TNC is added as an additional mode at the top level of the nesting structure, directly competitive with both auto and transit. Variable coefficients for the mode are borrowed from existing modes.
- For the CAV ownership segment, CAV trips can be SOV, HOV2, or HOV3+ trips. The in-vehicle travel time coefficient is adjusted to 25% lower in magnitude (i.e., less negative in value), and the parking cost variable is removed.

The mode structures for CAV ownership only and Non-CAV ownership households are shown in Figure 4 and Figure 5 respectively.

For the new TNC mode, results from a survey conducted in San Francisco revealed that two-thirds of TNC users reported waiting 5 minutes or less, and nearly 90% waited 10 minutes or less[3]. Table 3 provides the assumed wait times for TNCs, adapted from those implemented in Houston.

Table 3. TNC Wait Time

Area Type	Wait Time
CBD	3
Urban	3
Sub Urban	4
Sub Urban Fringe	6
Rural	12

[2] Determined based on CAV scenario analyses conducted in Seattle and Atlanta utilizing activity-based models; Childress, S., B. Nichols, B. Charlton, and S. Coe. "Using an Activity-Based Model to Explore Possible Impacts of Automated Vehicles." Transportation Research Record Vol. 2493, Issue 1, 2015; Rousseau, G. "Model Development & Applications at the Atlanta Regional Commission for Transportation Planning." Presentation to FDOT District 4 Southeast Florida FSUTMS Users Group Meeting, September 14, 2018.

[3] Shaheen, S., Chan, N., and Rayle, L. *Ridesourcing's Impact and Role in Urban Transportation*. ACCESS Magazine, Spring 2017.

Source: Adapted from Cambridge Systematics,2020, Houston SMART Study Travel Demand Model Calibration, Validation and Sensitivity Testing, prepared for TxDOT.

TNC fares represent another critical element of consideration. Unlike traditional taxis, which have fixed fare structures related to trip distance or zone definitions, TNC fares vary widely depending on demand and supply levels (e.g., surge pricing) and by type of service (e.g., shared services). To simplify the assumed TNC fare, we make the fare vary by distance and travel time. For the base year 2017, the following relationship was used[4]:

TNC Fare = Maximum (5.30, 3.47 + 0.71* Distance in miles + 0.15* In-vehicle Time in minutes)

TNC fares have increased considerably since 2020. In 2021, the Uber website (https://www.uber.com/fare-estimate/) were used to calculate fares for a set of select origins and destinations were selected across the Washington region, and Google Maps were used to estimate trip distance in miles. For reasonableness checking, these 2021 fares were compared with those computed above for 2017 and those computed for 2021, using the following[5]:

TNC Fare = Maximum (0.3* In-vehicle Time in minutes +0.8* Distance in miles +3.21, 7)

For the planning horizon years such as 2045, TNC operations will likely have an adoption of thus its service characteristics such as fare, costs, and time will change accordingly. For scenario analyses, various assumptions about service characteristics such as fares, wait times, etc. can be made to represent the shared-CAVs.

CAVs are able to drop off passengers at their exact locations and park elsewhere, minimizing terminal time. CAV-specific terminal times and costs can be set in the scenario manager. For the purpose of simplicity, parking costs will be set to zero as default.

Traveler values of time may be reduced as a result of being able to use time spent in a CAV more productively (e.g., reading or working). Typical estimates of value of time reduction are in the range of 10 to 50 percent. Our default will be a 25 percent reduction.

[4] There is a lack of actual fare information for the base year 2017, except for some reported cases, which were used to check for reasonableness of computed TNC fares using the equation.

[5] These are UberX fare rates, based on the one published on [http://taxihowmuch.com/location/washington-dc-us, accessed on June 28](http://taxihowmuch.com/location/washington-dc-us), 2021.

Figure 4 Mode Choice Structure for CAV Households

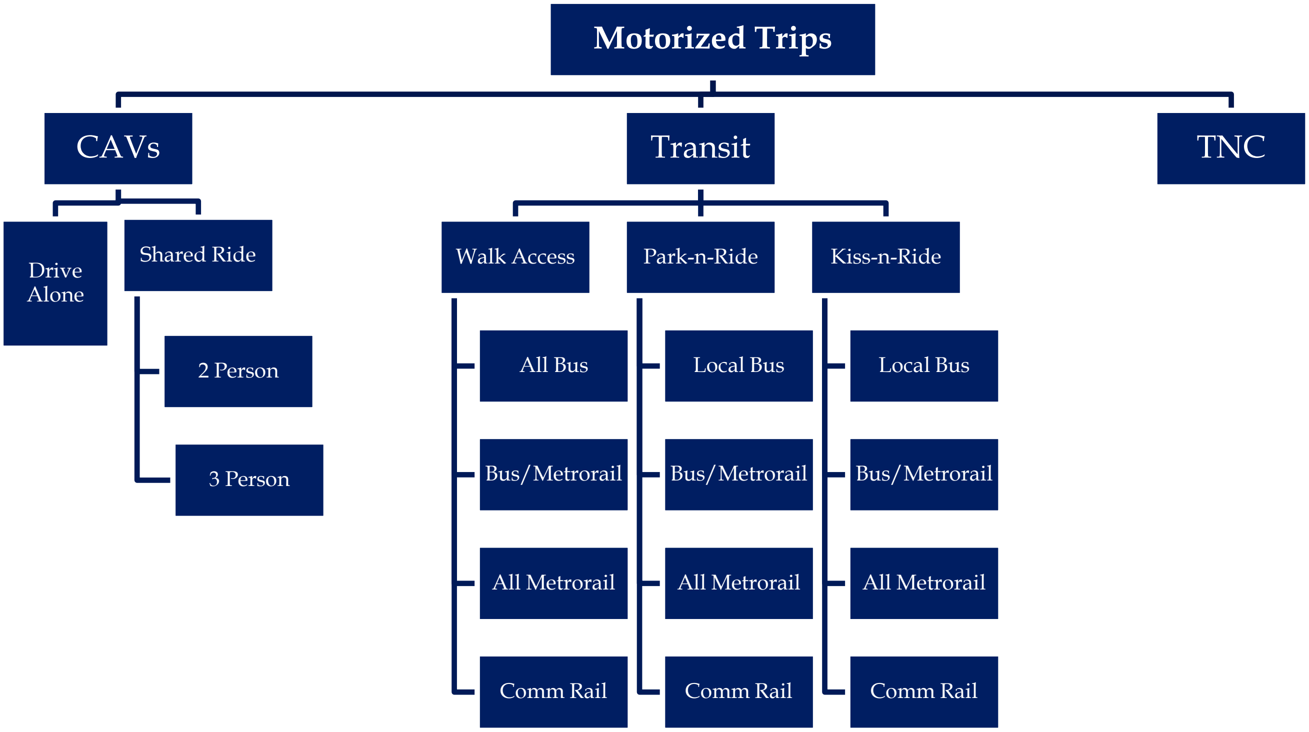
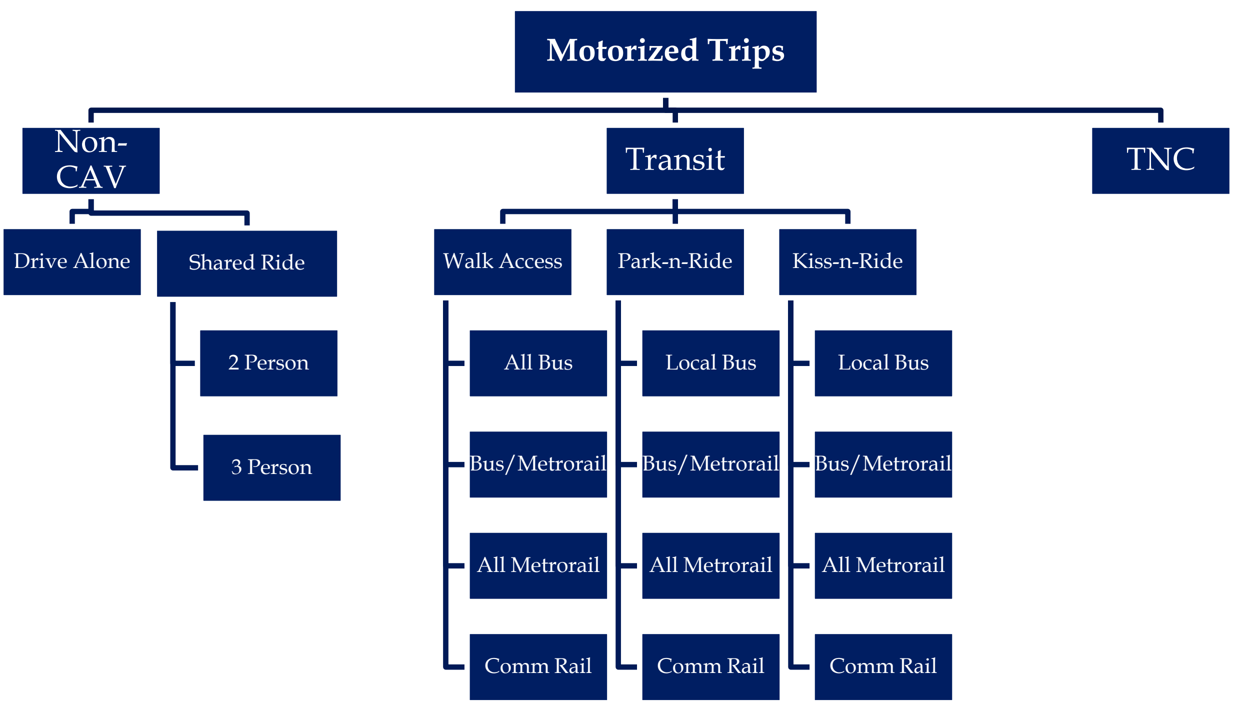


Figure 5 Mode Choice Structure for Non-CAV Ownership Households



1.2.6 Zero-Passenger Processor

The Zero-passenger processor is a new model component that adds TNC and P-CAV trips to the trip tables generated from the mode choice model. Prior to highway assignment, the P-CAV and TNC trip tables are adjusted to account for P-CAVs making zero-occupant trips and TNCs making zero-passenger trips. CAVs can park at a household's home location or return to pick up another passenger after dropping a household member off at work. It is assumed that 10% of home-based work trips return back home after dropping off a household member at work to either park at home for the day or return to pick up another passenger[6]. Zero-occupancy P-CAV trip tables are generated from the P-CAV trip tables produced from the mode choice model using this assumption. TNC zero-passenger trip tables are developed by adding additional trips to balance productions and attractions of TNC trips between TAZs.

The CAV zero processor uses the CAV trip table for HBW trips as input. The processor replicates 10% of the HBW trips and reverses their productions and attraction locations to capture the assumption that some HBW trips will return to home to park for the day or to serve other household members.

1.2.7 Highway Assignment

For input into the highway assignment module, the CAV and non-CAV trip tables are added together as one set of inputs into assignment, along with passenger and zero-passenger TNC trips. Medium and heavy trucks can also be CAV trips, based on assumed levels of CAV market penetration for each vehicle type. Coded into the model network during the Network Development stage, capacity by roadway type is utilized in highway assignment. The capacity values on interstates and freeways will be factored based on the CAV market penetration.

Studies show a wide variation for CAVs' impact on roadway capacity, varying by the proportion of CAVs in the vehicle fleet, among other factors. Typical estimates of the capacity improvement show increases of up to 50 to 100 percent on freeways. Capacities on arterials may be slightly improved with full CAV adoption, typically estimated between 10 to 20 percent increase, while signalized intersections may be improved to a larger degree due to connectivity. Table 4 shows the capacity adjustment factors for different freeway configurations under varying CAV conditions, as part of an update to the Highway Capacity Manual, while Table 5 displays example capacity adjustment factors at signalized intersections. Figure 6 illustrates the capacity adjustment factors for interstate and freeways facilities with beginning capacities of 1900 and 2000 vehicle per hour per lane (vphpl) at different level of CAVs in the vehicle fleet.

Table 4. Capacity adjustment factors (CAFs) for different freeway configurations

	Capacity adjustment factors (CAFs)		
	Basic Freeway Segment		
CAV Market Penetration Rate (MPR) /Starting Capacity	2400	2100	1800
0	1.00	1.00	1.00
20	1.02	1.02	1.15
40	1.07	1.10	1.27

[6] Cambridge Systematics,2020, Houston SMART Study Travel Demand Model Calibration, Validation and Sensitivity Testing, prepared for TxDOT.

	Capacity adjustment factors (CAFs)		
60	1.13	1.25	1.40
80	1.22	1.37	1.60
100	1.35	1.53	1.82
Freeway Weaving Segment (without Advanced Merging)			
MPR /Volume Ratio	0.2	0.3	0.4
0	1.00	1.00	1.00
20	1.03	1.04	1.05
40	1.08	1.08	1.09
60	1.15	1.15	1.13
80	1.23	1.22	1.20
100	1.37	1.37	1.34
Freeway Weaving Segment (with Advanced Merging)			
MPR /Volume Ratio	0.2	0.3	0.4
0	1.00	1.00	1.00
20	1.05	1.05	1.08
40	1.11	1.13	1.14
60	1.17	1.20	1.18
80	1.25	1.26	1.24
100	1.37	1.38	1.35
Freeway Merge Segment			
MPR	CACC	CACC+A.M.	Advanced Merging
0	1.00	1.00	1.0
20	1.02	1.07	1.01
40	1.07	1.11	1.03
60	1.16	1.21	1.06
80	1.33	1.35	1.06
100	1.49	1.50	1.07

Source: A. Adebisi, et al., Developing Highway Capacity Manual Capacity Adjustment Factors for Connected and Automated Traffic on Freeway Segments. TRB 2020. CACC= Cooperative Adaptive Cruise Control. A.M.= Advanced Merging.

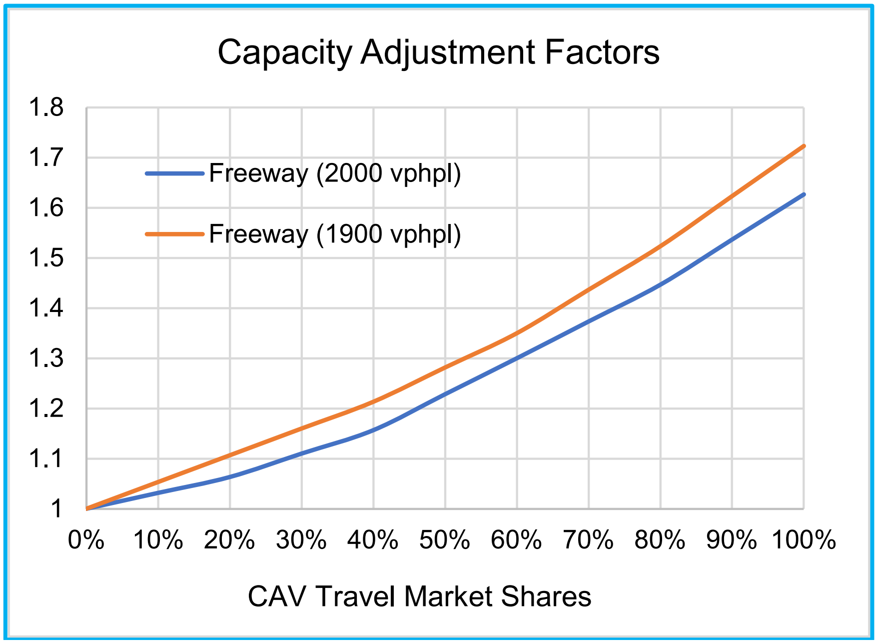
Table 5. Adjustment Factors Lookup Table ("Normal" CACC Gap Settings)

	Protected Left-Turn		Through Movement	
Market Penetration Rate	CACC	ACC	CACC	ACC
0	1.00	1.00	1.00	1.00
20	1.01	1.01	1.06	1.05

	Protected Left-Turn		Through Movement	
40	1.07	1.02	1.13	1.08
60	1.11	1.05	1.19	1.07
80	1.21	1.08	1.36	1.04
100	1.56	1.16	1.52	1.01

Source: A. Adebisi, et al., Highway Capacity Manual (HCM) Capacity Adjustment Factor (CAF) Development for Connected and Automated Traffic at Signalized Intersections. TRB 2021. CACC= Cooperative Adaptive Cruise Control. ACC= Adaptive Cruise Control.

Figure 6 Freeway Capacity Adjustment Factors



Source: Adapted from Table 3.

1.2.8 Telework

The enhanced model incorporates a mechanism to reflect the effects of changing telework assumptions that could continue long after the pandemic. This mechanism would allow testing of different telework assumptions in the scenario analysis. The most significant changes associated with the increase in telecommuting would be on trip rates for home-based-work trips, and to a lesser degree, work-related trips.

The model would assume that the differentiation in the propensity for telework by household characteristics would remain the same as in 2019. Recent survey data were used as the data source to derive adjustment factors, including the MWCOG's 2019 State of the Commute Survey Report and 2020 Employer Telework Survey Summary Report. Based on these surveys, lower income households are much less likely to telework than higher income households, due primarily to the types of jobs they are likely to work at. As shown in Table 6, HBW trip productions will be adjusted to represent continued increases in telework through 2045.

Table 6. HBW Trip rate adjustments

Income Group	2019 Commute Share	Relative to Regional Average	Expected HBW Reduction 2045	HBW Trip Rates Adjustment Factor
1	10%	0.29	9%	0.91
2	25%	0.71	20%	0.80
3	36%	1.03	28%	0.72
4	48%	1.37	37%	0.63

Source: Cambridge Systematics, 2021.

These assumptions will be used for scenario analysis, evaluating the effects of telework and pandemic on the transportation performance in the study area.

1.3 DTALite Model Functionality

1.3.1 Model Architecture

The enhanced COG/TPB model will estimate travel demand by modes and by time periods, under a static user equilibrium assignment process, for the model area. These demands will be refined before use in the DTALite mesoscopic modeling which uses a dynamic traffic assignment process to assign traffic more accurately across the regional network. The process and architecture are displayed in Figure 7, with components listed below:

a. Network Data includes two essential files, node.csv and link.csv for the mesoscopic network representation.

b. OD Demand Meta Database includes the setting.csv as the configuration file that describes information such as agent type, demand period, and demand file list, which help users to represent the OD demand information for different user types at specific demand periods.

c. Traffic Assignment Module includes the key steps of the assignment, including the BPR Volume Delay Function, Shortest Path Tree Generation, and Flow Assignment, which generates the path flow and link flow according to the User Equilibrium principle.

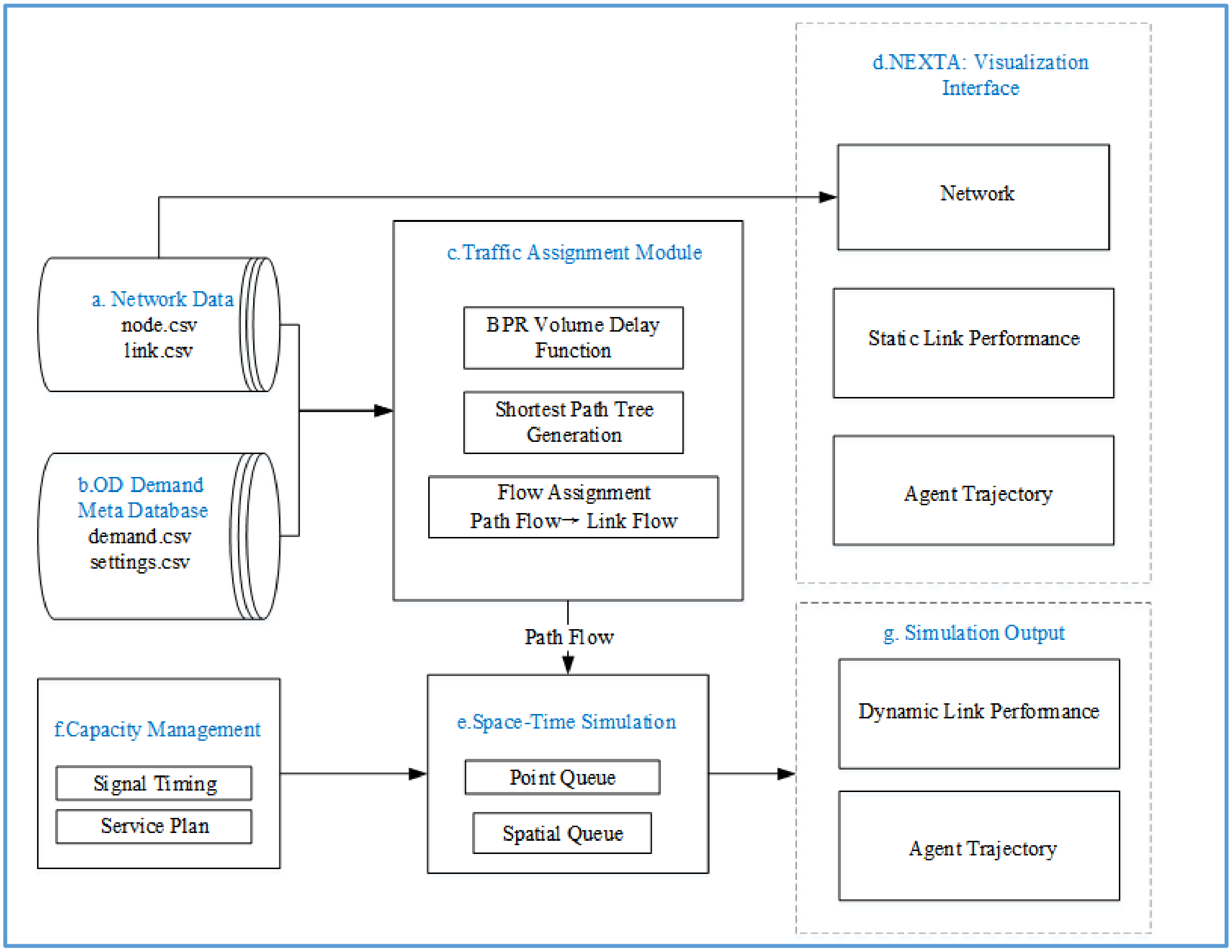
d. NEXTA: Visualization Interface Module is able to visualize the network and the output of traffic assignment, including Static Link Performance and Agent Trajectory.

e. Space-Time Simulation Module utilizes the path flow output of Traffic Assignment Module to perform Space-Time Simulation. The underlying traffic flow models in the Space-Time Simulation Module are Point Queue (PQ) and Spatial Queue (SQ). A simplified kinematic wave (KW) model can be also used in an advanced mode.

f. Capacity Management aims to manage the static and time-dependent link capacity input for Space-Time Simulation, such as signal timing plans and multi-modal service plans.

g. Simulation Output Module covers the output file of Space-Time Simulation Module, including Dynamic Link Performance and Agent Trajectory in terms of link_performance.csv and agent.csv, which can be visualized in NeXTA.

Figure 7 DTALite Model Architecture



1.3.2 Network Development

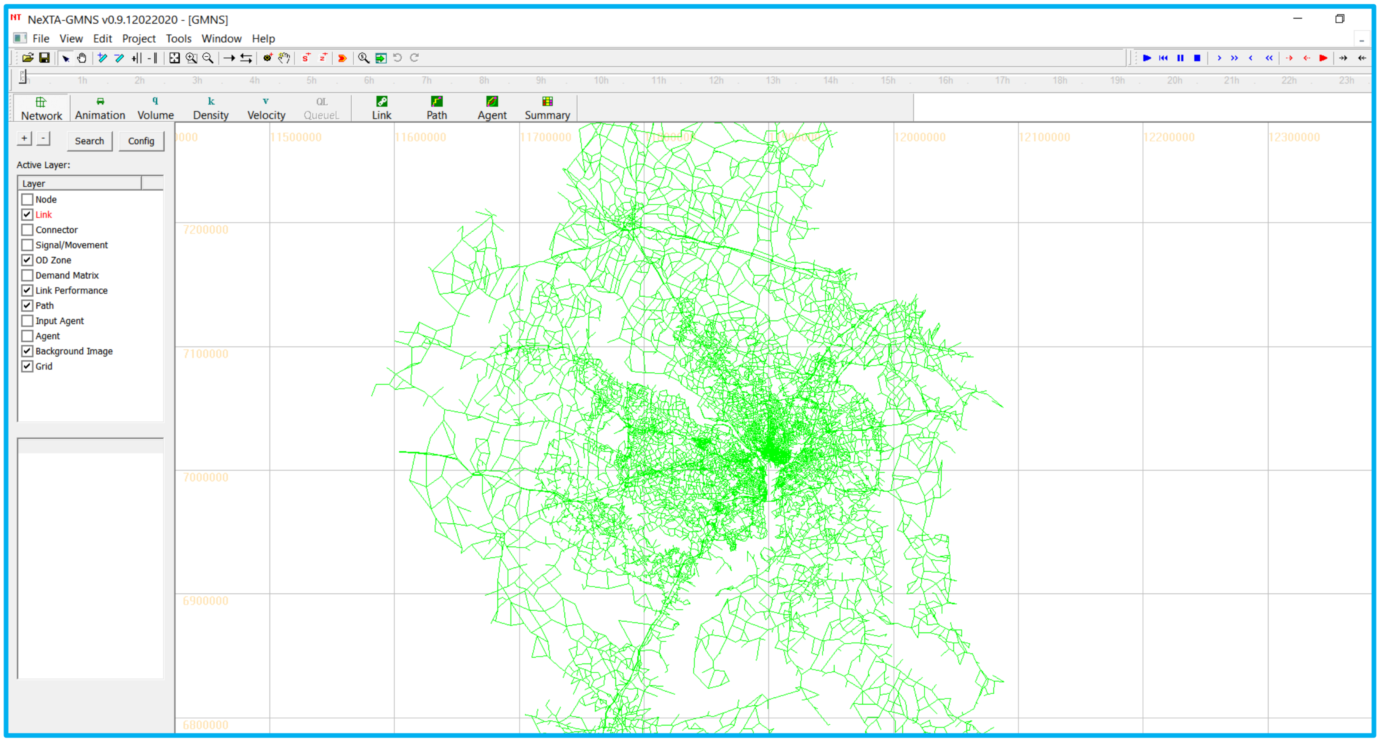
The DTALite network uses General Modeling Network Specification (GMNS), in which all GMNS data files are in CSV format. A generic network used for GMNS includes a set of three layers: node, link and movement. Roadway network data defines the basic node-link structure, along with attributes for each link and node. A link is defined using upstream node and downstream node IDs, with essential attributes such as length, free-flow speed, lanes and capacity, typically required for traffic assignment. Additionally, nodes are related to movements, which contain the individual's movement from node to node.

A mesoscopic roadway network in DTALite was developed for the Northern Virginia region, using the following data sources:

- COG/TPB Cube network: include link attributes that are used to run the COG/TPB regional model.
- OpenStreetMap: a free open-source map with an editable geographic database
- NVTA's TRANSIMS Network: includes the attributes transferred from the COG/TPB model for the previous TransAction update, and additional operational attributes.

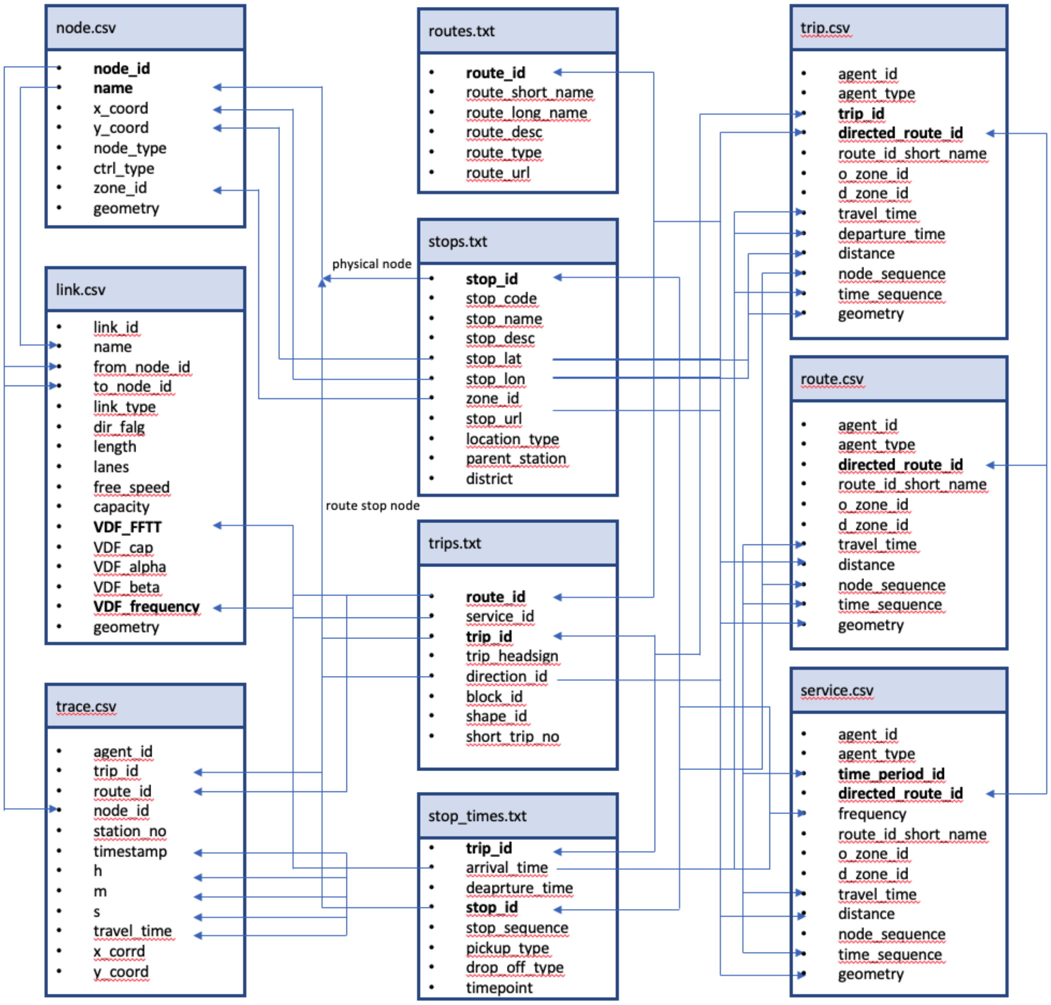
The roadway network is visualized (see Figure 8) and validated in NeXTA (Network EXplorer for Traffic Analysis), which is a graphical user interface to facilitate preparation, post-processing and analysis of simulation-based dynamic traffic assignment datasets. NeXTA Version 3 uses DTALite as fast dynamic traffic assignment engine for transportation network analysis. NeXTA has been used as a multiresolution data hub in the FHWA analysis, modeling, and simulation (AMS) data hub concept of operations project. NEXTA is distributed as a free open-source software package for transportation analysis and simulation.

Figure 8 Network Visualization and Management in NeXTA



The transit network was developed using the General Transit Feed Specification (GTFS) data from the transit service providers in the region. The GTFS defines a common format for public transportation schedules and associated geographic information, including the information of basic routes, trips, stops and stop times. The GTFS data files (e.g., trip.txt, route.txt, stop_times.txt. and stops.txt) were converted into the standard node and link network files using the GMNS, which follows the data structure outlined in Figure 9.

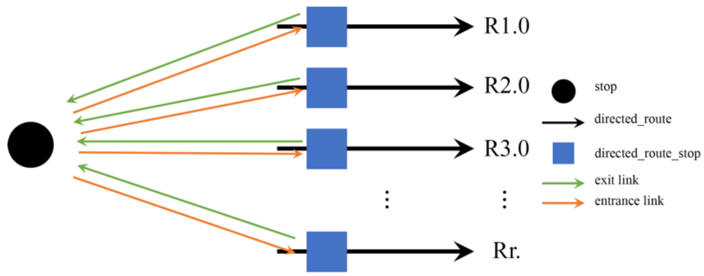
Figure 9 Transit Network Data Structure



Source: ASU, 2021, User Guide for NeXTA for GMNS GTFS-GMNS Model.

For each directed route stop node, there are service links to connect the corresponding transit stop (Figure 10). The entrance link is a boarding link, defined with the cost of the entrance including the passenger's waiting time. The exit link is a deboarding link whose cost is zero.

Figure 10 Relationship between physical stop and route stops



Source: ASU, 2021, User Guide for NeXTA for GMNS GTFS-GMNS Model.

2.0 MODEL CALIBRATION AND VALIDATION

2.1 Macroscopic Model Calibration and Validation

The objective of this macroscopic model calibration and validation is to make sure that the macroscopic model is doing the best job possible of replicating observed data for the base year, and therefore produce more reasonable forecasts in Northern Virginia. The focus is on the model components that have been refined, especially trip production, mode choice, and traffic assignments. The data used for calibration and validation include:

- 2017/2018 Regional Travel Survey
- Average Annual Weekday Daily Traffic (AAWDT) volumes and Vehicle Miles Travel (VMT) from VDOT and COG/TPB
- Transit boardings from COG/TPB and transit agencies

2.1.1 Trip Generation

Estimated trip rates per household by trip purpose from the model were compared to those derived from the 2017/2018 Regional Travel Survey, as summarized in Table 7 and shown in Figure 11. The differences between estimated and observed trip rates are small, within 3 percent across all purposes.

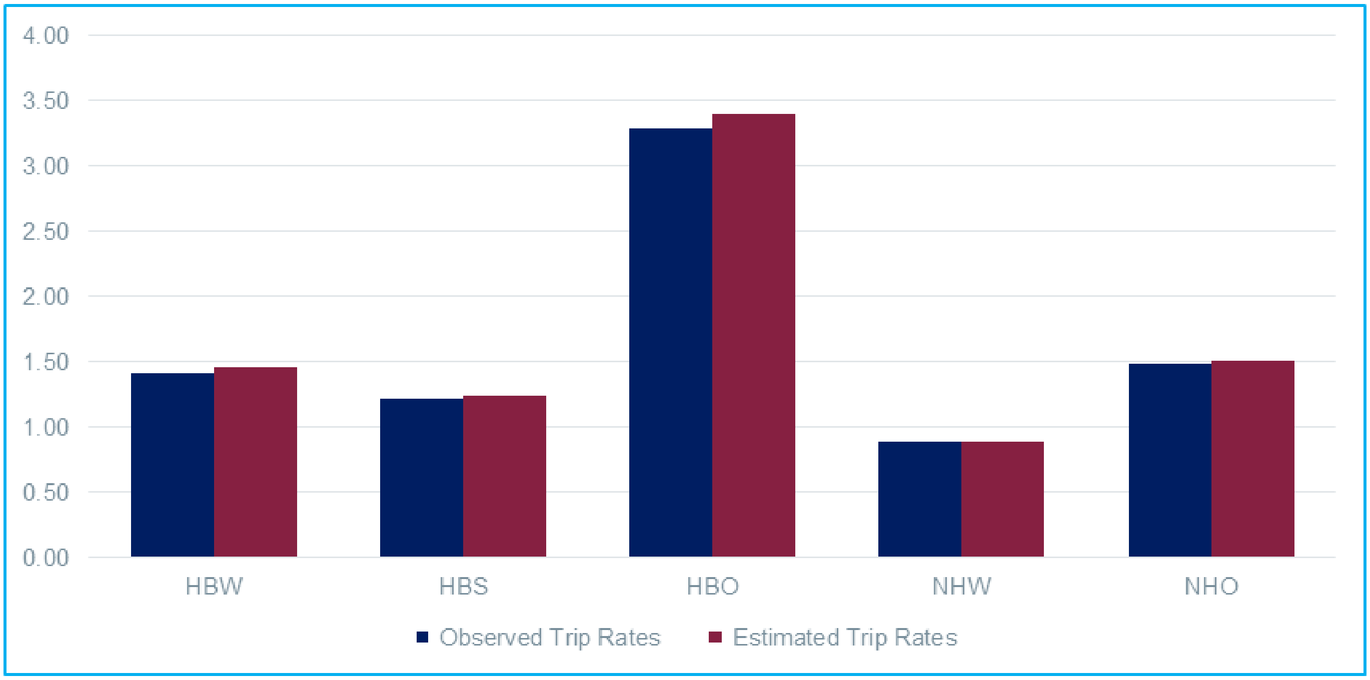
Table 7. Trip rates per household

	HBW	HBS	HBO	NHW	NHO	Total
Observed Trip Rates	1.41	1.21	3.29	0.88	1.48	8.28
Estimated Trip Rates	1.46	1.24	3.39	0.88	1.50	8.47
Difference	0.05	0.03	0.10	0.00	0.02	0.19
Difference %	3%	2%	3%	1%	1%	2%

Source: Observed trip rates were derived from the 2017/2018 Regional Travel Survey.

Trip attraction rates are the same as originally used in the COG/TPB model. In the Appendix, attraction rates for HBW are compared with the NCHRP 716, along with ratios of productions to unbalanced attractions. In addition, the Appendix includes some trip distribution metrics and figures such as percentage of intrazonal trips, average trip length (in minutes), frequency distributions of trip lengths in minutes by trip purposes, and the trip flows at the jurisdictional and district levels. These metrics and figures indicate that the distribution results are reasonable.

Figure 11 Trip Production Rates by Trip Purposes



2.1.2 Mode Choice

The enhanced mode choice model was calibrated using the latest 2017/2018 Regional Travel Survey, which provides the latest data on observed travel behaviors related to mode choice and in particularly TNC travel behavior in the region. Transit modal shares by trip purposes in the whole region, as shown in Figure 12, demonstrate a close match between the estimated and observed, with the HBW having the highest transit share. As displayed in Figure 13, TNC modal shares are less than 2% in the whole region, with NHW showing the highest share. The estimated shares are reasonably close to the observed shares. The estimated auto modal shares by trip purposes, as illustrated in Figure 14, show close matches with the observed. The Appendix section includes detailed tabulations of modal shares, auto occupancy rates by trip purposes, and mode choice coefficients. Mode choice coefficients and constants were checked against the relevant guidelines for reasonableness. In general, mode choice coefficients reflect appropriate relationships between in-vehicle time and out-of-vehicle time and values of time by four income groups. Constants are mostly in a reasonable range, with a few exceptions.

Figure 12 Transit Modal Shares by Trip Purposes

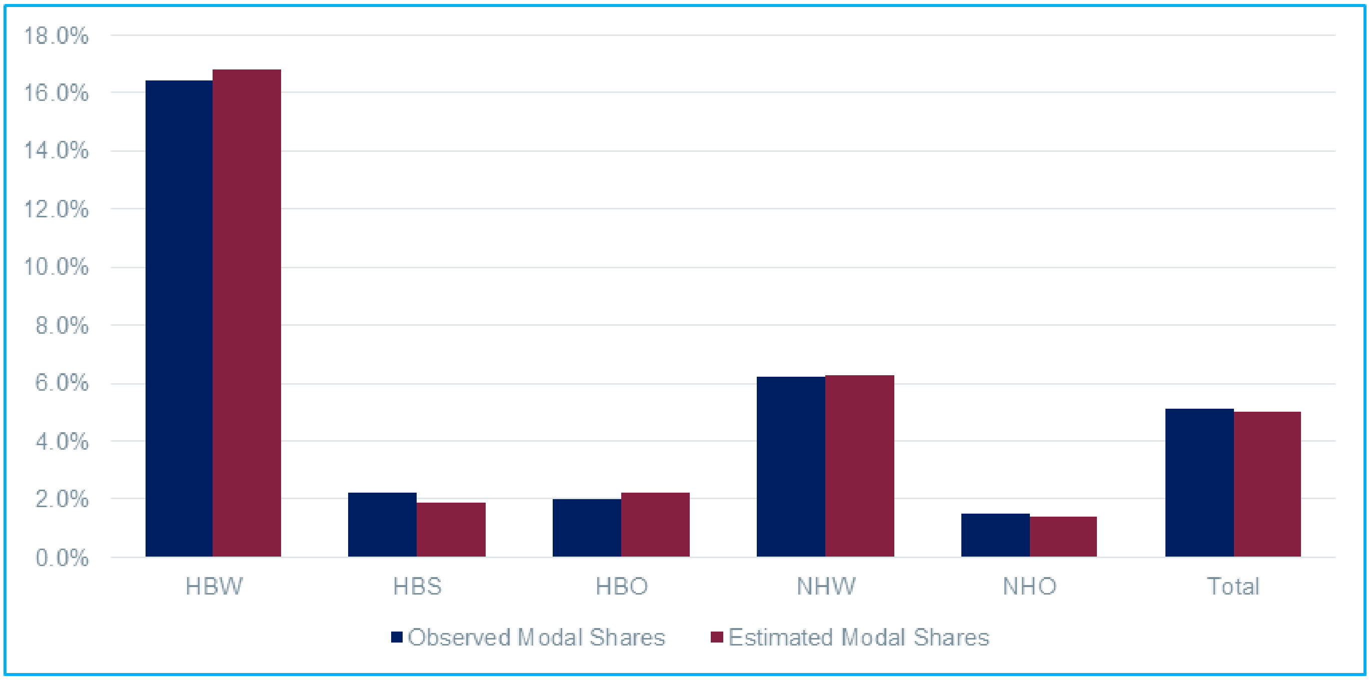


Figure 13 TNC Modal Shares by Trip Purposes

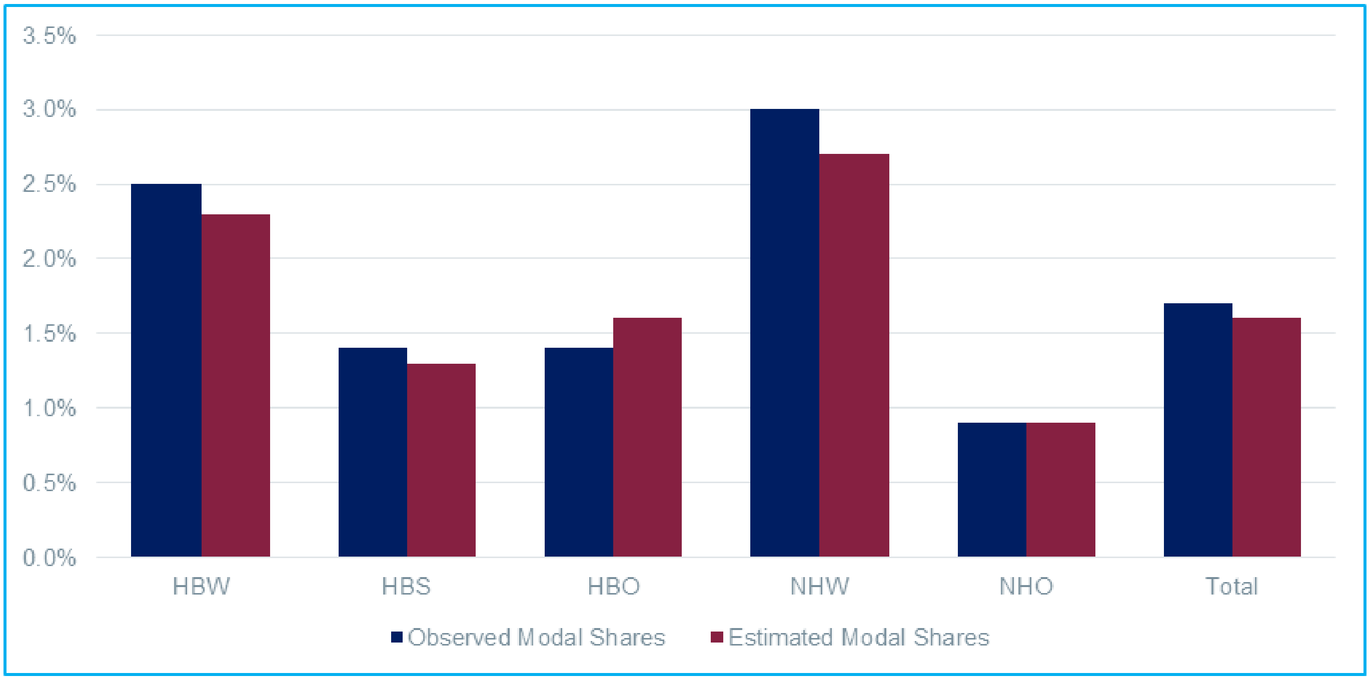
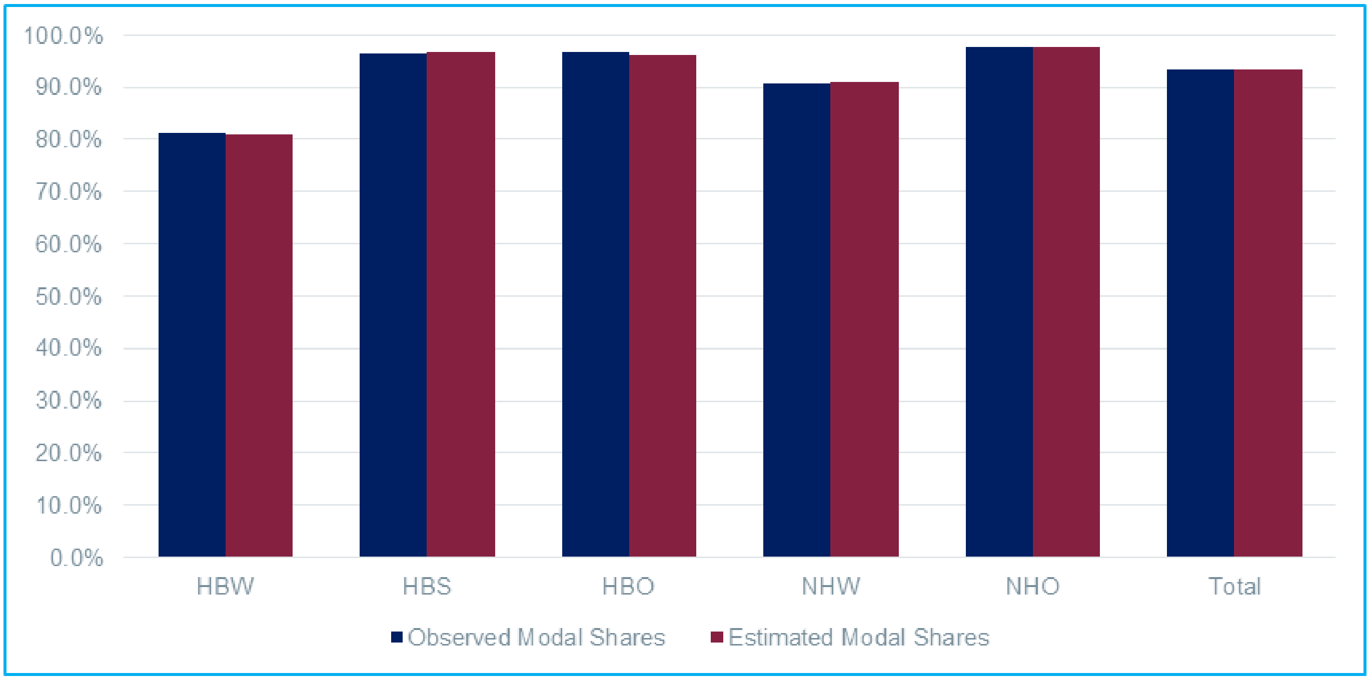


Figure 14 Auto Modal Shares by Trip Purposes



The modal shares were also summarized by sub-regions, including DC, urban areas in Maryland (MD Urban) and Virginia (VA Urban), suburban areas in Maryland (MD Suburban) and in Virginia (VA Suburban). Figure 15 displays the comparison of estimated vs observed HBW transit shares by sub-regions; as expected, DC has the highest HBW transit shares, followed by urban areas and then suburban areas. The estimated HBW transit shares replicated the observed transit shares for each of the sub-regions. For TNC usage for HBW trips (Figure 16), the estimated modal shares by sub-regions are reasonably consistent with the observed modal shares, including those in Virginia. HBW auto modal shares by sub-region are also matched well between the estimated and observed data (Figure 17).

Figure 15 HBW Transit Modal Shares by Sub-Regions

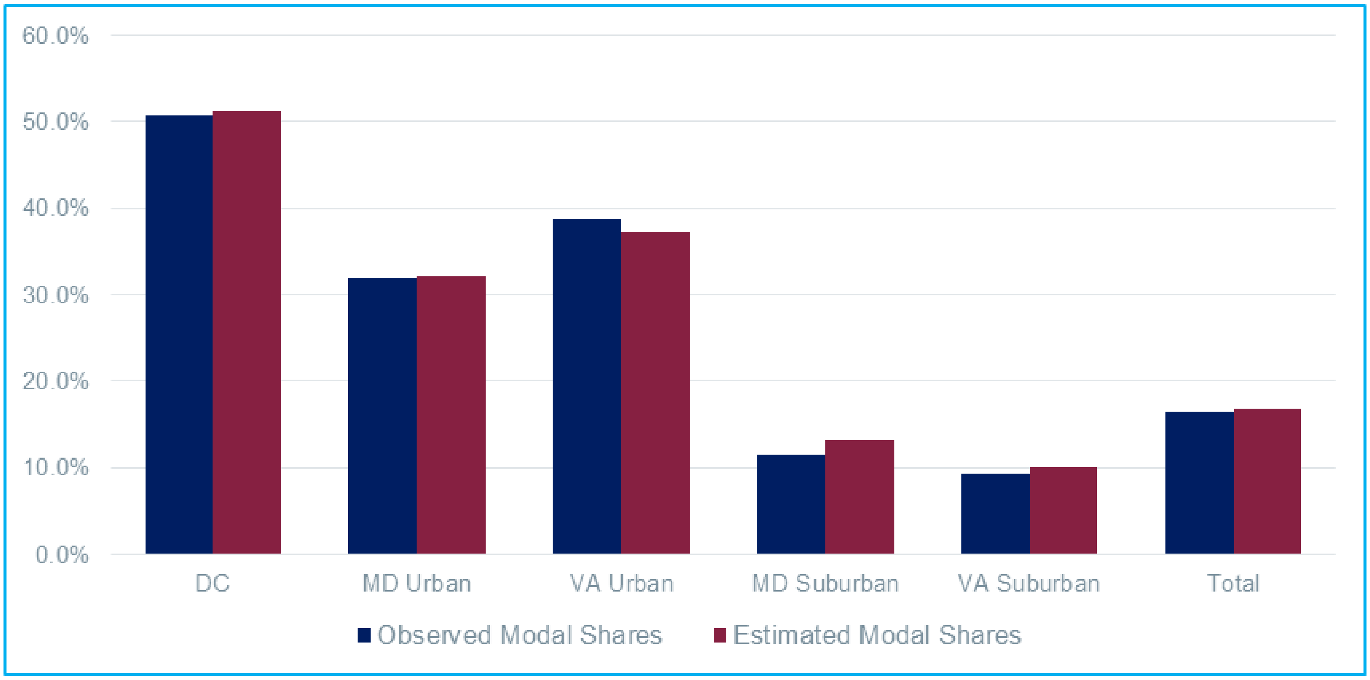


Figure 16 HBW TNC Modal Shares by Sub-Regions

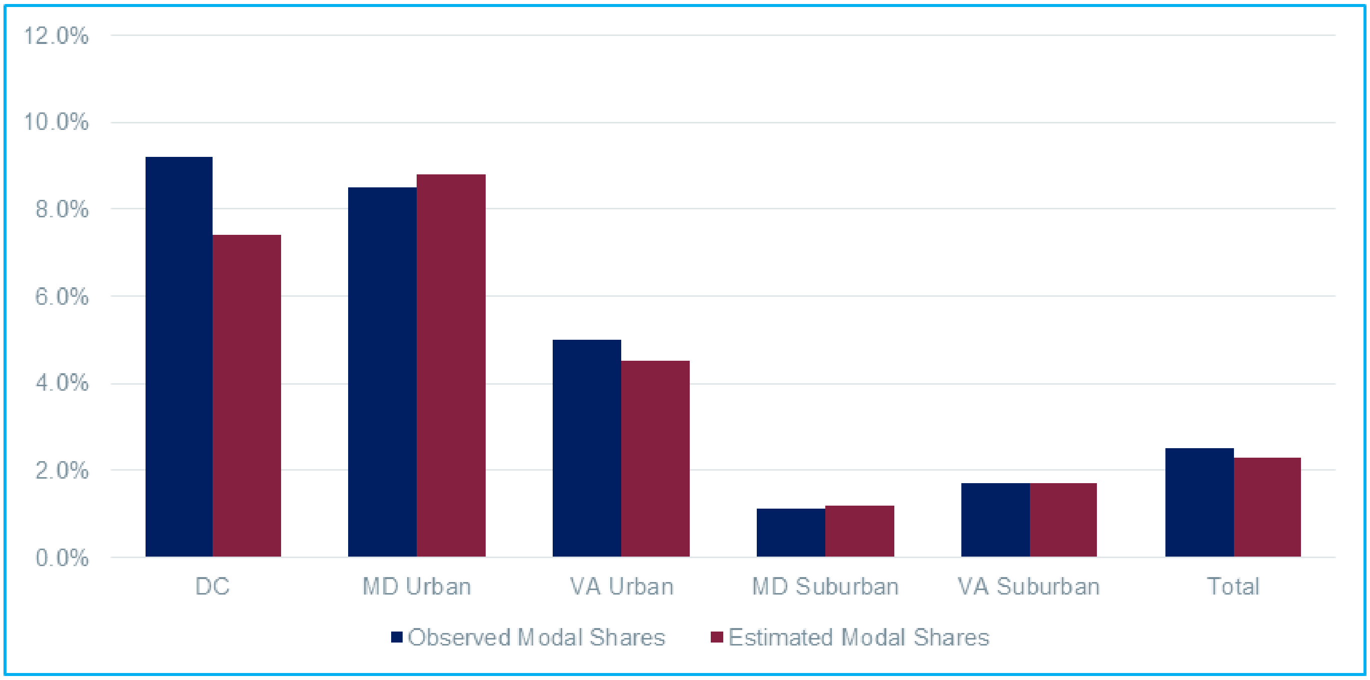
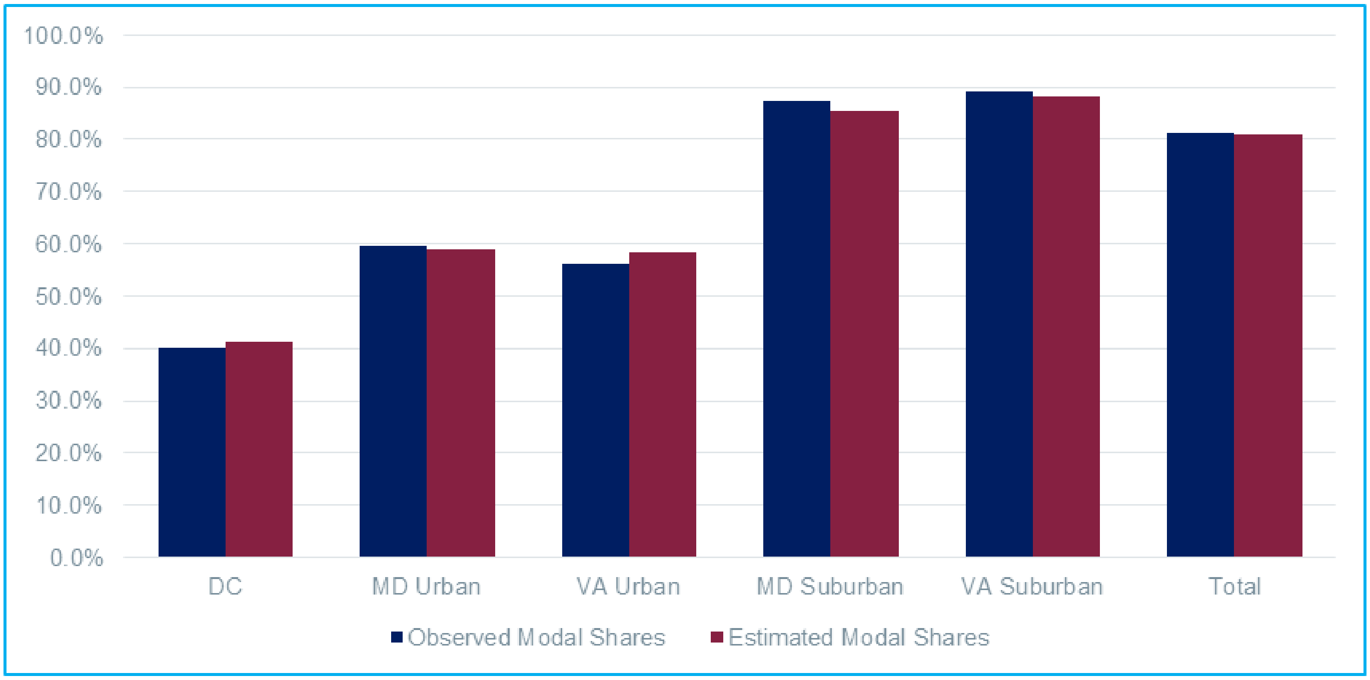


Figure 17 HBW Auto Modal Shares by Sub-Regions

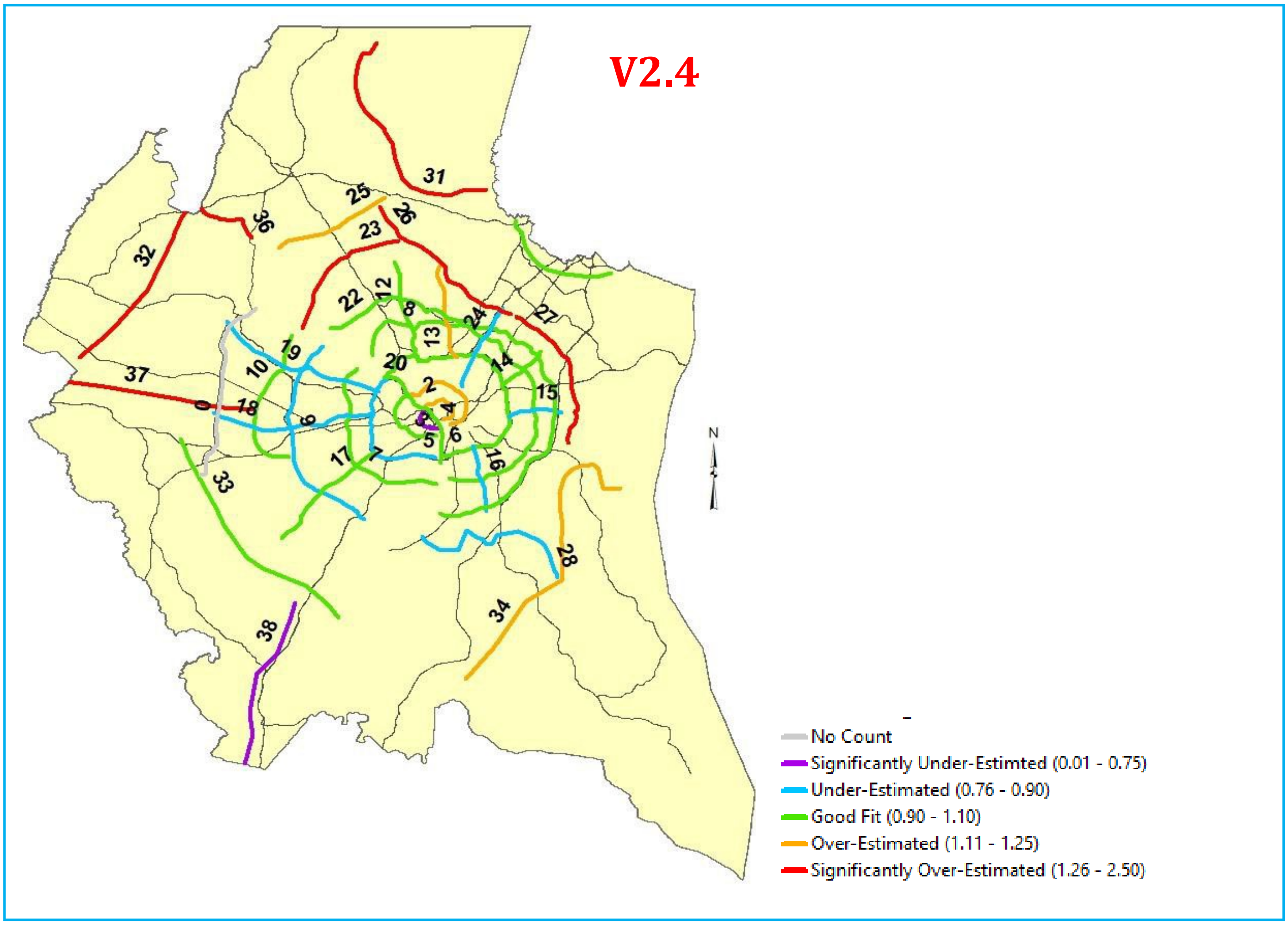


2.1.3 Traffic Assignment

COG/TPB has defined 35 screenlines and cutlines for use in traffic assignment validation. The validation results from the COG/TPB Version 2.4 were classified into five categories based on the degree of deviations from the observed counts (Figure 18). Out of the 35 screenlines and cutlines, the NVTA model performance improved validation to a better category for seven screenlines and cutlines, validation performance was made worse at four locations, while the remainder stayed within the same category. Notably, the improved screenline and cutlines include the Potomac River (-4% vs -10% in Version 2.4), central Fairfax County, and west Fairfax County. The patterns are the same, with the best validation in the central areas of the model domain and the worst validation in the buffer areas outside the TPB planning area.

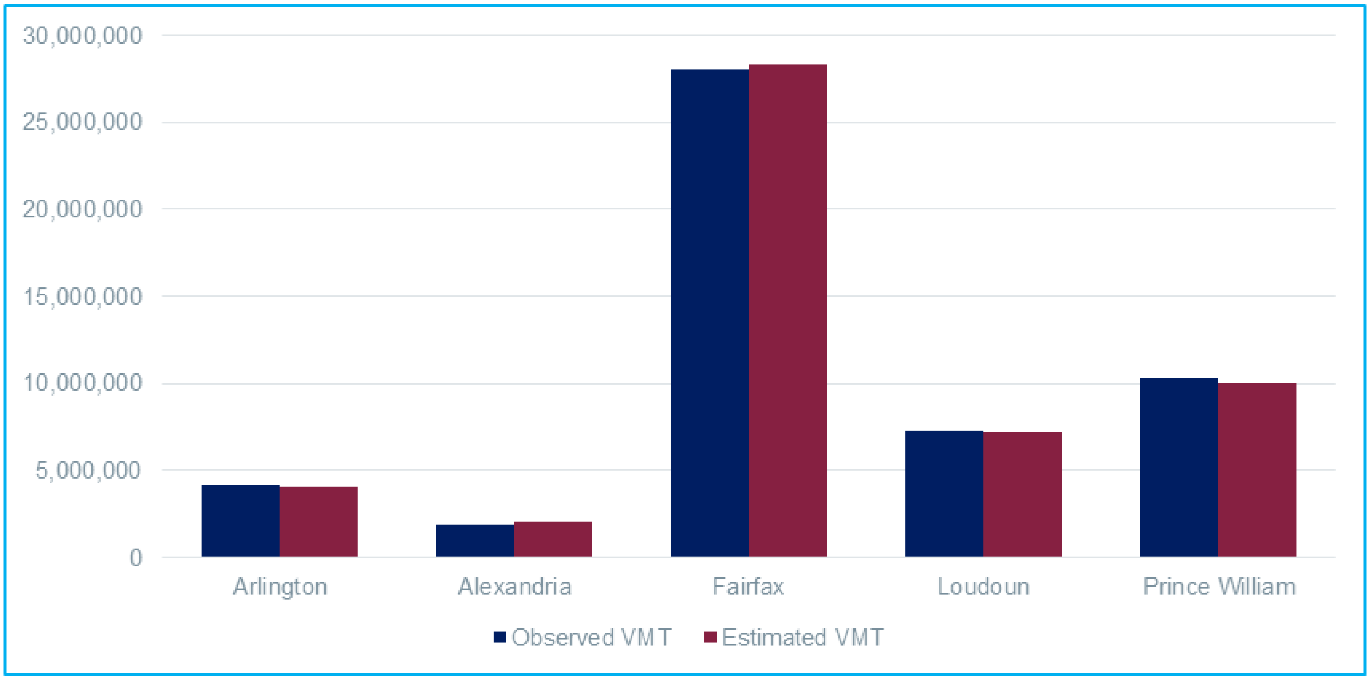
The HPMS VMT by jurisdiction, which were compiled for the regional model domain by the COG/TPB, were used for validation against the model estimates of VMT by jurisdiction, especially those in Northern Virginia. For the NVTA region as a whole, the NVTA model estimates VMT within 0.1 percent of the observed total. By way of comparison, the COG/TPB Version 2.4 underestimates VMT in Northern Virginia by 0.6 percent. At the jurisdictional level for Northern Virginia (Figure 19), relative deviations in estimating VMT are all relatively small, and all except Alexandria are within 3 percent of observed VMT. For the TPB planning area as a whole, the NVTA model estimated VMT is 2.6 percent lower than observed, while the COG/TPB version 2.4 model underestimates total VMT by three percent.

Figure 18 COG/TPB Screenline/Cutline Definition



Source: COG/TPB, 2020. Year-2014 Validation of TPB Version 2.4 Travel Model.

Figure 19 VMT by Jurisdictions



2.1.4 Transit Assignment

Transit assignment validation compares observed daily boardings by transit submodes with the model estimates. For the model domain (Figure 20), the estimated daily boardings closely match with the observed, with all submodes having a deviation of 5% or less, except for MARC. For Northern Virginia (Figure 21), the estimated daily boardings are reasonably close to the observed, with a deviation of 7.1% in total and some overestimation for bus boardings. In addition, estimated and observed boardings by station and station groups are tabulated in the Appendix.

2.1.5 Sensitivity Tests

A sensitivity test was conducted for the base year, using a factor of 1.5 for trip rates of households in the modeling domain. The model results show an increase of VMT by 27% in the NVTA region.

- Miscellaneous trips were not factored and remained the same as before as they were not estimated as part of the model and were provided as fixed inputs for each year, including commercial vehicle trips, truck trips, school trips, visitor/tourist trips, and airport trips.

- Congestion delays would increase dramatically, now three times the original values. These dramatic increases in travel time would change the travel patterns, mode choices, and route choices significantly, damping the VMT increase. Transit trips would increase by nearly 60%, reflecting a shifting to transit from auto trips.

- Typically in a congested area, VMT would increase in a lower rate than the demand increase.

Given these considerations, it appears that the model behaved reasonably well in response to the increase in trip rate increases.

Figure 10 Daily Boardings by Modes in the Model Domain

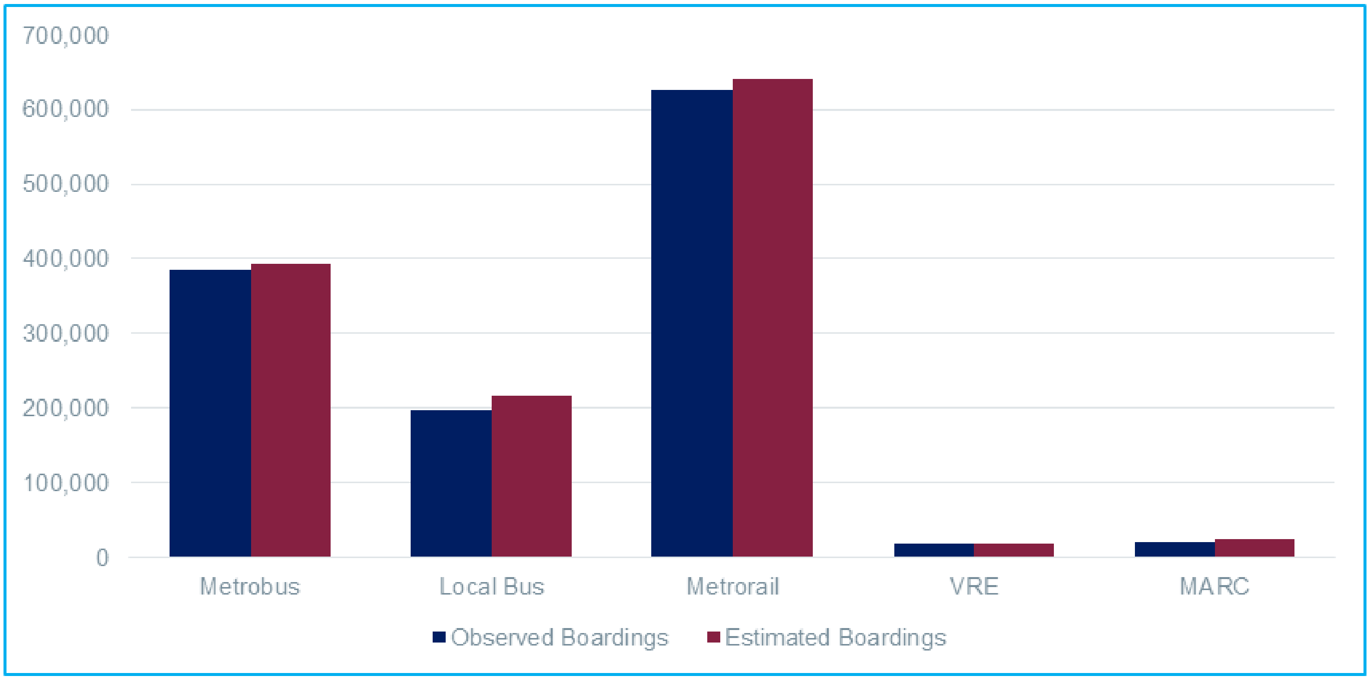
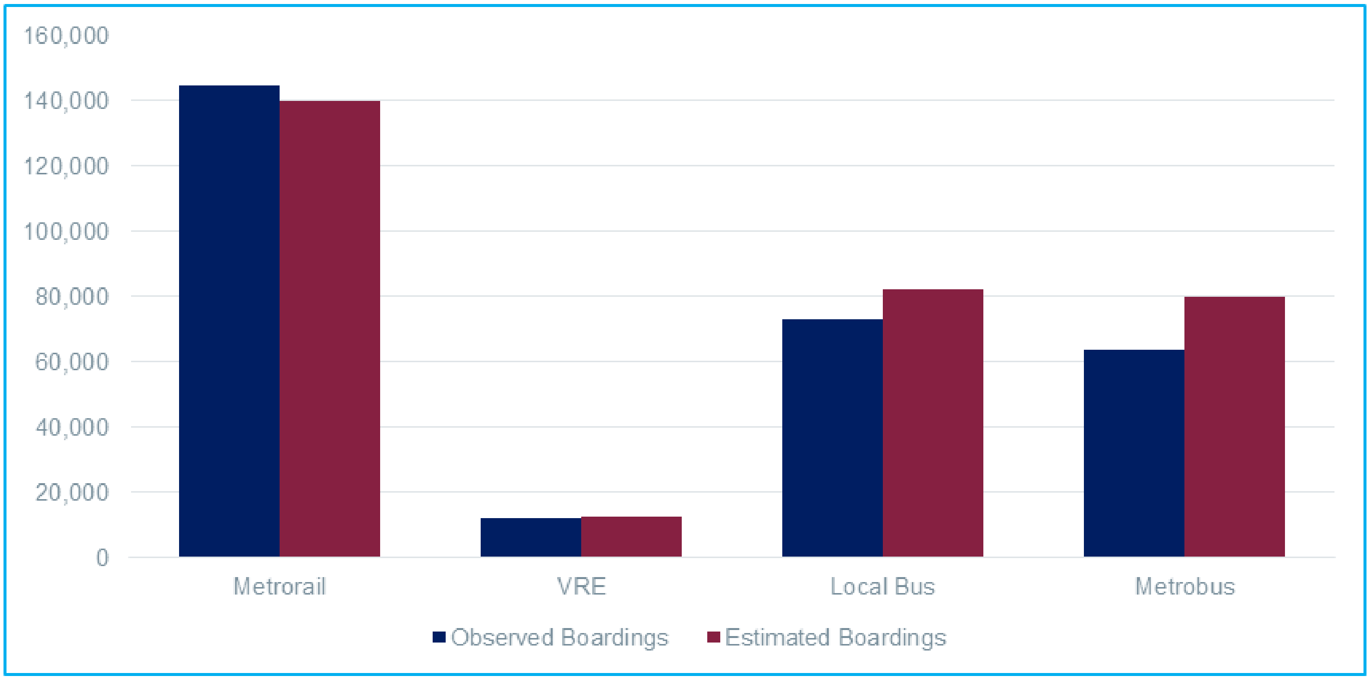


Figure 11 Daily Boardings by Modes in Northern Virginia



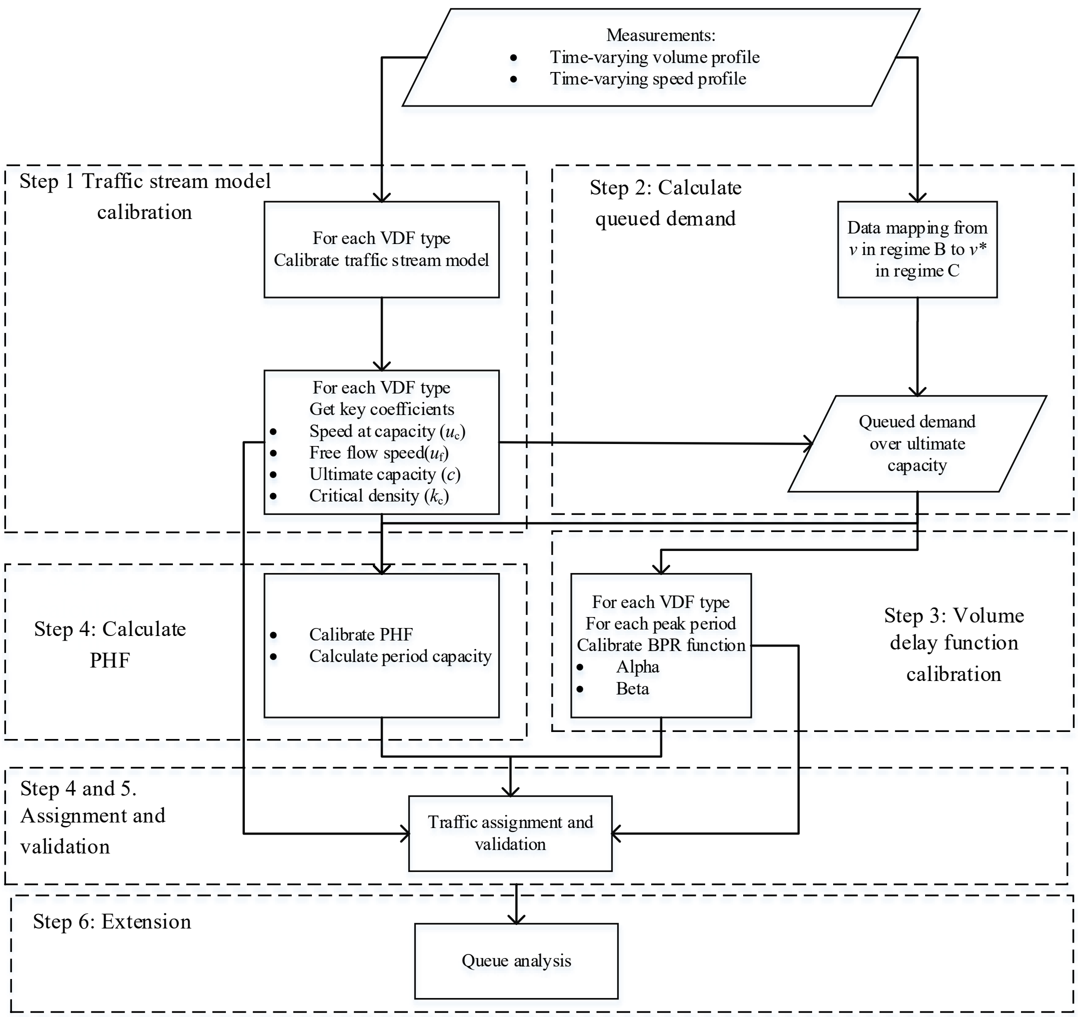
2.2 Mesoscopic Model Calibration and Validation

Calibration and validation procedures for the mesoscopic model uses a process developed for time-dependent volume-delay functions for highly congested bottlenecks. The open-source procedure is able to help automate the following calibration tasks:

- Traffic stream model calibration for free-flow speed, ultimate capacity, and critical density.
- Volume delay function calibration.
- Hour-to-period conversion.

The procedure was extended from that currently used in the Phoenix metropolitan area as shown in Figure 22.

Figure 12 Mesoscopic Model Calibration Procedure



Source: Xu et al. (2021). Characterization and calibration of volume-to-capacity ratio in volume-delay functions on freeways based on a queue analysis approach. TRB 2021 Annual Meeting.

The calibration process includes the following steps:

1. Traffic stream model calibration: For each VDF type, calibrate the coefficients of the traffic stream model, including free-flow speed, ultimate capacity, and speed at capacity.
2. Calculate queued demand: for each link, calculate the queued demand during the congestion duration.
3. Volume Delay Function (VDF) calibration: For different peak periods and VDF types, calibrate the coefficients (e.g., α and β in the BPR function) in the VDFs.
4. Peak hour factor: Calibrate the peak period factors (PHF) and period capacity.
5. Traffic assignment: Given the peak period OD matrix, perform traffic assignment based on the calibrated period capacity, α, and β to obtain link volumes and path flows.
6. Assignment validation: Compare the assigned link flows with the observed link volume based on calibrated VDF and traffic steam model.
7. Time-dependent Queue: Extend the static link volumes to time-dependent queue length.

2.2.1 Speed/Travel Time Data

The DTA model calibration and validation leveraged ‘big data’ sources, such as those available in RITIS, to identify the locations and extents of recurring congestion at a high level of spatial and temporal detail. The recurring congestion can then be used to validate the DTA portion of the model on key corridors in Northern Virginia. The 11 priority corridors in Northern Virginia are shown in Figure 23 and were further segmented into priority corridor segments for validation purposes.

Traffic message channel (TMC) locations from RITIS, as shown in Figure 24, were matched to the transportation networks in DTALite for these priority corridors, with special attention to the distinctions between HOV/HOT and general purpose (GP) lane locations. Figure 25 demonstrates an example of TMC locations matched to the network links along I-395, while Figure 26 illustrates the distinctions of HOV vs GP locations along the same roadway. Additional checking of results was conducted visually and using the TMC distance in comparison with the network distances.

Figure 13 NVTA Priority Corridors

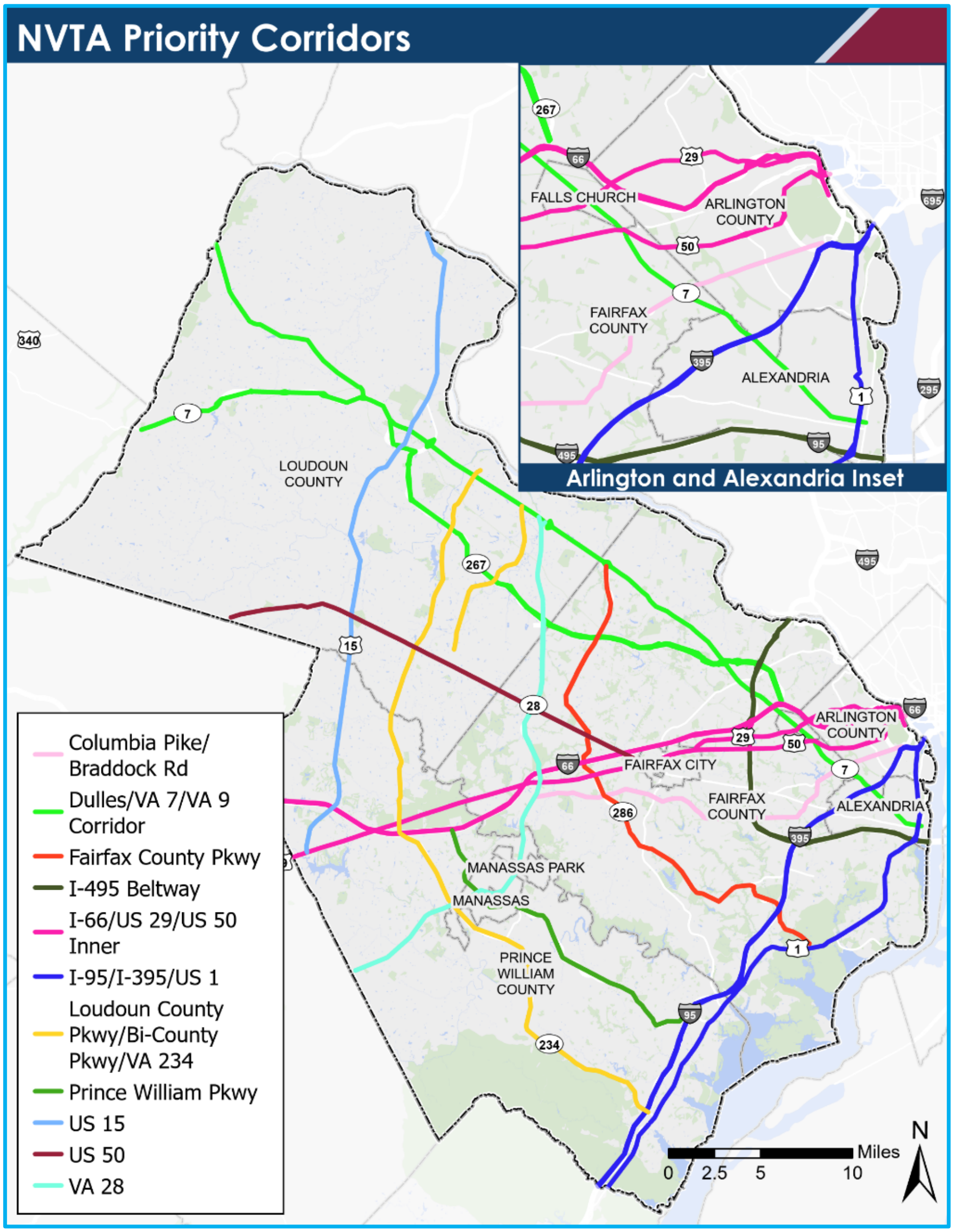


Figure 14 RITIS TMC Locations along Priority Corridors

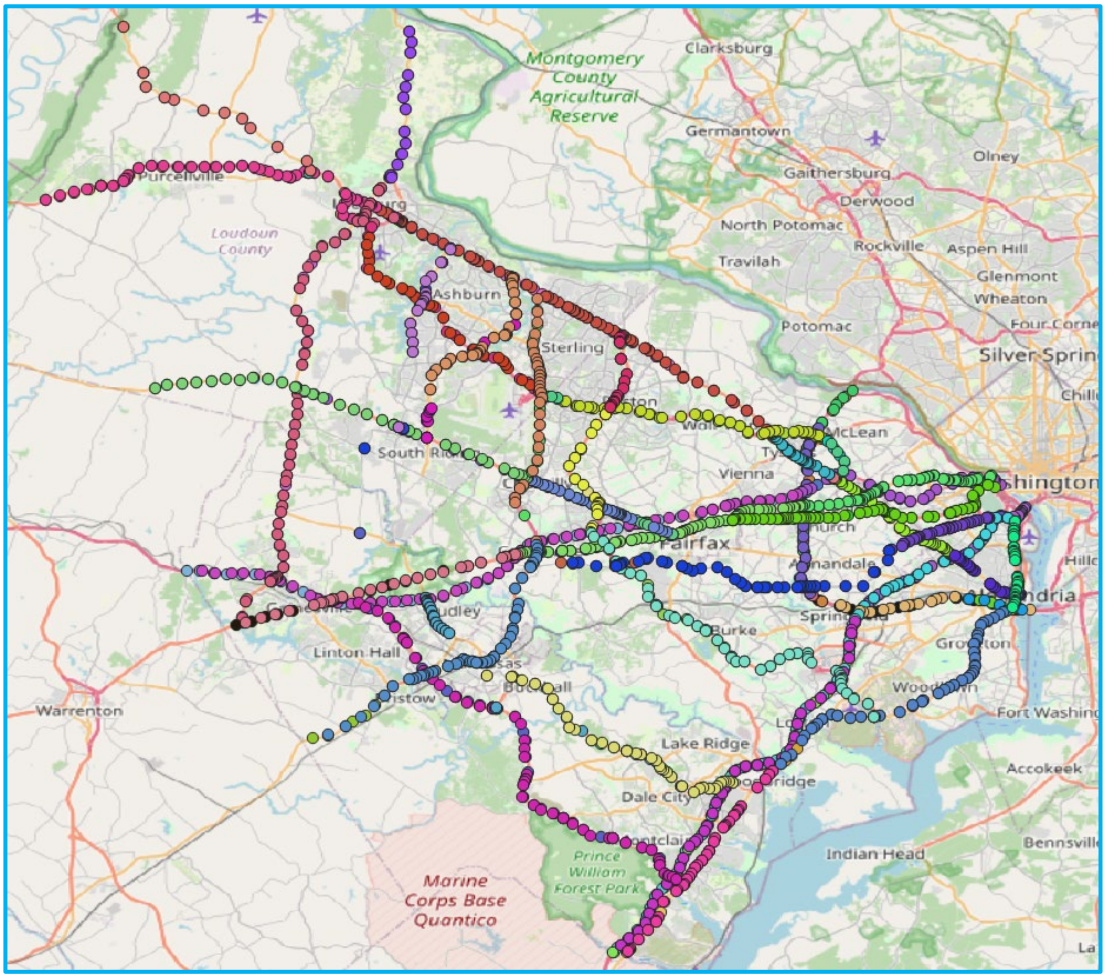


Figure 15 RITIS TMC Location Matching to the Network: An Example of I-395

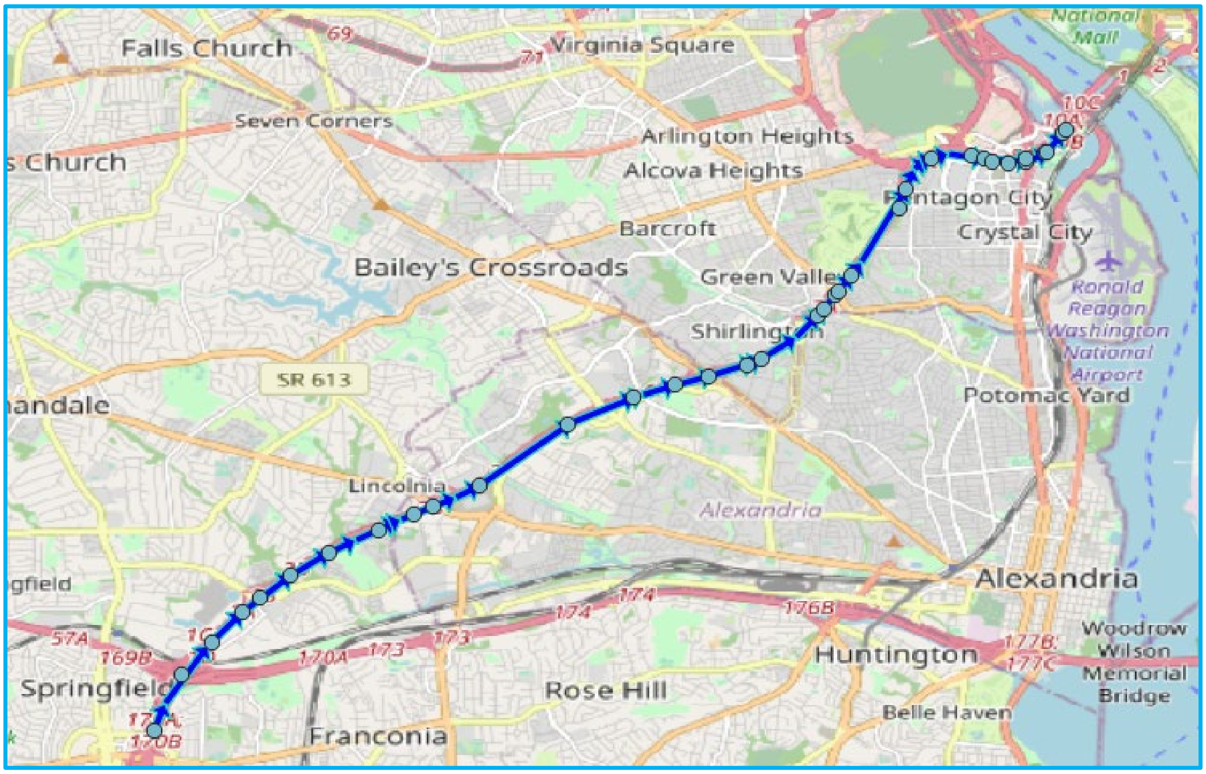
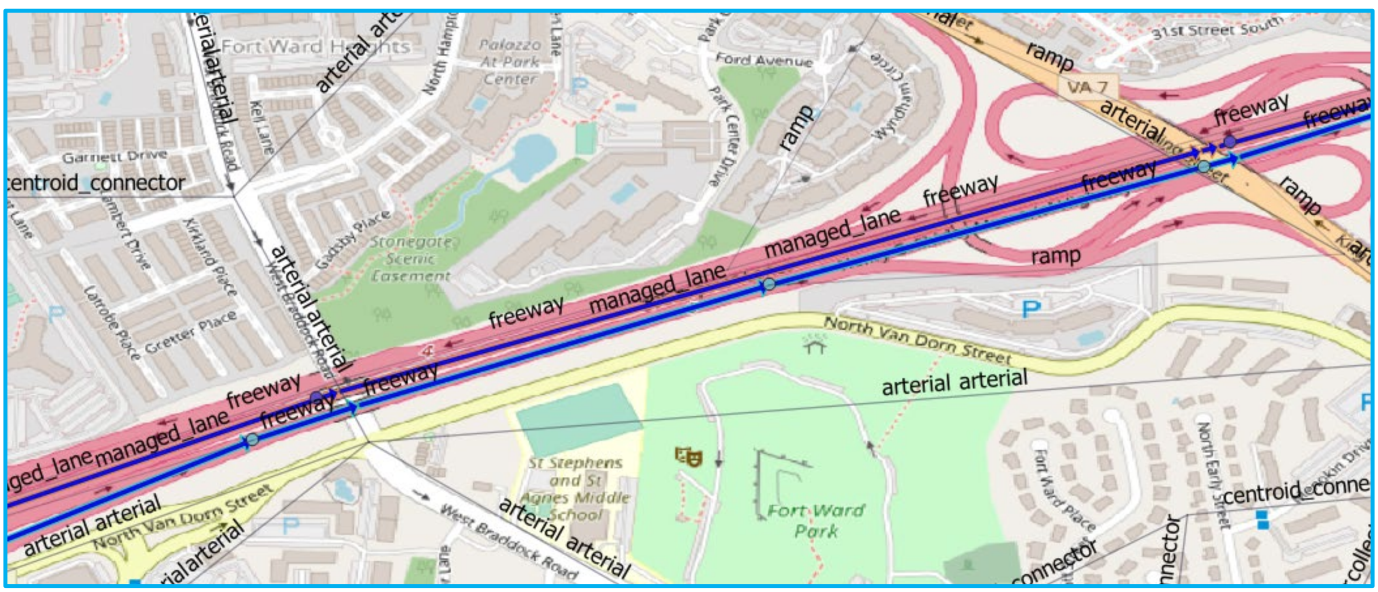


Figure 16 RITIS TMC Location Matching to the Network: HOV and GP Lane on I-395



2.2.2 Identification of Congestion

The congestion identification was conducted for priority corridor segments, using the Congestion and Bottleneck Identification (CBI) Software Tool sponsored by FHWA. For priority corridor segments by direction, the following measures were computed and summarized for AM and PM peak periods:

- Average speed
- Average congestion duration
- Minimum and maximum speeds
- Maximum congestion duration
- Distance-weighted speed
- Distance-weighted congestion duration

Link speeds were weighted by link distances to generate distance-weighted average link speeds for priority corridor segments, as shown in Figures 27 and 28. Distance-weighted average speeds demonstrate a clear contrast between inbound and outbound directions for some corridor segments, typically lower speeds for inbound in the morning and outbound in the evening. The difference by direction is smaller for arterials and managed lane segments.

Link congestion durations were weighted by link distances to generate distance-weighted average congestion durations for priority corridor segments, as shown in Figures 29 and 30. Distance-weighted average congestion durations show a clear contrast between inbound and outbound directions, displaying severe congestion for some major freeway corridor segments such as PM outbound for the I-395 general purpose lanes, I-495 general purpose lanes, and I-66. Among arterial corridor segments, Route 7 corridor segments in the Tysons area and north, show the longest congestion duration in the evening. Overall, PM congestion durations tend to be longer than the AM congestion durations.

Similar charts are included in Appendix for average speed, average congestion duration, minimum speeds, and maximum congestion duration.

Figure 17 Distance-Weighted Link Speed for Priority Corridor Segments: Freeways

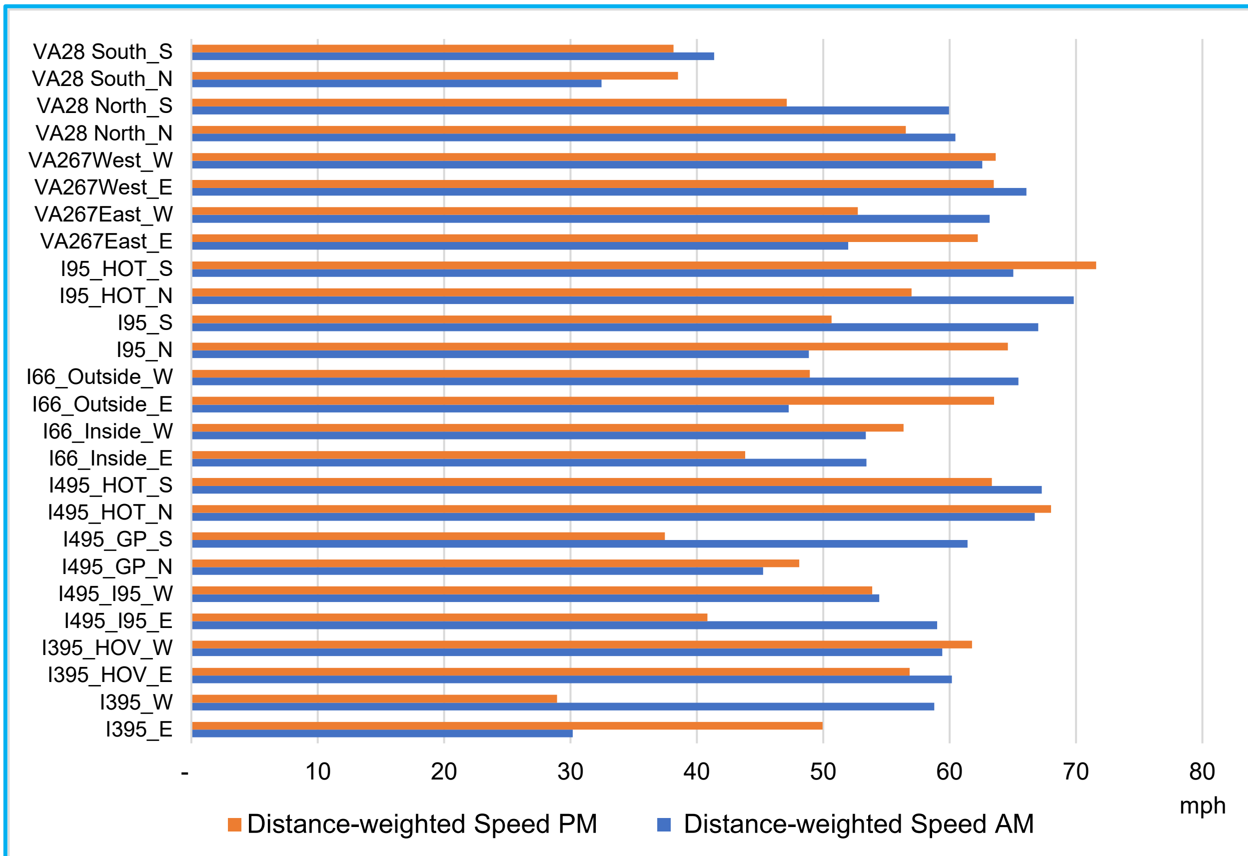


Figure 18 Distance-Weighted Link Speed for Priority Corridor Segments: Arterials

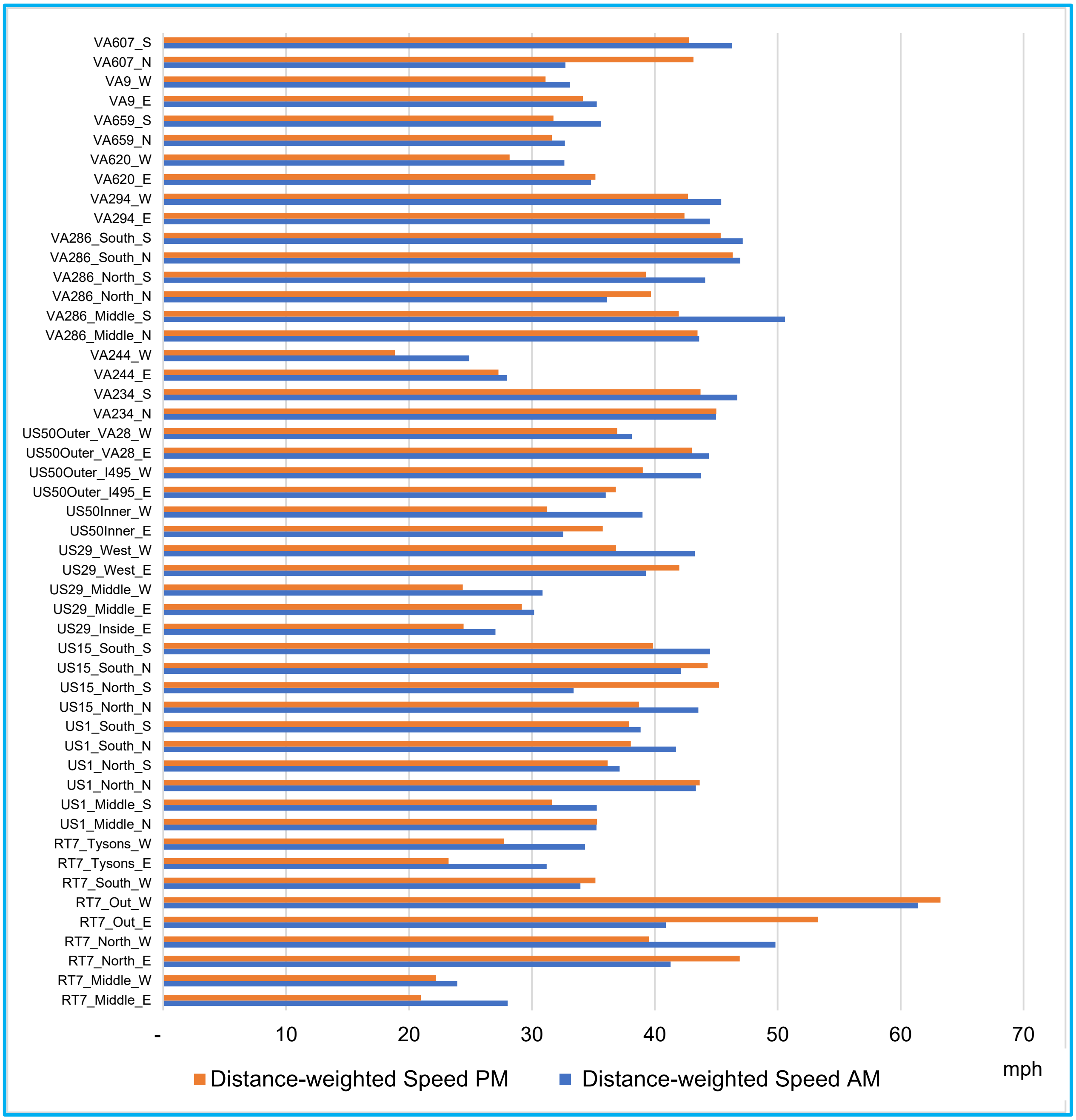


Figure 19 Distance-Weighted Link Congestion Duration for Priority Corridor Segments: Freeways

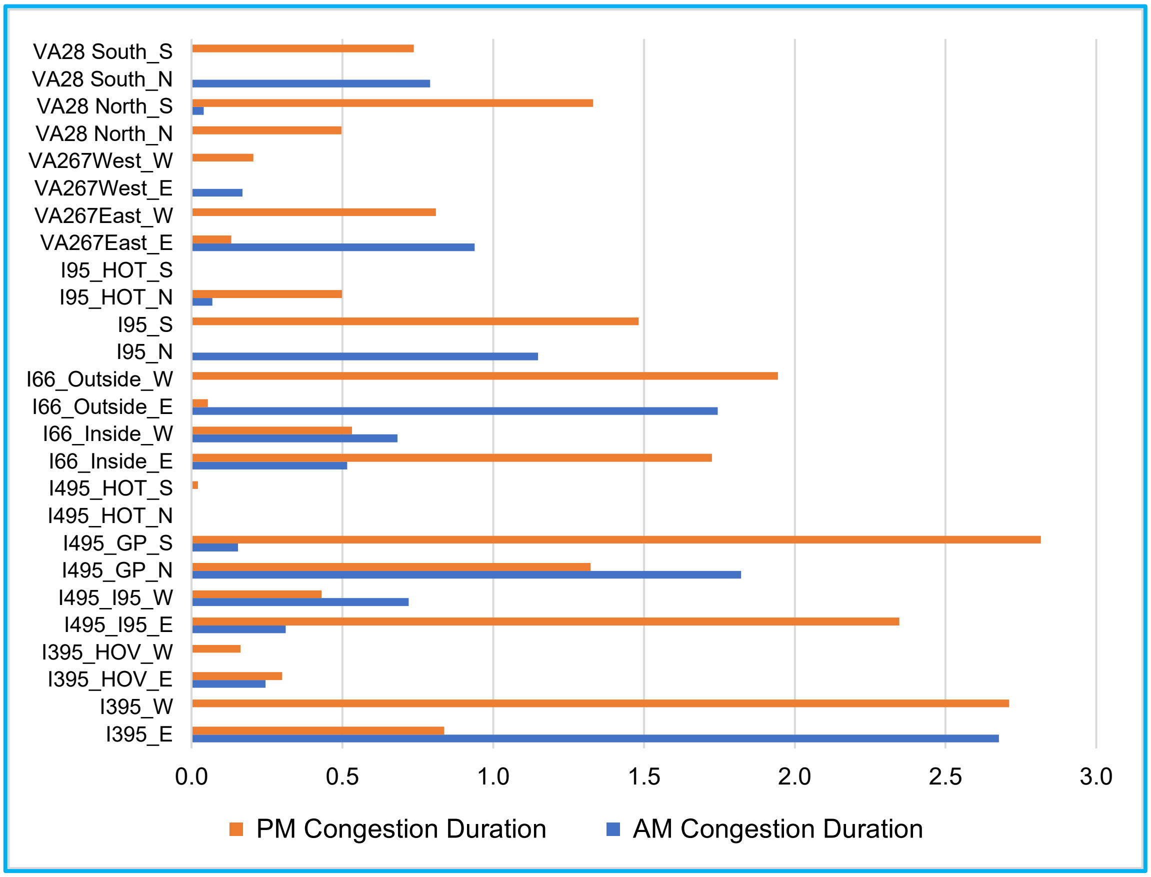
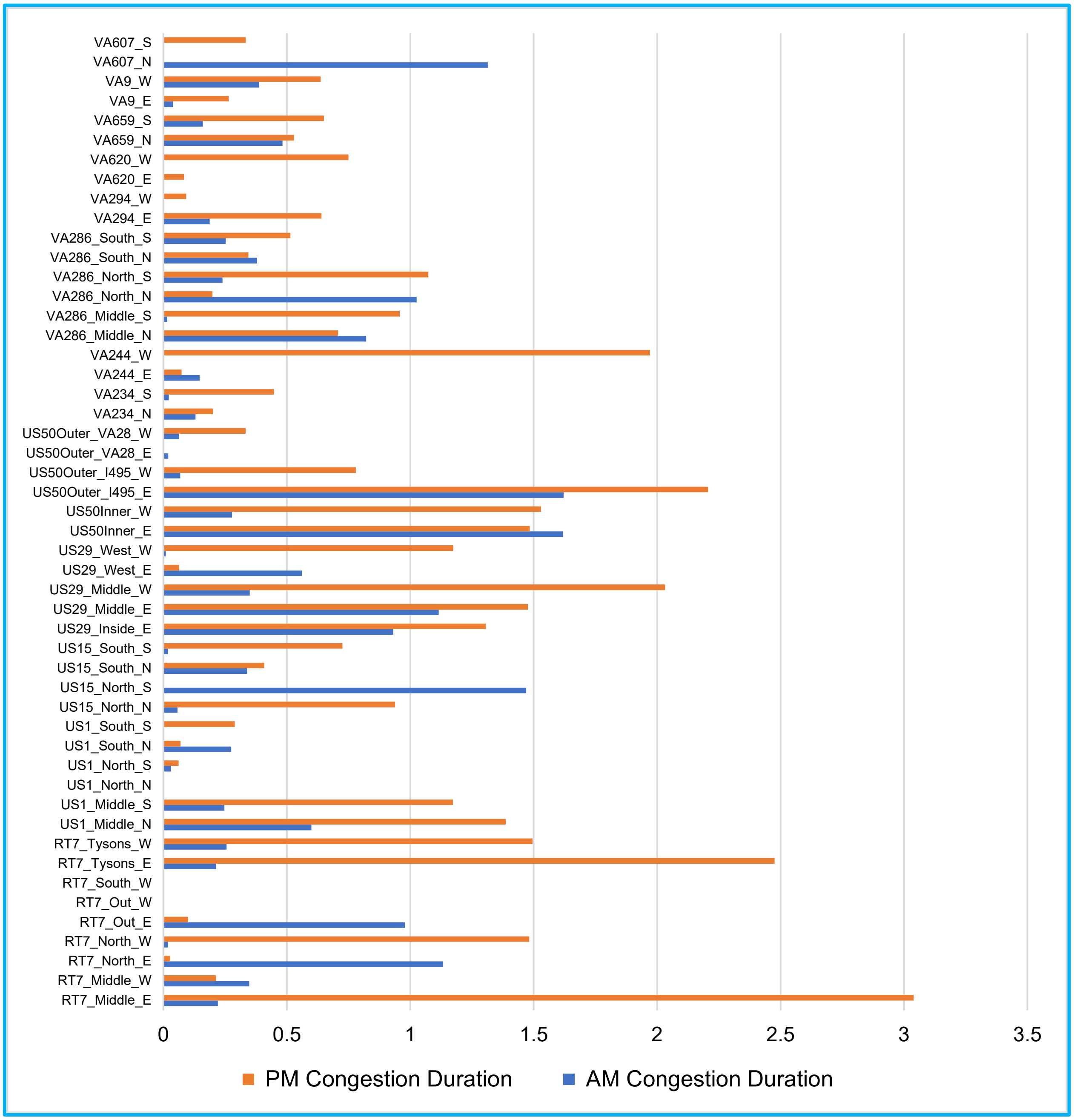


Figure 20 Distance-Weighted Link Congestion Duration for Priority Corridor Segments: Arterials



2.2.3 Corridor Congestion State Estimation

The congestion estimation was conducted for priority corridor segments, using the DTALite model. For priority corridor segments by direction, the following measures were computed and summarized for AM and PM peak periods:

- VMT-weighted speed

- VMT-weighted congestion duration

Link speeds for priority corridor segments were weighted by VMT to derive an VMT-weighted average for each corridor segment, as shown in Figures 31 and 32. Similar to the distance-weighted speeds in the previous section, the DTALite estimates of VMT-weighted speeds display clear patterns of contrast between peak direction and non-peak direction for some corridor segments. Typically, inbound AM directions and outbound PM directions have lower speeds than non-peak directions, such as AM inbound for I-395, I-95, and I-66 general purpose lanes.

Figure 21 VMT-weighted Link Speed for Priority Corridor Segments: Freeways

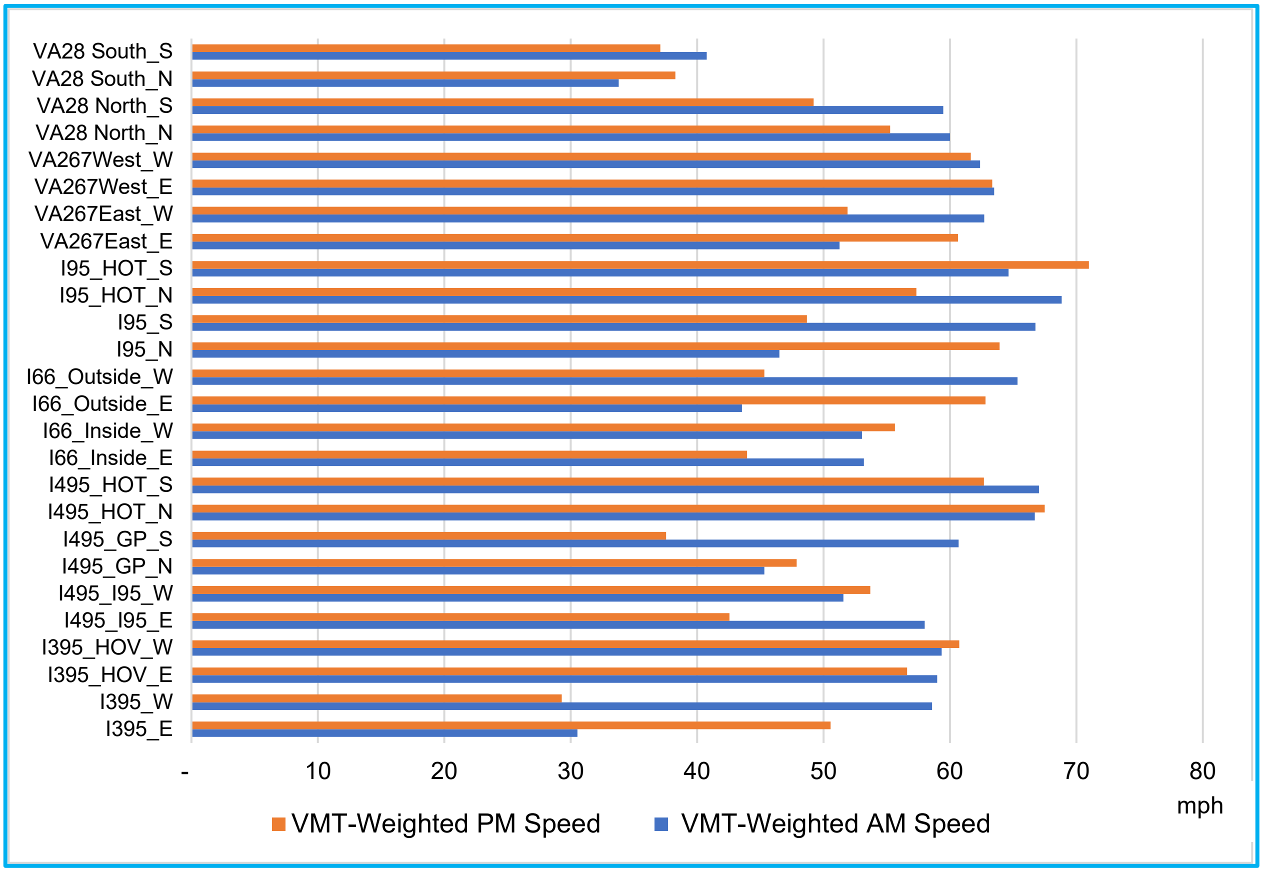
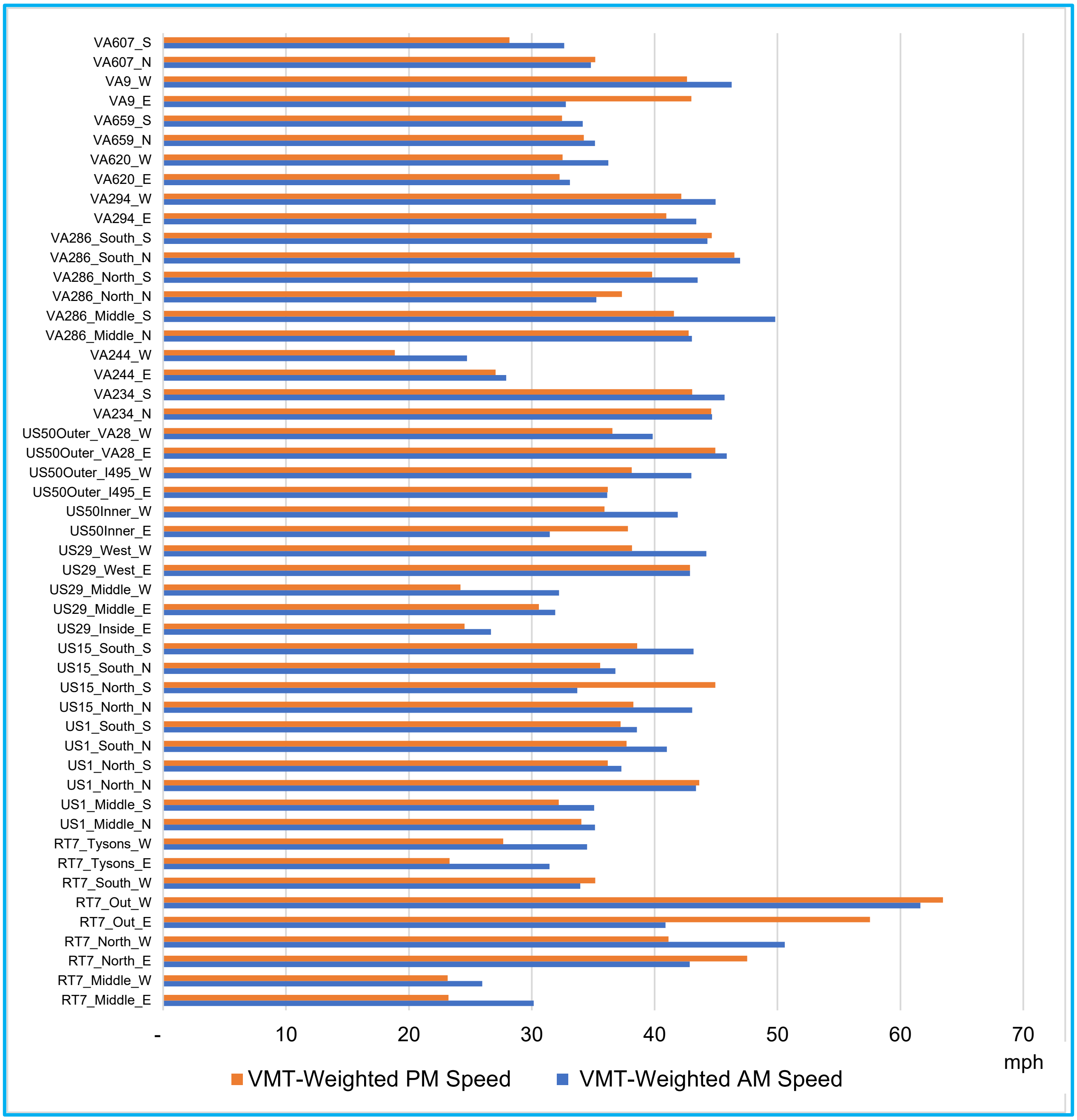


Figure 22 VMT-weighted Link Speed for Priority Corridor Segments: Arterials



Link congestion durations for priority corridor segments were weighted by VMT to derive an VMT-weighted average for each corridor segment, as shown in Figures 33 and 34. The DTALite estimates of VMT-weighted congestion duration display patterns similar to those of the distance-weighted congestion durations in the previous section. Overall, inbound AM directions and outbound PM directions have longer congestion duration than non-peak directions, and PM peak-direction congestion durations are longer than those for AM peak directions.

Figure 23 VMT-weighted Congestion Duration for Priority Corridor Segments: Freeways

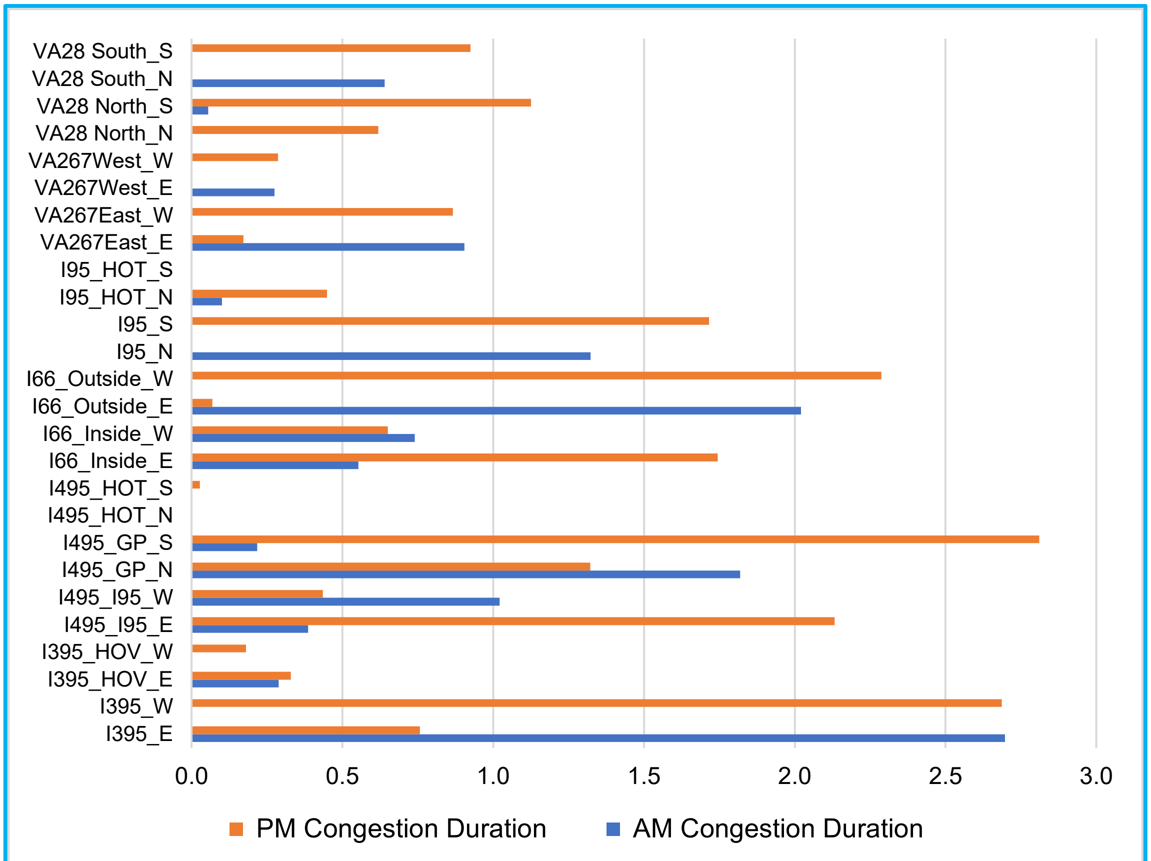
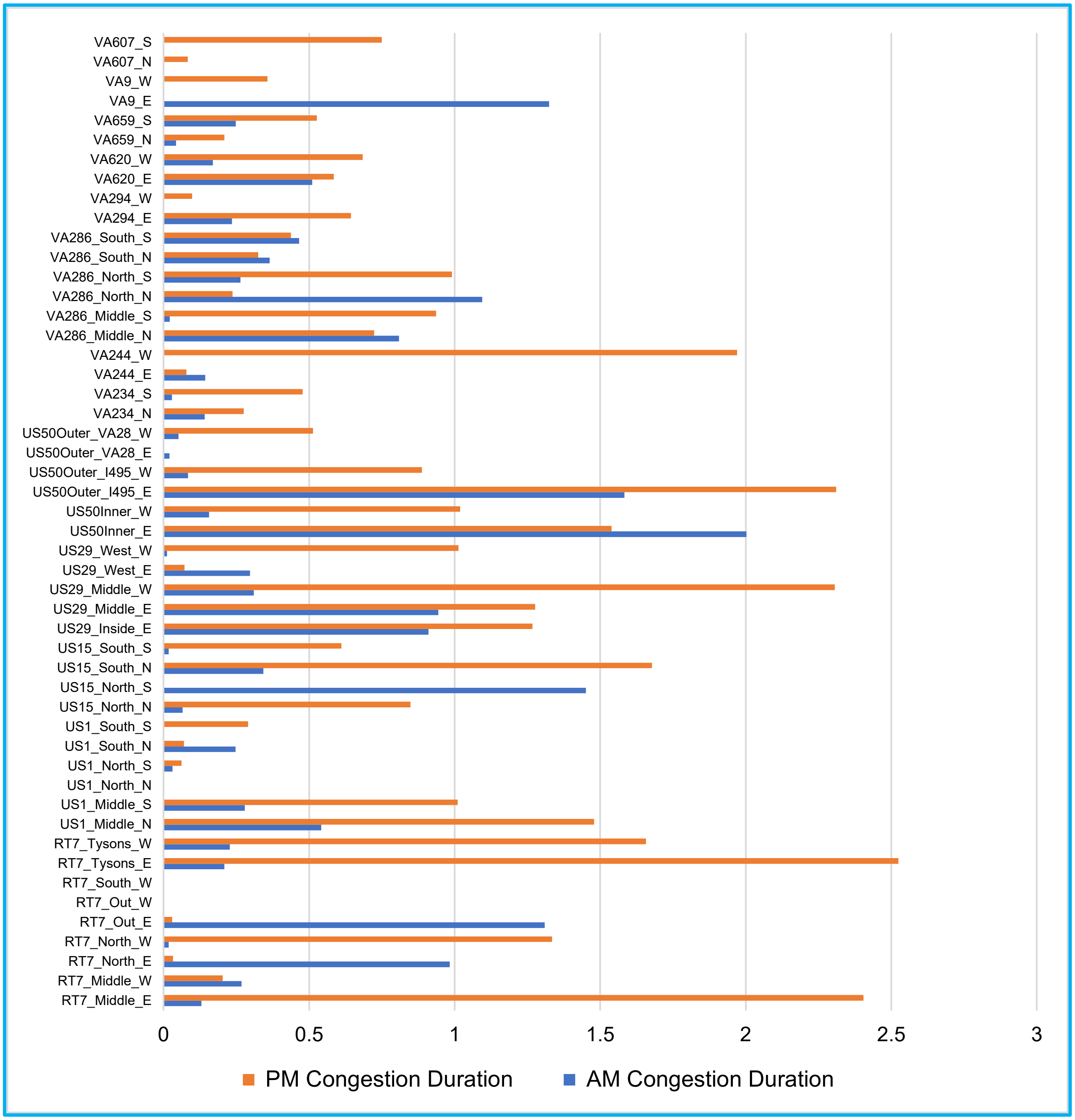


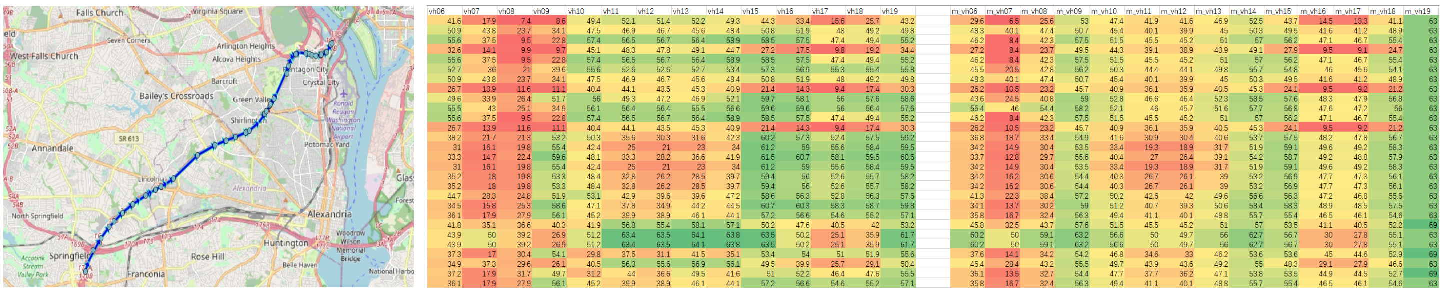
Figure 24 VMT-weighted Congestion Duration for Priority Corridor Segments: Arterials



2.2.4 Corridor Validation

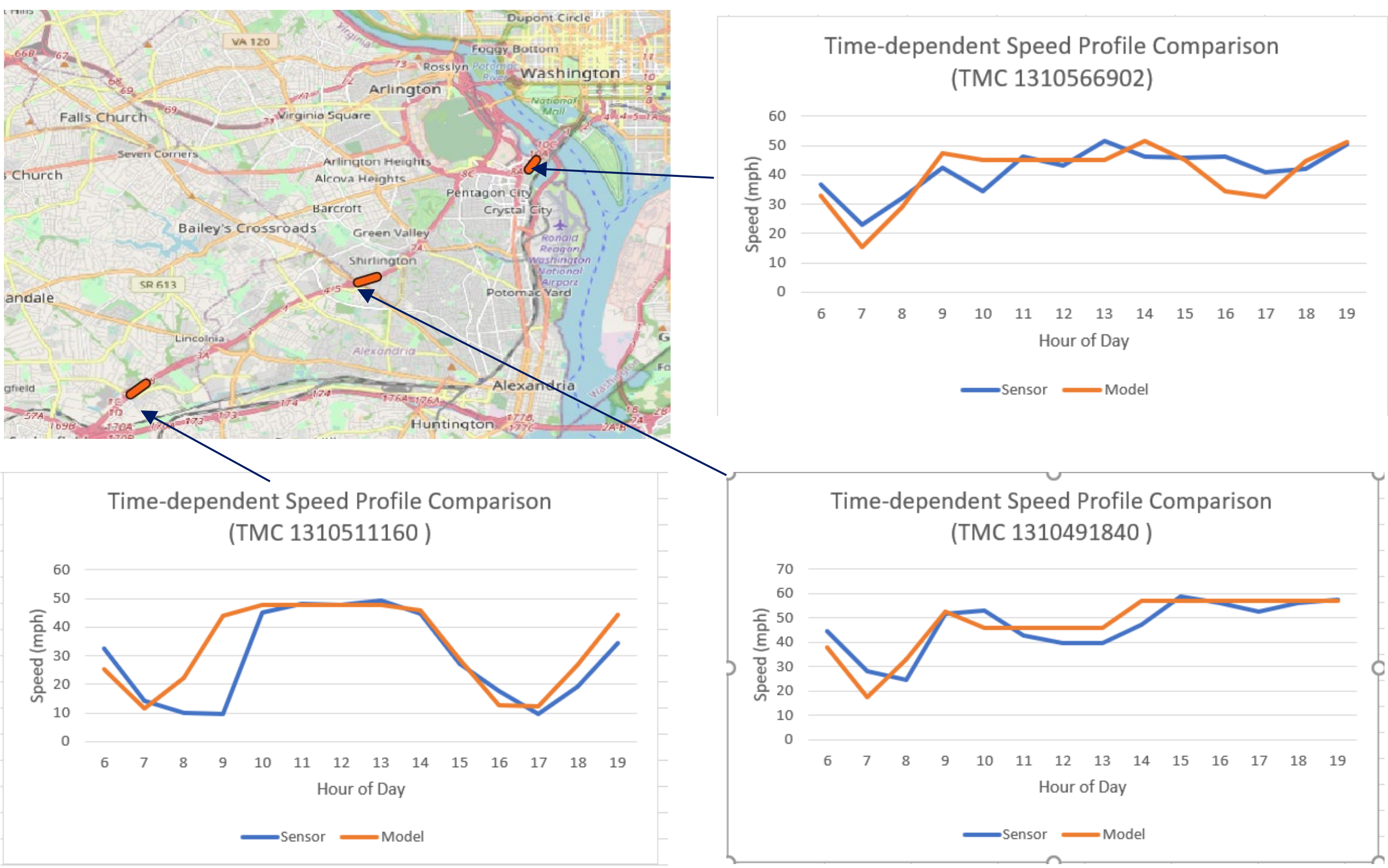
The RITIS speed data were used to compare observed conditions with the estimated speeds from the DTALite model. Figure 35 shows the speed heat maps for the northbound traffic along the I-395 corridor, with the observed speeds on the left and estimated speeds on the right. The two heat maps show similar patterns of congestion in the AM peak period. Speed heatmaps for I-95, I-495, and I-66 can be found in the Appendix.

Figure 25 Speed Heatmaps for Northbound Traffic along I-395



Speed profiles for the three select locations along I-395 were shown in Figure 36 and demonstrated the patterns of speed changes during the day. The modeled speeds generally follow the patterns of RITIS speed profiles. Speed profiles for I-95, I-495, and I-66 can be found in the Appendix.

Figure 26 Speed Profiles for Three Locations along I-395



The DTALite model estimates of speed were compared with the RITIS speed at the corridor segment level and descriptive statistics were summarized, including:

- MAE: Mean Absolute Error = |Model speed – observed speed|
- MAPE: Mean Absolute Percentage Error = |Model speed – Observed speed|/observed speed
- RMSE: Root-Mean Squared Error= [Average ((Model speed – Observed speed)^2)]^0.5

Figures 37 and 38 show MAEs and RMSEs for freeways and arterials, respectively, while Figures 39 and 40 display the MAPEs. As can be seen from the figures, most corridor segments have absolute errors smaller than 5 mph, with few exceptions. The relative errors are also reasonable overall.

Figure 27 Mean Absolute Error (MAE) and Root-Mean Squared Error (RMSE): Freeways

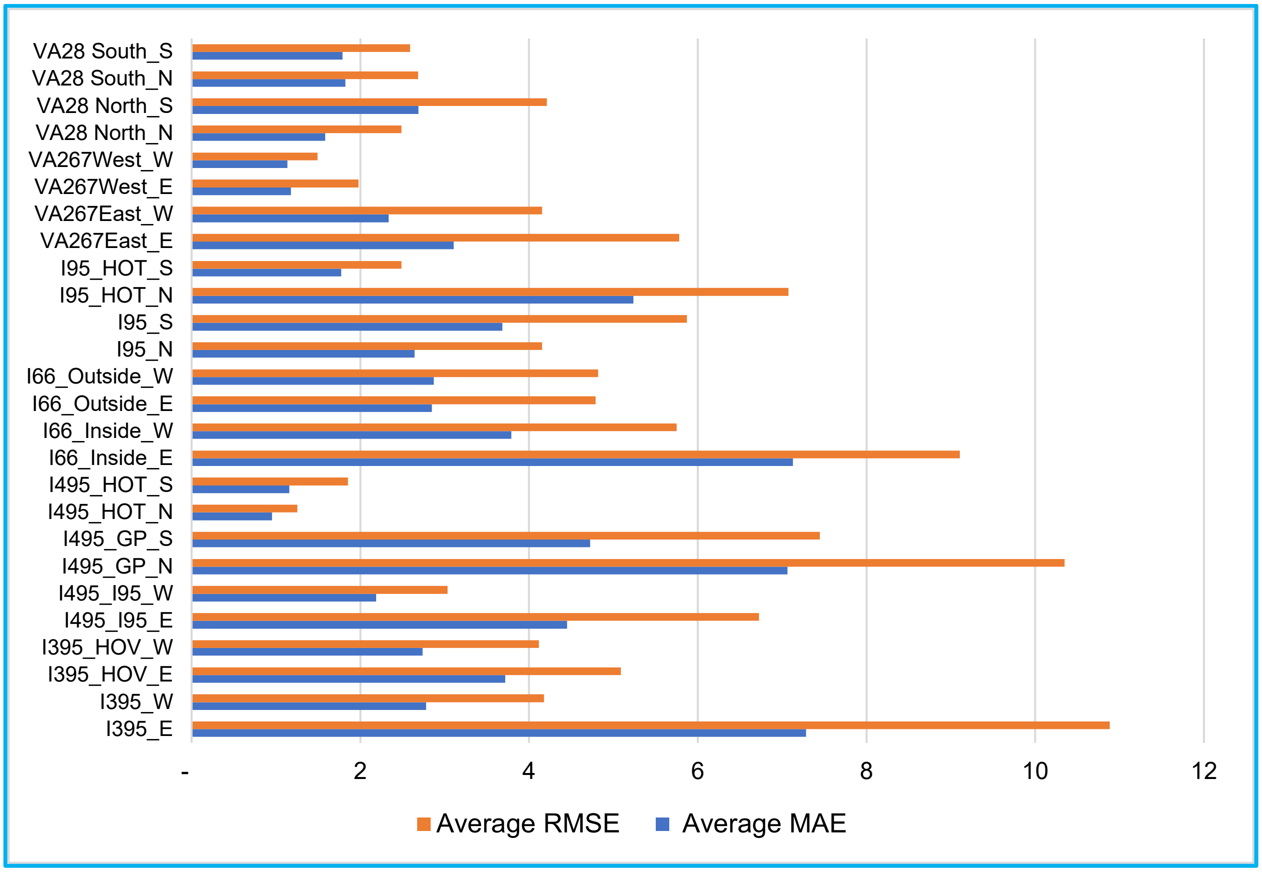


Figure 28 Mean Absolute Error (MAE) and Root-Mean Squared Error (RMSE): Arterials

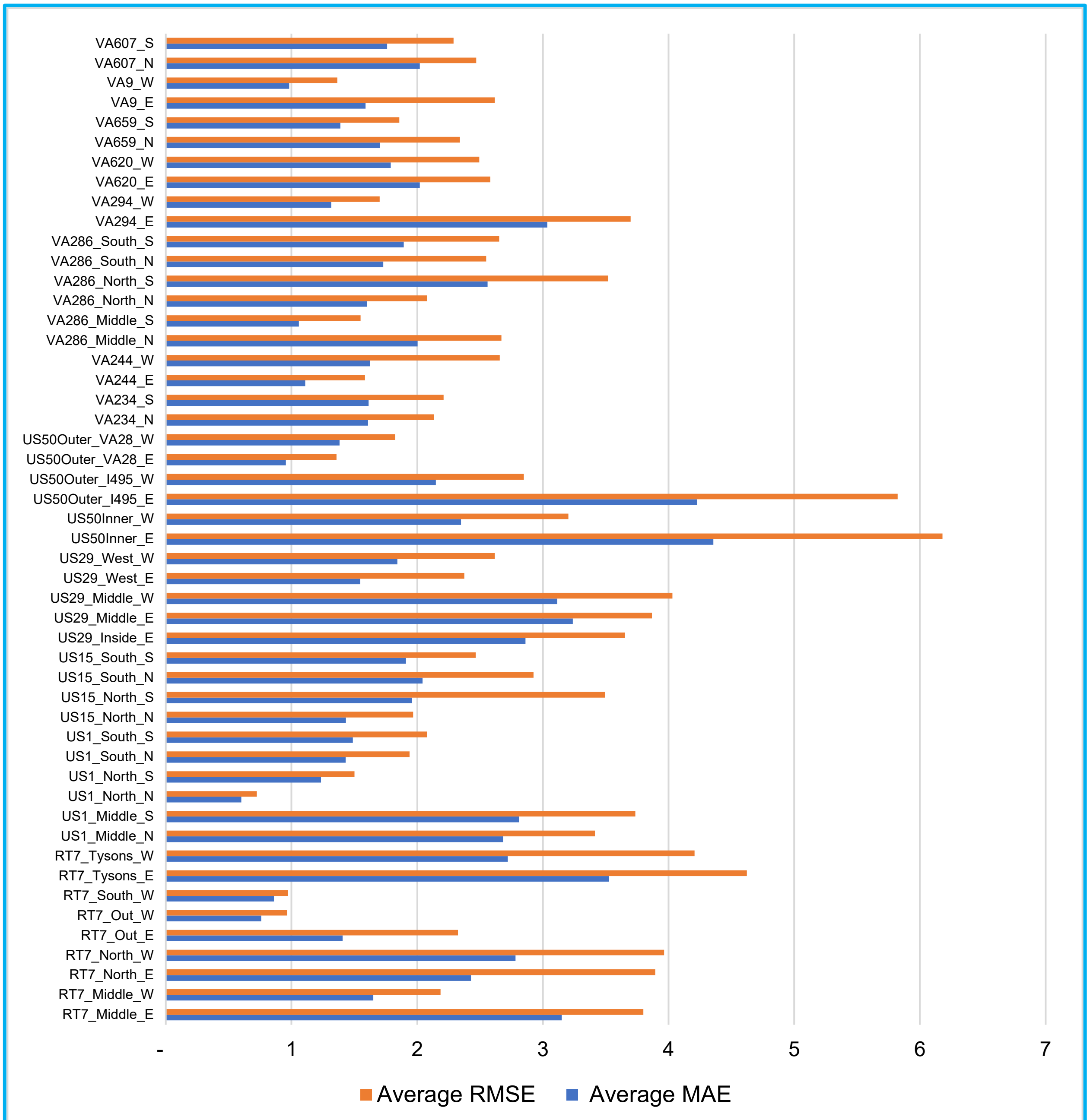


Figure 29 Mean Absolute Percentage Error (MAPE): Freeways

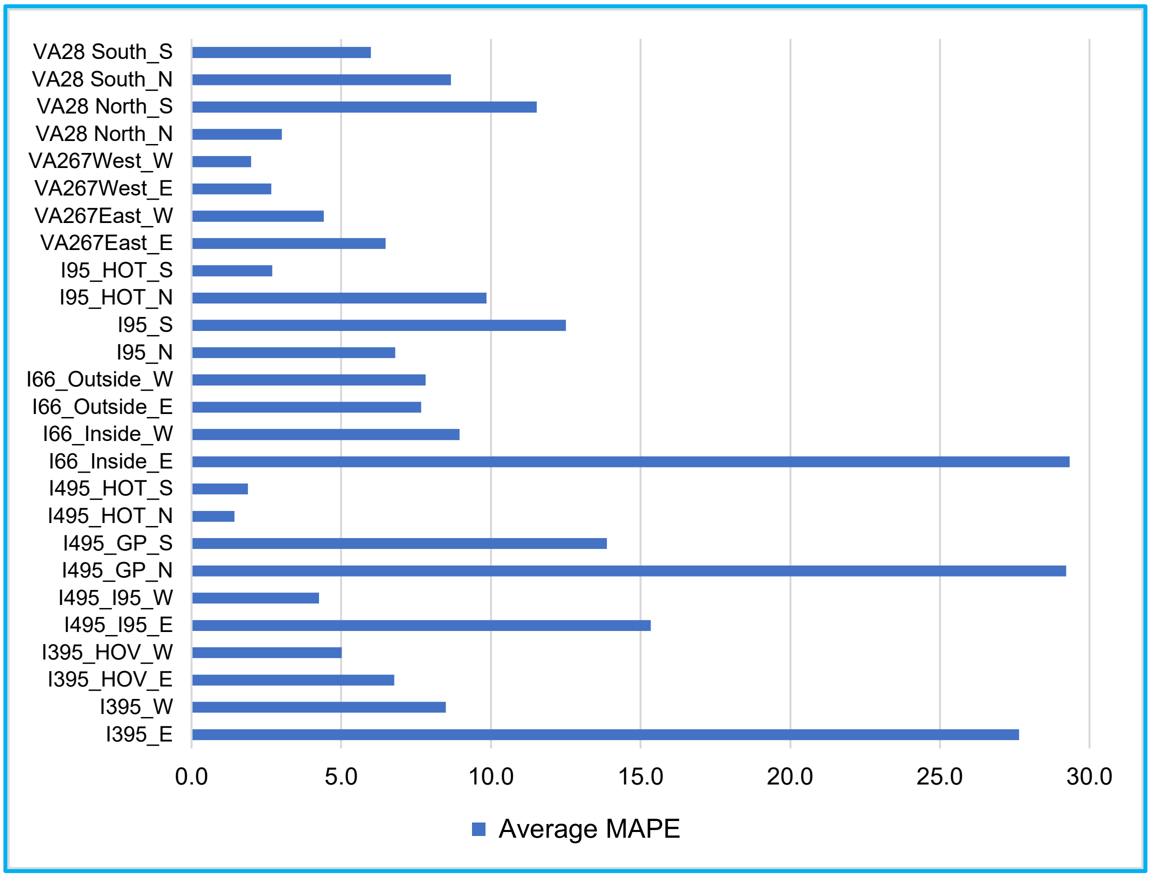
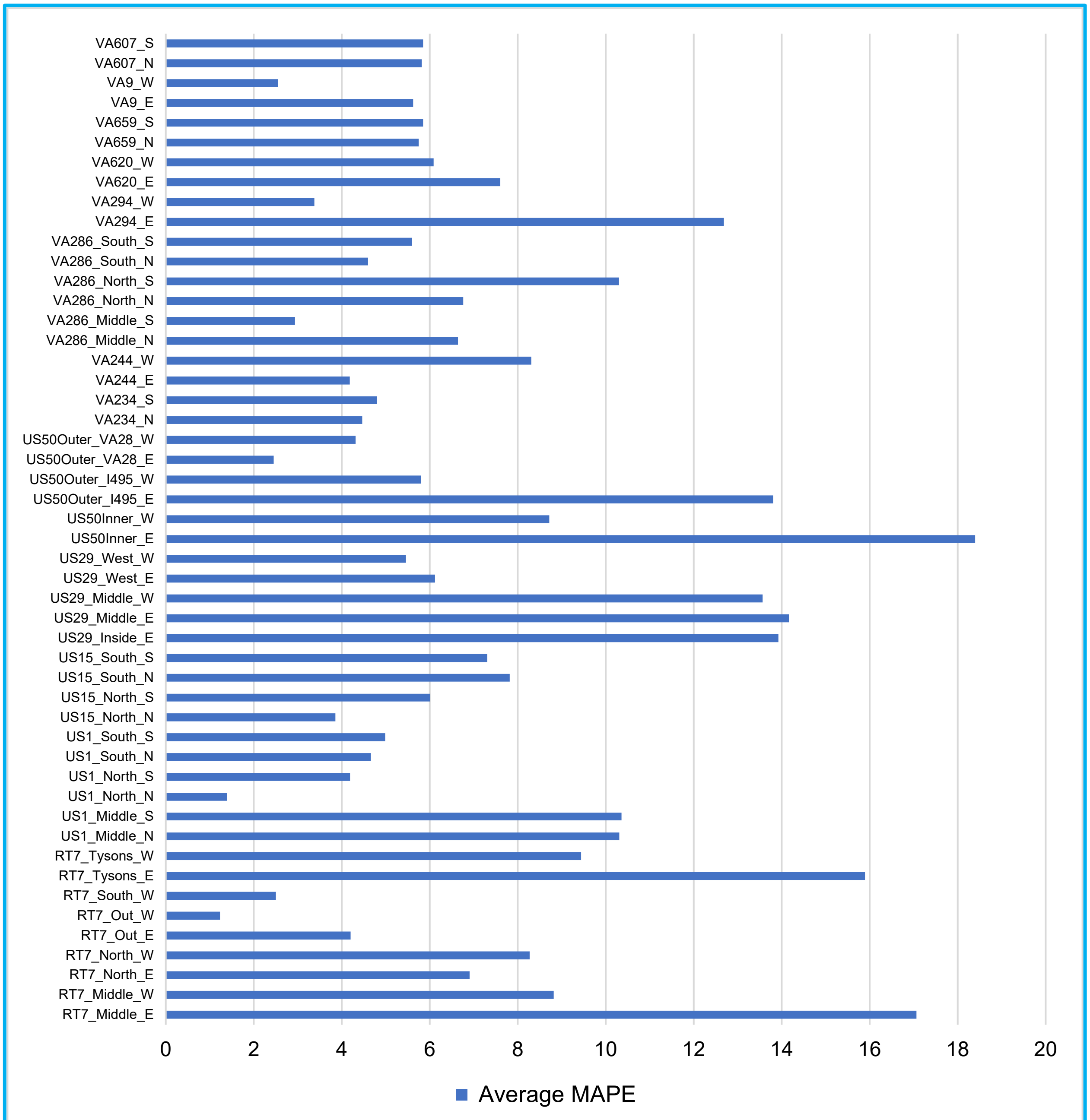


Figure 30 Mean Absolute Percentage Error (MAPE): Arterials



Traffic count data in 15-min intervals from several VDOT permanent count locations in October 2018 were compared with the model estimated volumes at the same locations. Figures 41-44 illustrate the profiles of observed and estimated volumes, with the speed profiles as a reference. For these locations, the estimated volume profiles are mostly consistent with the observed ones.

Figure 31 Profiles of Estimated and Modeled Volumes: I-95S

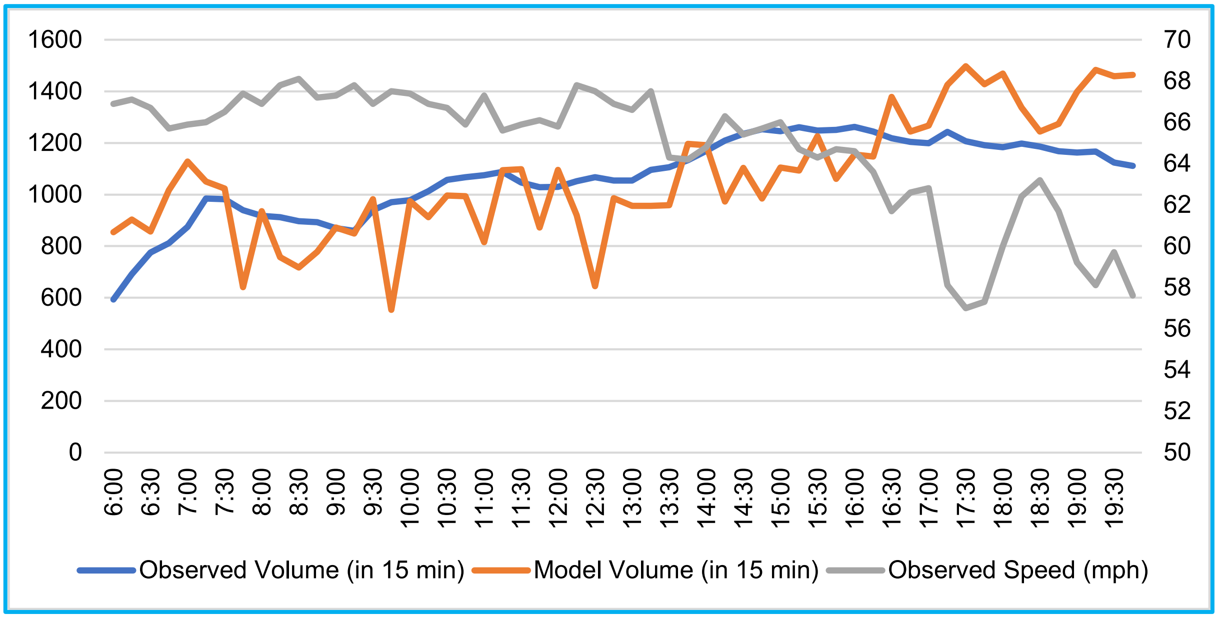


Figure 32 Profiles of Estimated and Modeled Volumes: I-495N GP

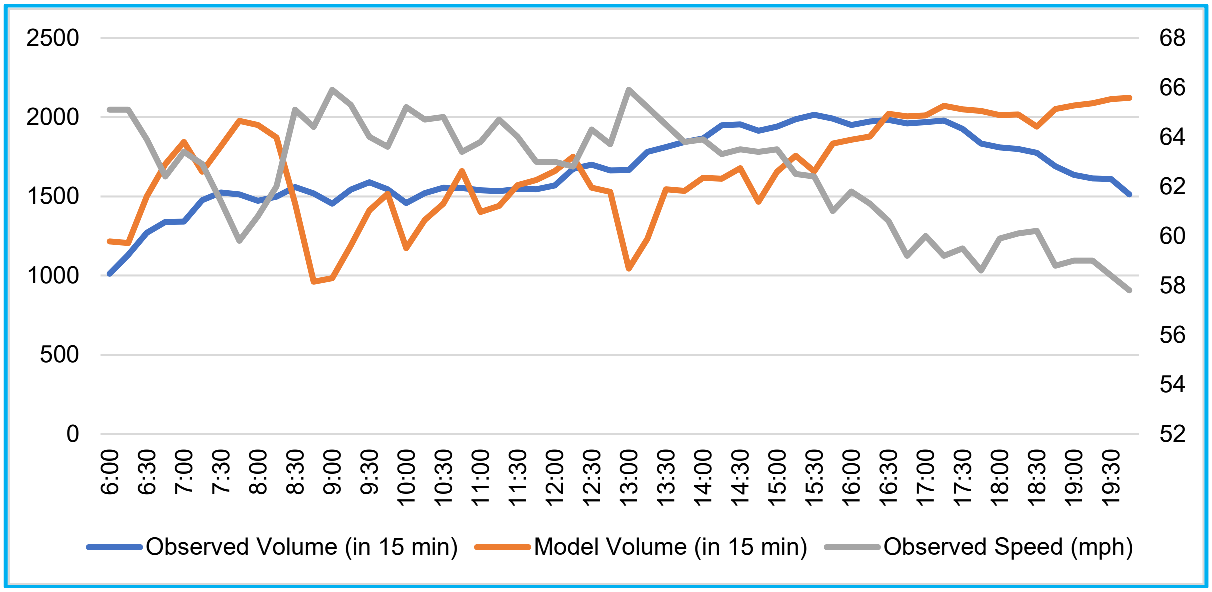


Figure 33 Profiles of Estimated and Modeled Volumes: I-495W GP

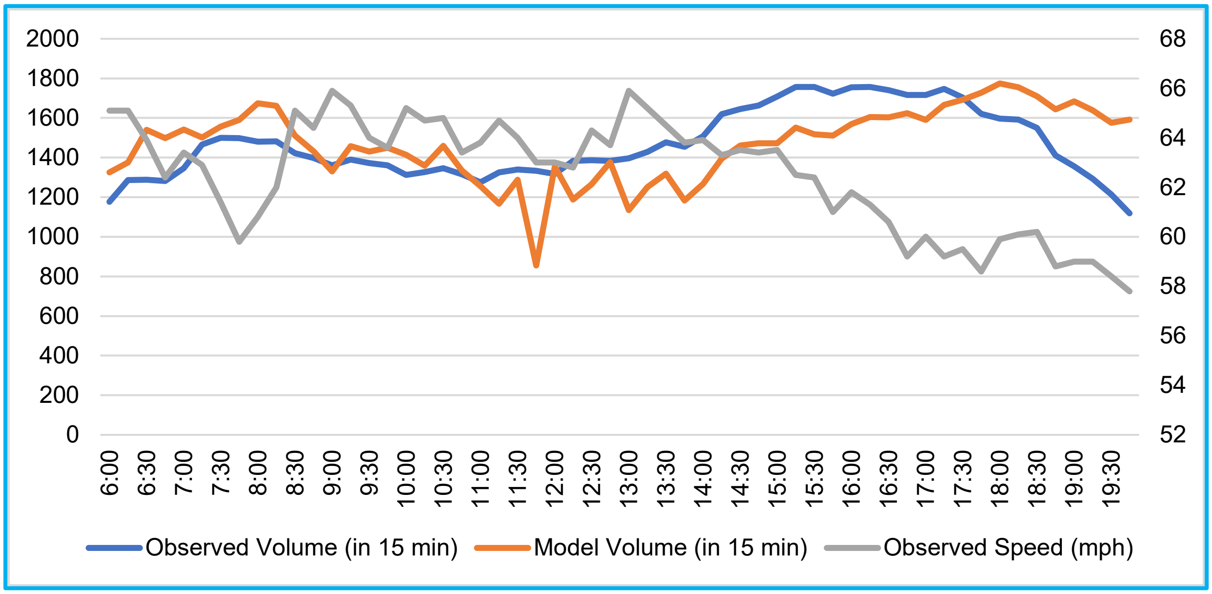
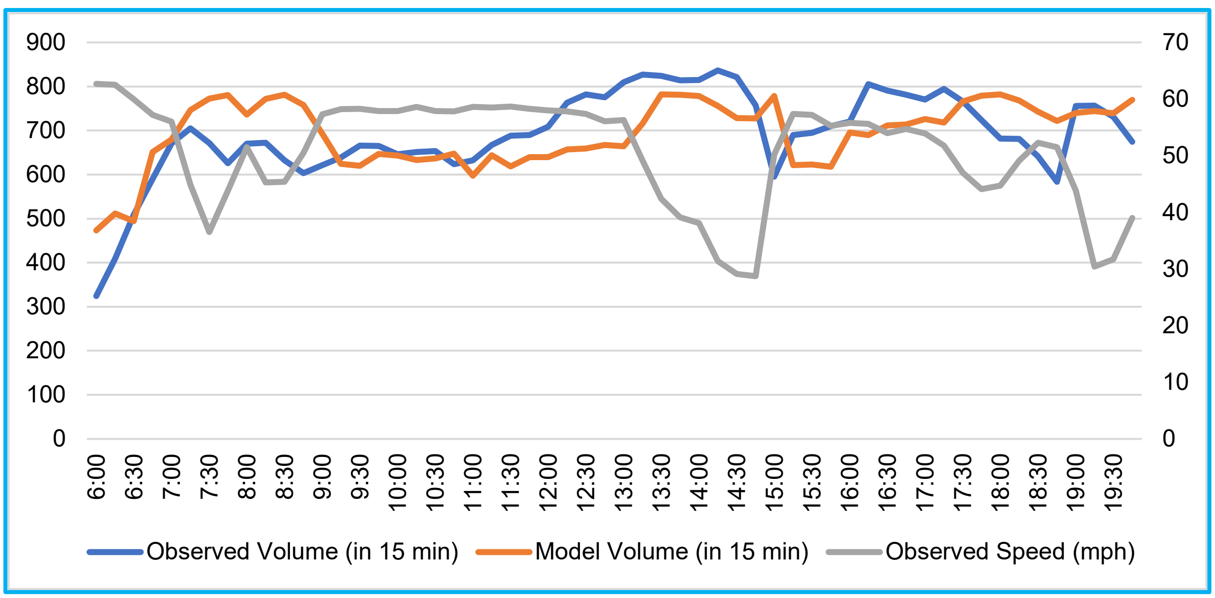


Figure 34 Profiles of Estimated and Modeled Volumes: I-66W



2.2.5 Transit Validation

Transit assignment results from the DTALite were summarized in terms of boardings by transit modes and compared with those estimated from the Cube model and the observed boardings. Figures 45 and 46 show the comparisons of daily boardings by transit modes among the DTALite estimates, the observed, and the Cube model estimates, for the model domain and Northern Virginia, respectively. As can be seen from both figures, the daily boarding estimates from the DTALite are close to both the observed and the Cube model estimates.

Figure 35 Daily Boardings by Modes in the Model Domain

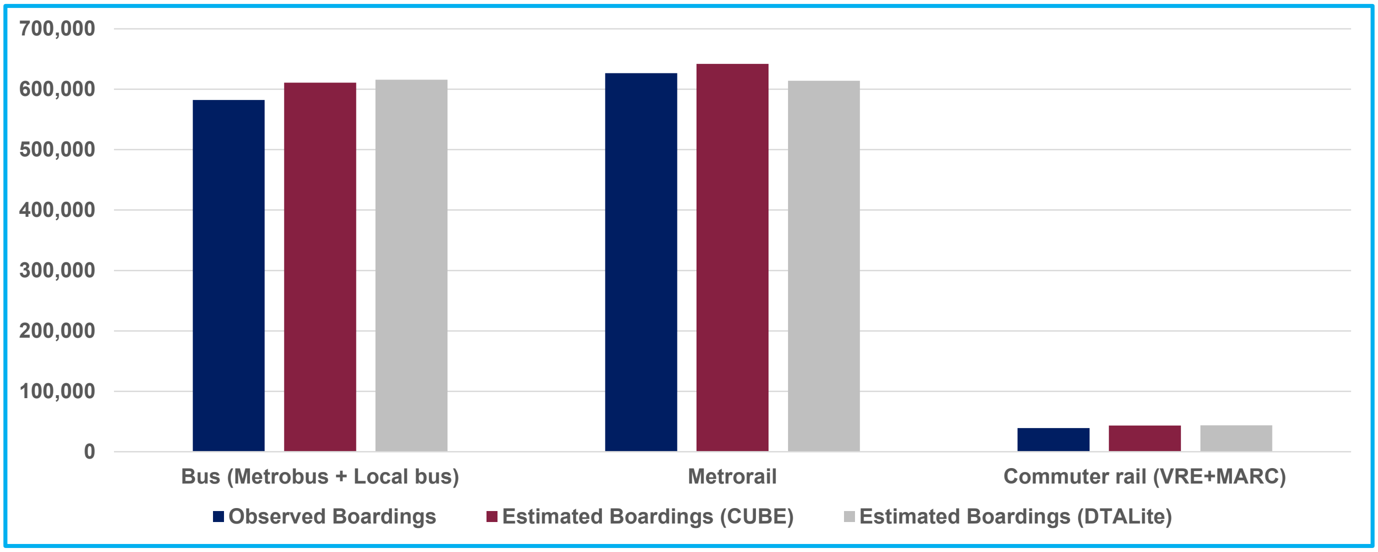
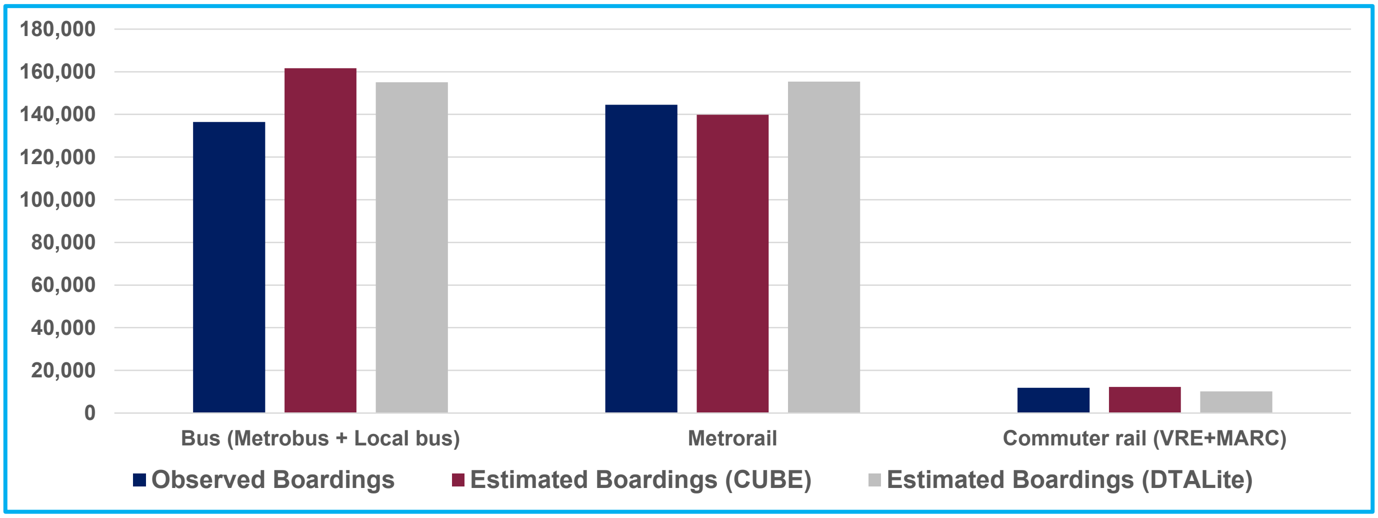


Figure 36 Daily Boardings by Modes in Northern Virginia



APPENDIX A. MODEL CALIBRATION AND VALIDATION SUMMARY

A.1 Macroscopic Model Validation

Table A1. Ratios of Productions to Unbalanced Attractions

	HBW	HBS	HBO	NHW	NHO	Total
P/A Ratios	0.97	0.93	1.07	1.03	1.14	1.03

Table A2. Trip Attraction Rates

	HBW Area Type 1-2	HBW Area Type 3-6	HBW (NCHRP 716)
Total Employment	1.118	0.8546	1.2

Table A3. Average Trip Length (in minutes) and Intrazonal Trips

	HBW	HBS	HBO	NHW	NHO
Average Trip Length	33.9	15.0	16.4	16.3	11.7
% Intrazonal Trips	3.5%	21.2%	19.8%	23.4%	25.0%
% Intrazonal Trips (COG/TPB 2017)	3.2%	20.4%	18.4%	22.7%	23.8%

Figure 37 Frequency Distribution of Trip Length (HBW)

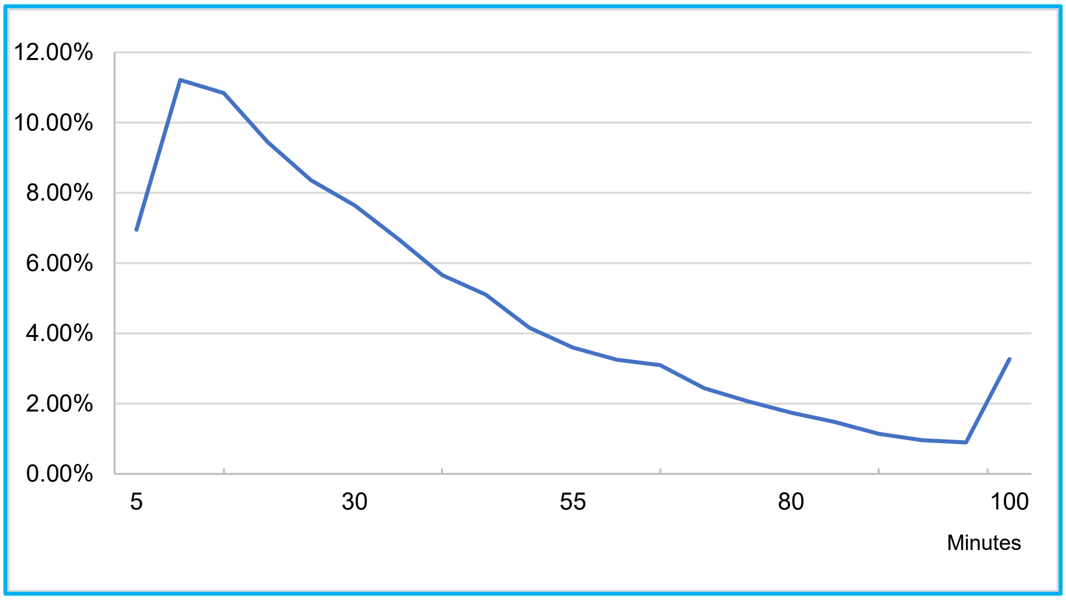


Figure 38 Frequency Distribution of Trip Length (HBS)

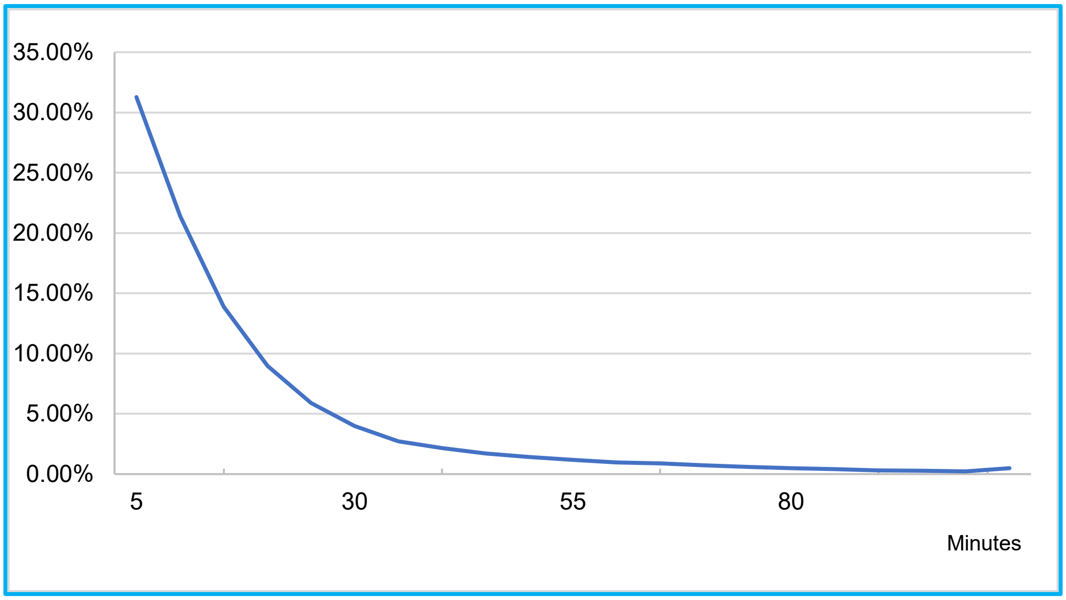


Figure 39 Frequency Distribution of Trip Length (HBO)

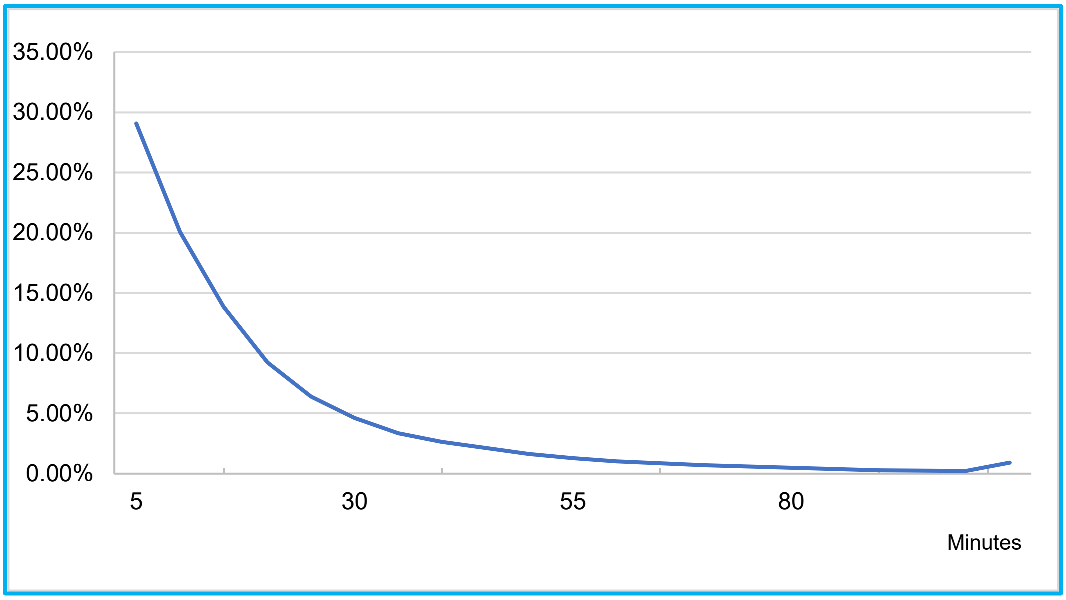


Figure 40 Frequency Distribution of Trip Length (NHW)

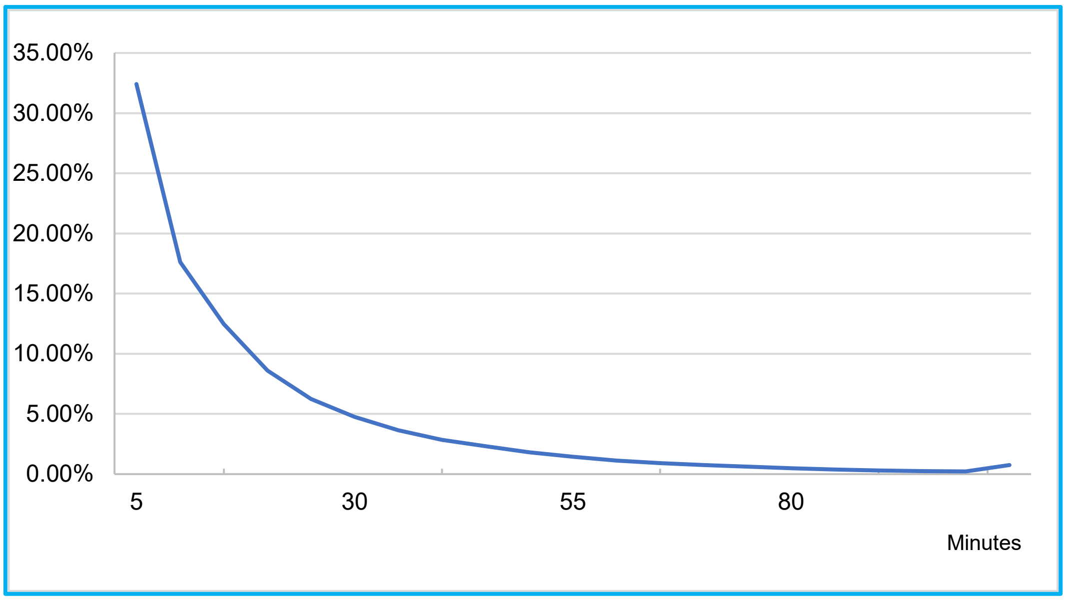
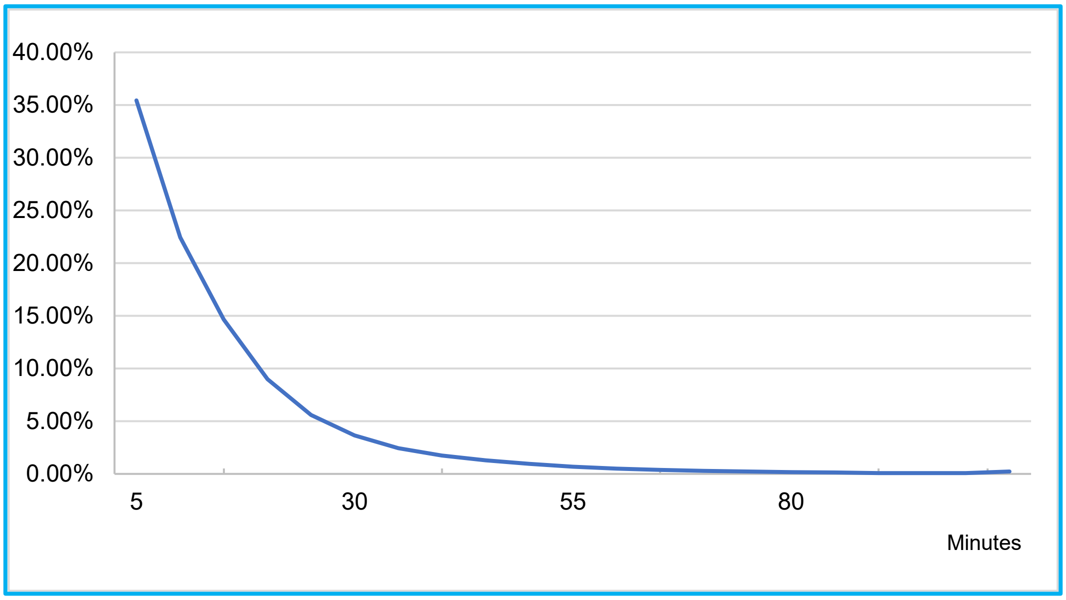


Figure 41 Frequency Distribution of Trip Length (NHO)



Source: Observed trip rates were derived from the 2017/2018 Regional Travel Survey.

Table A4. Motorized Person Trip Flows among Jurisdictions (HBW)

	HBW	ATTRACTIONS																							
	PRODUCTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
1	DC CR	16258	6143	2925	1777	667	1500	405	1661	75	65	19	8	245	374	7	4	41	3	1	0	1	1	474	32654
2	DC NC	138865	44633	29199	21724	3685	8693	2593	11397	572	497	238	111	2756	4244	135	69	555	26	14	2	10	18	3954	273990
3	MTG	128068	40321	228392	31061	4641	11496	3033	24441	1843	1215	6459	1987	16131	11477	166	183	446	97	61	161	87	41	15539	527346
4	PG	92230	57903	47458	151420	5541	13620	5480	19656	830	1028	595	422	13026	23854	1023	786	4692	51	57	11	76	161	16754	456672
5	ARLCR	2366	337	265	101	804	1307	273	1031	45	49	3	1	16	25	1	1	5	3	2	0	1	0	30	6668
6	ARNCR	34493	6662	5257	2146	9205	28397	6733	26064	992	1184	88	30	343	553	21	32	116	63	52	9	49	9	544	123043
7	ALX	23606	4949	3484	2433	5206	15471	11299	21394	669	1278	64	24	270	572	37	45	180	50	72	7	61	13	521	91705
8	FFX	102233	29366	31604	14096	19129	57062	27453	304501	25113	26109	949	338	2449	4064	221	392	983	1476	979	299	970	144	3825	653754
9	LDN	12920	5909	9601	2720	2580	7191	2438	63216	70453	8983	2704	643	1255	1350	46	121	184	1292	266	1607	316	49	2192	198034
10	PW	17516	7535	7685	3685	3826	10735	5146	99875	6869	86498	408	143	705	1325	67	154	289	3518	3194	237	2084	280	1606	263377
11	FRD	6888	3843	22336	3050	660	1738	502	5565	3381	719	66394	9832	8294	3738	34	55	89	170	34	927	42	13	5944	144248
12	CAR	1950	1098	4883	975	158	408	118	1016	271	82	3445	35133	2730	1284	10	18	28	15	4	84	8	4	28932	82657
13	HOW	11760	7012	19478	10371	749	1827	581	3460	324	220	2387	2009	49531	14698	79	94	186	21	15	77	25	20	47718	172642
14	AAR	23600	13421	17628	21698	1513	3809	1446	6037	438	494	858	788	18346	128234	1168	474	923	33	43	44	61	81	54730	295866
15	CAL	6086	3276	2346	4133	430	1110	517	1954	121	193	75	56	708	3855	13359	4045	1534	12	39	4	81	133	611	44681
16	STM	4983	2637	1811	3276	371	1003	507	1970	117	240	53	41	526	1860	3153	47937	3568	31	134	2	250	565	427	75461
17	CHS	14043	7611	4199	10273	991	2676	1381	4863	245	427	96	70	1030	3318	1378	2713	20646	29	114	4	231	608	681	77626
18	FAU	1453	675	985	336	305	890	361	6367	2000	6769	161	51	129	175	10	38	45	8847	942	143	661	88	2798	34229
19	STA	3898	1731	1736	996	841	2356	1163	9120	952	11957	95	39	220	471	66	256	312	1633	19823	63	11177	1109	1301	71316
20	CL/JF	911	475	2045	313	158	444	157	3709	4347	1144	2145	481	716	377	4	9	14	386	45	13542	43	8	3388	34861
21	SP/FB	1990	879	935	525	449	1260	623	5169	535	5583	46	17	117	268	60	223	311	921	7528	34	29943	1213	5367	63995
22	KGEO	675	342	228	365	66	180	89	668	62	628	6	4	62	186	59	206	382	96	679	4	1051	4637	903	11576
23	EXTL	11562	4434	15963	17280	653	1830	723	12279	10739	8697	12734	25332	60311	86922	276	752	2035	8619	7747	3605	19902	3831	0	316226
	TOTAL	658354	251192	460443	304754	62628	175003	73021	635413	130993	164059	100022	77560	179916	293224	21380	58607	37564	27392	41845	20866	67130	13026	198239	4052627

Table A5. Motorized Person Trip Flows among Jurisdictions (Non-HBW)

	Non Work	ATTRACTIONS																							
	PRODUCTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
1	DC CR	53310	39180	15113	17840	1842	5511	3149	8302	508	770	309	81	1119	2432	187	124	685	65	100	20	76	17	1713	152453
2	DC NC	125265	448172	106510	90089	5407	23119	14337	50296	5641	4046	1207	809	6933	8067	358	177	1947	714	1594	26	1094	35	15217	911060
3	MTG	43742	89706	2014283	89171	1664	6703	3311	25325	4532	1865	29448	17287	43542	18727	289	170	810	338	318	214	307	50	40798	2432600
4	PG	85807	165221	158363	1268192	3981	17910	18105	53363	4921	4780	1501	2676	54666	65935	2824	1153	25911	629	2229	29	1626	482	44787	1985091
5	ARLCR	1836	1794	1112	982	8364	9311	4003	8044	405	708	59	15	105	229	23	19	72	58	108	8	79	5	183	37522
6	ARNCR	13484	12414	6603	4805	15612	212565	36255	85727	3275	4974	247	82	429	923	71	68	315	474	1296	23	1142	33	3476	404293
7	ALX	7245	7271	3182	4880	6901	37071	167451	74666	1909	6126	119	35	277	718	87	80	496	265	1646	15	1293	37	2444	324214
8	FFX	36380	37868	27218	18905	16197	93748	97378	2279801	80281	83270	1369	603	2029	3924	331	465	1957	6248	14759	599	15058	601	18895	2837884
9	LDN	4917	4981	5169	2119	1002	3979	2286	91772	739791	13604	6144	2386	577	850	31	24	182	4328	933	13839	1191	103	9018	909226
10	PW	3734	3706	2538	1993	1584	7222	8714	103261	12121	976914	171	53	226	530	48	62	263	19912	33546	323	20047	727	10735	1208430
11	FRD	825	1227	40952	982	116	445	196	3134	5751	208	509022	36870	8472	1100	16	12	37	65	15	1419	13	2	20495	631374
12	CAR	105	169	3058	339	19	51	31	212	139	36	5296	324975	3126	536	9	7	17	7	5	42	5	1	59982	398167
13	HOW	2134	4154	26289	21129	128	376	258	1306	218	157	3767	14563	599952	37510	92	54	195	23	19	50	18	10	88373	800775
14	AAR	6623	10714	18667	46100	399	1403	1191	3951	456	466	900	3026	74631	1200942	3324	307	1309	40	111	33	62	53	121693	1496401
15	CAL	1369	2062	1703	7132	128	570	727	1985	111	232	47	33	719	7144	155017	8490	4152	4	90	1	28	235	2361	194340
16	STM	1568	1684	1090	4024	147	691	1325	2656	40	129	16	8	261	997	8834	226007	13816	7	527	1	1120	1995	3040	269983
17	CHS	4484	6078	2709	19409	346	1703	2581	7256	361	605	45	24	620	1590	2622	4564	278869	32	769	3	1433	3799	3871	343773
18	FAU	111	110	152	80	54	199	141	4095	2019	8999	32	6	24	44	3	5	13	123418	3156	220	1577	69	13586	158113
19	STA	188	174	183	148	159	706	861	7622	306	14956	16	4	25	63	8	19	36	2577	240108	8	42087	1816	7461	319531
20	CL/JF	33	43	721	44	14	50	27	4471	22073	838	1613	258	140	48	2	1	4	1373	16	106775	16	1	8526	147087
21	SP/FB	107	106	143	117	113	517	591	6081	265	6757	16	4	24	59	12	34	49	983	31470	8	291721	1239	24672	365088
22	KGEO	24	27	22	69	14	59	65	702	15	658	2	1	9	29	17	75	222	83	3220	1	3793	40282	5259	54648
23	EXTL	7215	17787	28147	30056	417	3424	1901	16951	11960	11513	17740	36913	63407	88605	1471	2690	4131	13763	8090	3687	30291	5359	0	405518
	TOTAL	400506	854648	2463927	1628605	64608	427333	364884	2840979	897098	1142611	579086	440712	861313	1441002	175676	244607	335488	175406	344125	127344	414077	56951	506585	16787571

Table A6. Commercial Vehicle Trip Flows among Jurisdictions

	COMMERCIAL DESTINATION																								
	ORIGIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
1	DC CR	43406	22763	13342	15795	1194	4555	2515	6426	306	751	309	32	1384	3218	283	60	1190	31	57	0	21	20	4325	121982
2	DC NC	22852	14587	10681	12420	599	2283	1330	3500	138	341	209	23	1255	2561	215	36	888	11	20	0	4	14	2729	76697
3	MTG	13297	10779	72931	12811	472	1958	839	6381	591	428	5185	815	7487	4667	109	7	294	28	13	48	1	2	5128	144272
4	PG	15975	12521	12596	33869	378	1499	1435	3062	58	305	231	68	5036	11455	1037	238	3570	3	17	0	3	71	3826	107252
5	ARLCR	1190	597	452	372	389	1945	966	2755	155	321	12	1	29	65	7	1	32	18	27	0	12	1	344	9692
6	ARNCR	4600	2287	1909	1488	1954	8543	4561	13916	793	1523	49	3	110	252	24	3	140	89	120	1	50	2	1564	43980
7	ALX	2596	1338	836	1385	972	4646	5002	10152	300	1441	16	1	60	187	31	6	206	44	140	0	61	3	1083	30507
8	FFX	6562	3611	6515	3223	2731	13933	10303	101208	15031	16417	180	9	317	447	51	7	418	1475	925	112	399	10	6782	190667
9	LDN	318	149	622	62	148	727	292	15252	27981	2709	629	14	24	7	0	0	2	750	22	1242	4	0	1884	52838
10	PW	782	356	452	324	330	1591	1479	16945	2577	28448	5	0	6	23	3	0	46	2810	2464	59	1110	45	2215	62069
11	FRD	308	225	5529	241	14	54	18	199	670	5	25339	2508	1523	234	0	0	0	2	0	439	0	0	1377	38687
12	CAR	38	33	1027	89	1	3	1	10	16	0	2689	17058	1370	211	0	0	0	0	0	12	0	0	830	23387
13	HOW	1461	1323	7566	5319	31	114	64	318	22	7	1350	1128	21243	10286	39	2	84	0	0	8	0	0	1853	52216
14	AAR	3107	2503	4692	11114	64	243	185	408	5	20	215	180	10572	50660	840	38	469	0	0	0	0	4	3137	88456
15	CAL	324	248	118	1179	8	27	36	51	0	3	0	0	41	951	5232	1768	767	0	0	0	0	35	398	11185
16	STM	77	49	8	329	1	4	8	7	0	0	0	0	2	58	2005	12975	1363	0	3	0	9	229	632	17759
17	CHS	1277	952	318	3844	33	145	212	380	2	41	0	0	89	547	687	1055	9331	0	15	0	35	563	723	20249
18	FAU	31	11	32	4	18	92	48	1559	715	2883	2	0	0	0	0	0	0	5872	556	97	333	14	452	12716
19	STA	67	24	14	20	31	140	156	1043	22	2673	0	0	0	0	0	2	16	581	5594	0	4799	320	573	16076
20	CL/JF	0	0	58	0	0	1	0	130	1413	72	500	12	10	0	0	0	0	117	0	7332	0	0	355	10000
21	SP/FB	28	6	1	4	14	64	73	492	5	1309	0	0	0	0	0	7	36	350	4948	0	14156	583	813	22890
22	KGEO	24	16	2	86	1	2	4	14	0	58	0	0	0	6	32	182	605	15	341	0	602	1789	139	3918
23	EXTL	4328	2731	5132	3829	344	1566	1084	6787	1885	2216	1378	831	1854	3140	398	632	723	453	573	324	813	139	0	41163
	TOTAL	122648	77109	144833	107807	9727	44135	30611	190995	52685	61971	38298	22683	52412	88975	10993	17019	20180	12649	15835	9674	22412	3844	41162	1198658

Table A7. Mode Choice Model Coefficients

	HBW	HBS	HBO	NHW	NHO
In-vehicle time (IVT)	-0.025	-0.0125	-0.016666667	-0.025	-0.02
Auto access time (AAT)	-0.05	-0.025	-0.033333333	-0.05	-0.04
Out-of-vehicle time	-0.0625	-0.03125	-0.041666667	-0.0625	-0.05
COST- INC1	-0.002533784	-0.002533784	-0.002533784	-0.002533784	-0.002533784
COST- INC2	-0.001543739	-0.001543739	-0.001543739	-0.001543739	-0.001543739
COST- INC3	-0.001188276	-0.001188276	-0.001188276	-0.001188276	-0.001188276
COST- INC4	-0.000637936	-0.000637936	-0.000637936	-0.000637936	-0.000637936
Boarding penalty	-0.0625	-0.03125	-0.041666667	-0.0625	-0.05
Walk access time	-0.05	-0.025	-0.025	-0.05	-0.04
NEST- LEVEL1	0.5	0.5	0.5	0.5	0.5
NEST- LEVEL2	0.5	0.5	0.5	0.5	0.5
NEST- LEVEL3	0.5	0.5	0.5	0.5	0.5
CAV - IVT	-0.01875	-0.009375	-0.0125	-0.01875	-0.015
TNC COST	-0.001152959	-0.001152959	-0.001152959	-0.001152959	-0.001152959
TNC WAIT	-0.0625	-0.03125	-0.041666667	-0.0625	-0.05

Table A8. Auto Occupancy

	HBW	HBS	HBO	NHW	NHO
Internal trips	1.06	1.41	1.64	1.09	1.51
COG/TPB 2017	1.10	1.52	1.57	1.19	1.49
NCHRP 716	1.10		1.72		1.66

Table A9. Estimated and Observed Modal Shares (All Trips)

	Auto Modal Shares		Transit Modal Shares		TNC Modal Shares	
	Observed	Estimated	Observed	Estimated	Observed	Estimated
HBW	81.1%	80.9%	16.4%	16.8%	2.5%	2.3%
HBS	96.4%	96.8%	2.2%	1.9%	1.4%	1.3%
HBO	96.6%	96.2%	2.0%	2.2%	1.4%	1.6%
NHW	90.8%	91.0%	6.2%	6.3%	3.0%	2.7%
NHO	97.6%	97.8%	1.5%	1.4%	0.9%	0.9%
Total	93.3%	93.3%	5.1%	5.0%	1.7%	1.6%

Source: Observed trip rates were derived from the 2017/2018 Regional Travel Survey.

Table A10. Estimated and Observed Modal Shares (HBW)

	Auto Modal Shares		Transit Modal Shares		TNC Modal Shares	
	Observed	Estimated	Observed	Estimated	Observed	Estimated
DC	40.0%	41.4%	50.7%	51.3%	9.2%	7.4%
MD Urban	59.6%	59.1%	31.9%	32.2%	8.5%	8.8%
VA Urban	56.3%	58.2%	38.7%	37.3%	5.0%	4.5%
MD Suburban	87.3%	85.6%	11.6%	13.2%	1.1%	1.2%
VA Suburban	89.0%	88.2%	9.3%	10.1%	1.7%	1.7%
Total	81.1%	80.9%	16.4%	16.8%	2.5%	2.3%

Source: Observed trip rates were derived from the 2017/2018 Regional Travel Survey.

Table A11. Deviations of the Model Estimates from the Observed (VMT and Daily Boardings)

VMT (Model Domain)		Daily Boardings (Model Domain)		Daily Boardings (Northern Virginia)	
Modes	Deviations	Modes	Deviations	Modes	Deviations
Arlington	-1.4%	Metrobus	2.4%	Metrorail	-3.3%
Alexandria	11.7%	Local Bus	9.9%	VRE	3.8%
Fairfax	0.9%	Metrorail	2.5%	Local Bus	13.0%
Loudoun	-1.8%	VRE	-3.3%	Metrobus	24.7%
Prince William	-2.3%	MARC	24.4%		
Total	0.1%	Total	3.9%	Total	7.1%

Table A12. Estimated and Observed Boardings by Stations and Station Groups

	Daily Boardings by Station		Daily Boardings by Station Group		Deviations by Station Group	
	Observed	Estimated	Observed	Estimated	Observed	Estimated
Van Dorn Street	2,576	4,475				
Franconia-Springfield	5,940	4,162				
Huntington	6,896	8,822				
Eisenhower Avenue	1,919	2,740				
King Street	7,131	3,424				
Braddock Road	4,376	5,561	28,838	29,183	345	1%
National Airport	5,964	1,984				
Crystal City	10,795	12,018				
Pentagon City	12,311	6,576				
Pentagon	13,667	14,222				
Arlington Cemetery	1,485	36	44,222	34,835	(9,388)	-21%
Vienna	8,970	8,340				
Dunn Loring	3,789	3,098				
West Falls Church	2,544	1,498				
East Falls Church	4,023	6,268	19,326	19,204	(123)	-1%
Ballston	9,029	12,629				
Virginia Square	3,728	3,821				
Clarendon	4,375	5,079				
Court House	6,420	7,207				
Rosslyn	13,020	14,337	36,572	43,072	6,500	18%
McLean	1,830	3,202				
Tysons Corner	3,480	3,166				
Spring Hill	1,203	860				
Greensboro	1,265	1,730				
Wiehle	7,785	4,551	15,563	13,509	(2,055)	-13%
TOTAL	144,521	139,801	144,521	139,801	(4,721)	-3%

A.2 Mesoscopic Model Validation

Average speeds by corridor segments, as shown for freeways in Figure 52 and for arterials in Figure 53, display clear contrasts by direction for most freeway corridor segments, typically lower speeds for inbound AM and outbound PM. The discrepancy is smaller for arterials and managed lane segments.

Average link congestion duration, as displayed in Figures 54 and 55, demonstrates severity of congestion for some major freeway corridor segments such as AM inbound and PM outbound for I-395 general purpose lanes, I-495 general purpose lanes for PM, and I-66 for PM. Among arterial corridor segments, Route 7 corridor segments in the Tysons area and north, show the longest congestion duration in PM. Overall, PM congestion durations tend to be longer than the AM ones.

Some corridor links have really low speeds, below 20 mph for peak directions, as shown in Figures 56 and 57. For most arterial segments, the minimum link speeds tend to be below 30 mph.

Speed profiles for I-95, I-395, I-495, and I-66 are shown in Figures 58-68.

Figure 42 Average Link Speed for Priority Corridor Segments: Freeways

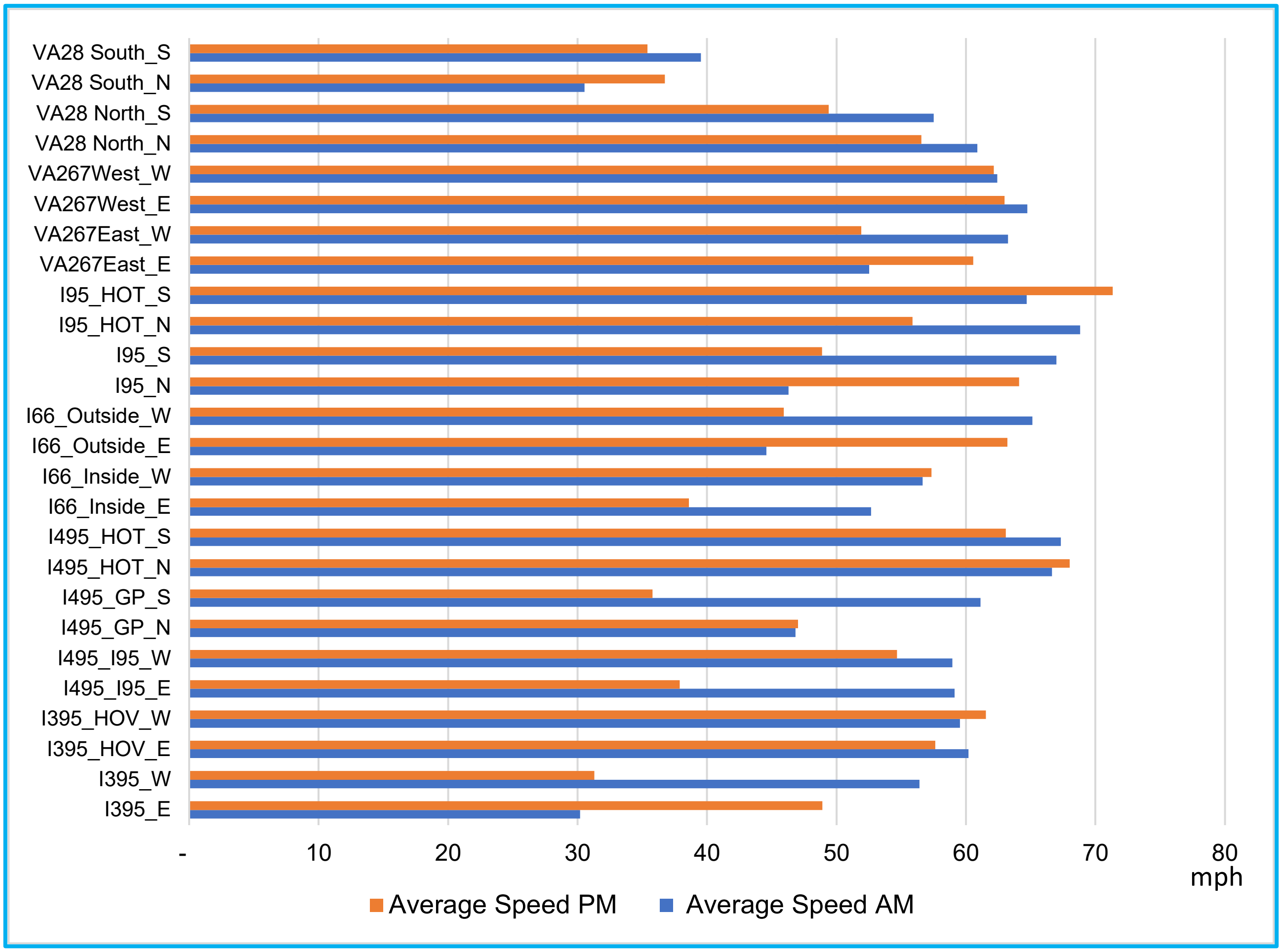


Figure 43 Average Link Speed for Priority Corridor Segments: Arterials

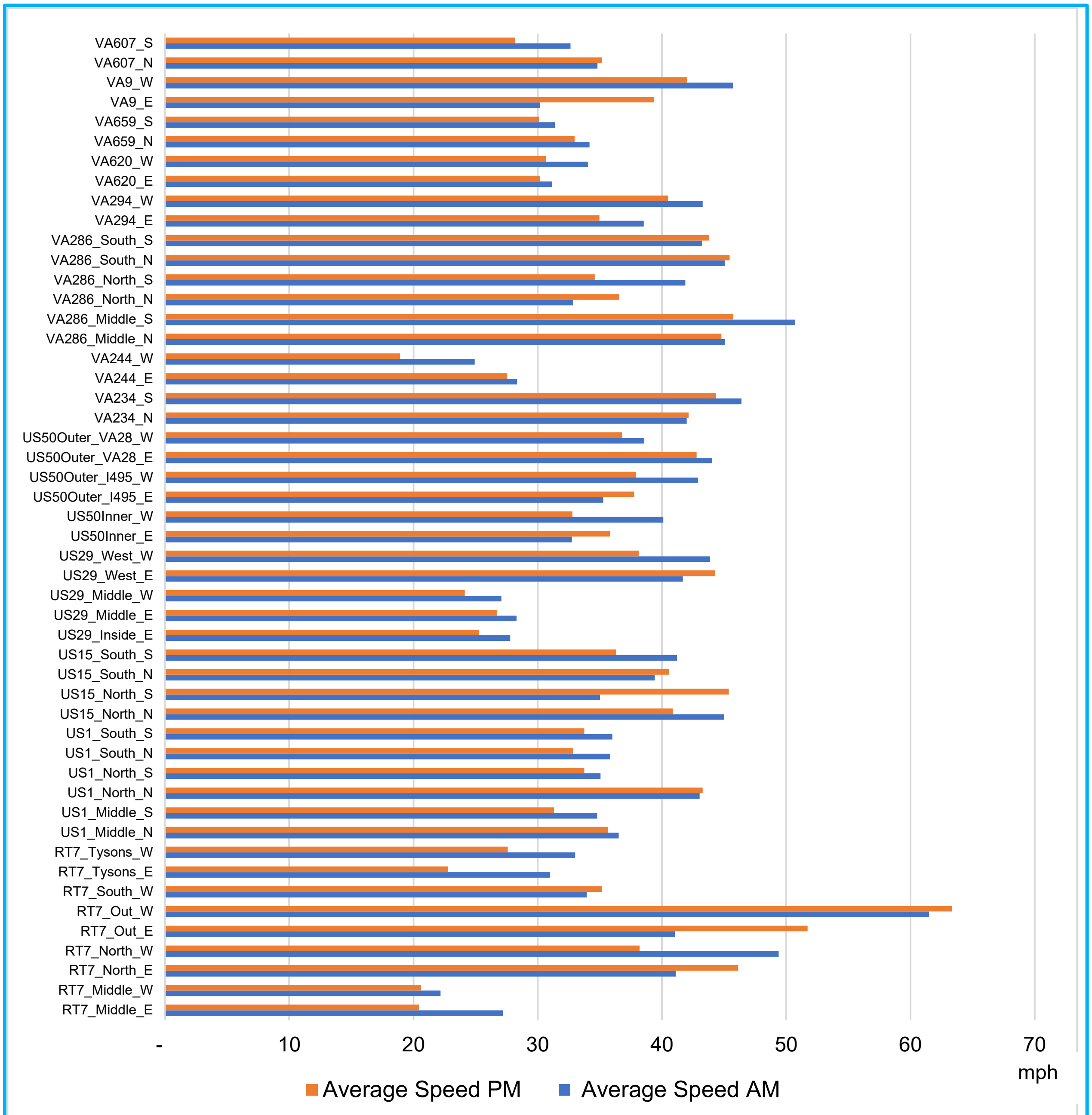


Figure 44 Average Link Congestion Duration for Priority Corridor Segments: Freeways

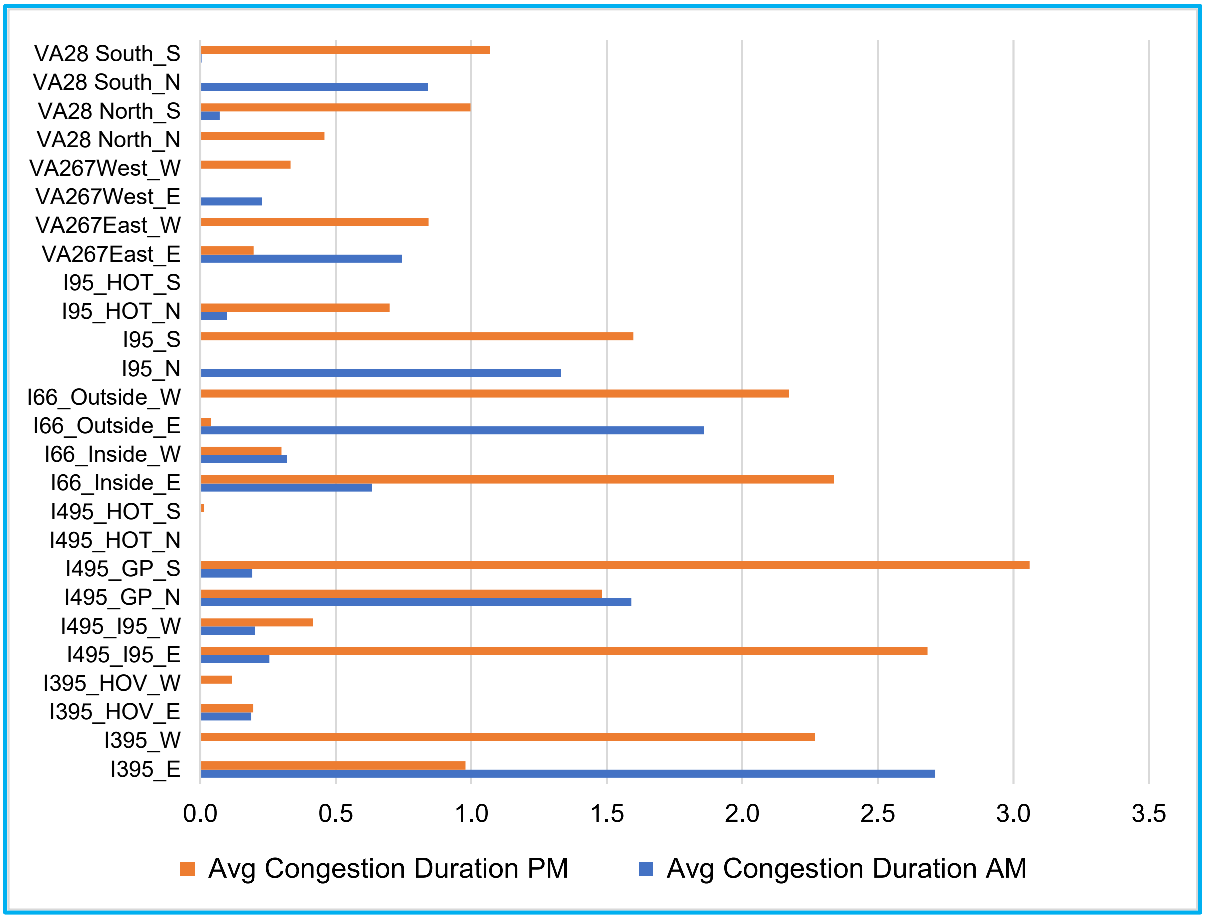


Figure 45 Average Link Congestion Duration for Priority Corridor Segments: Arterials

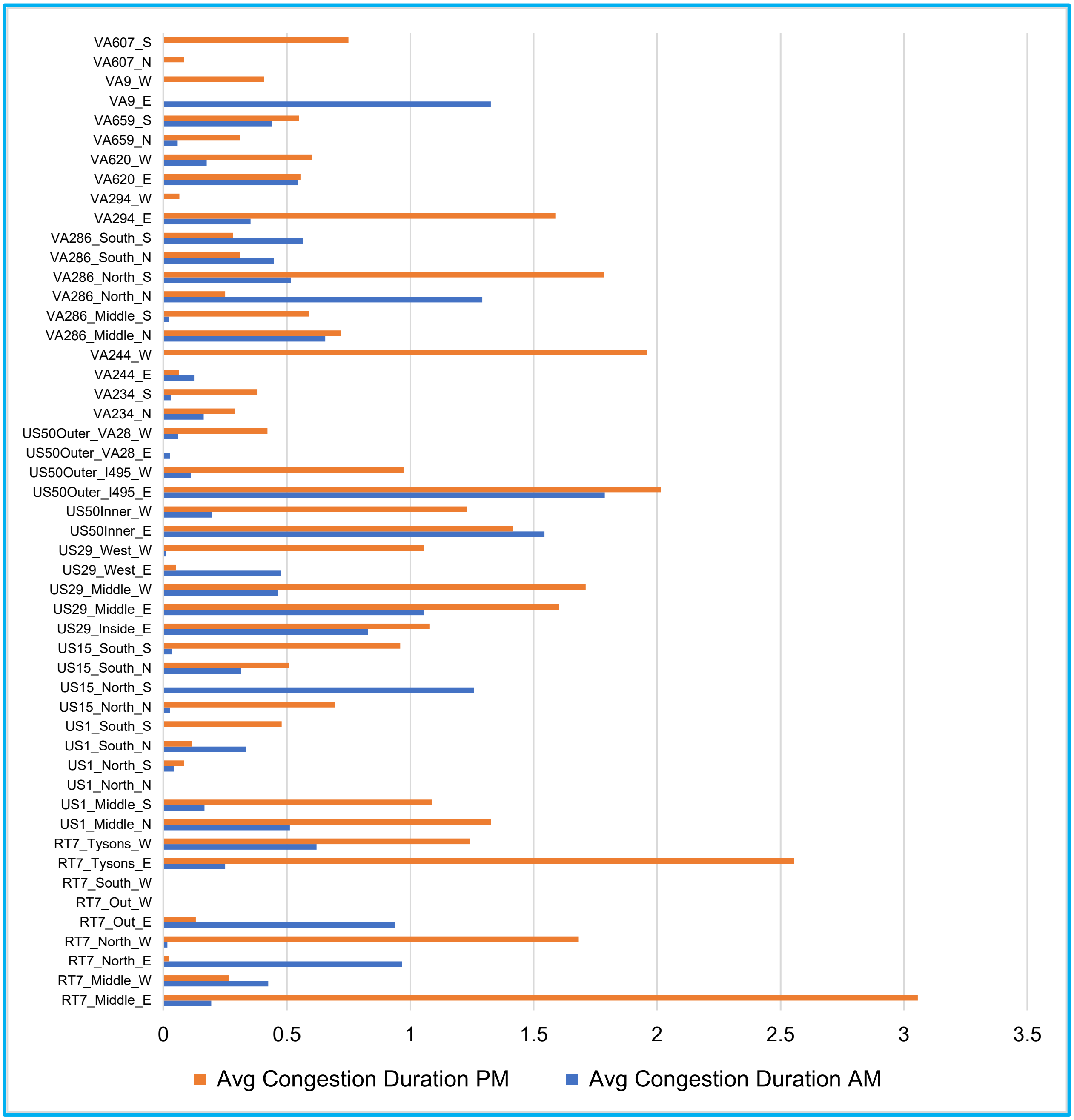


Figure 46 Minimum Link Speed for Priority Corridor Segments: Freeways

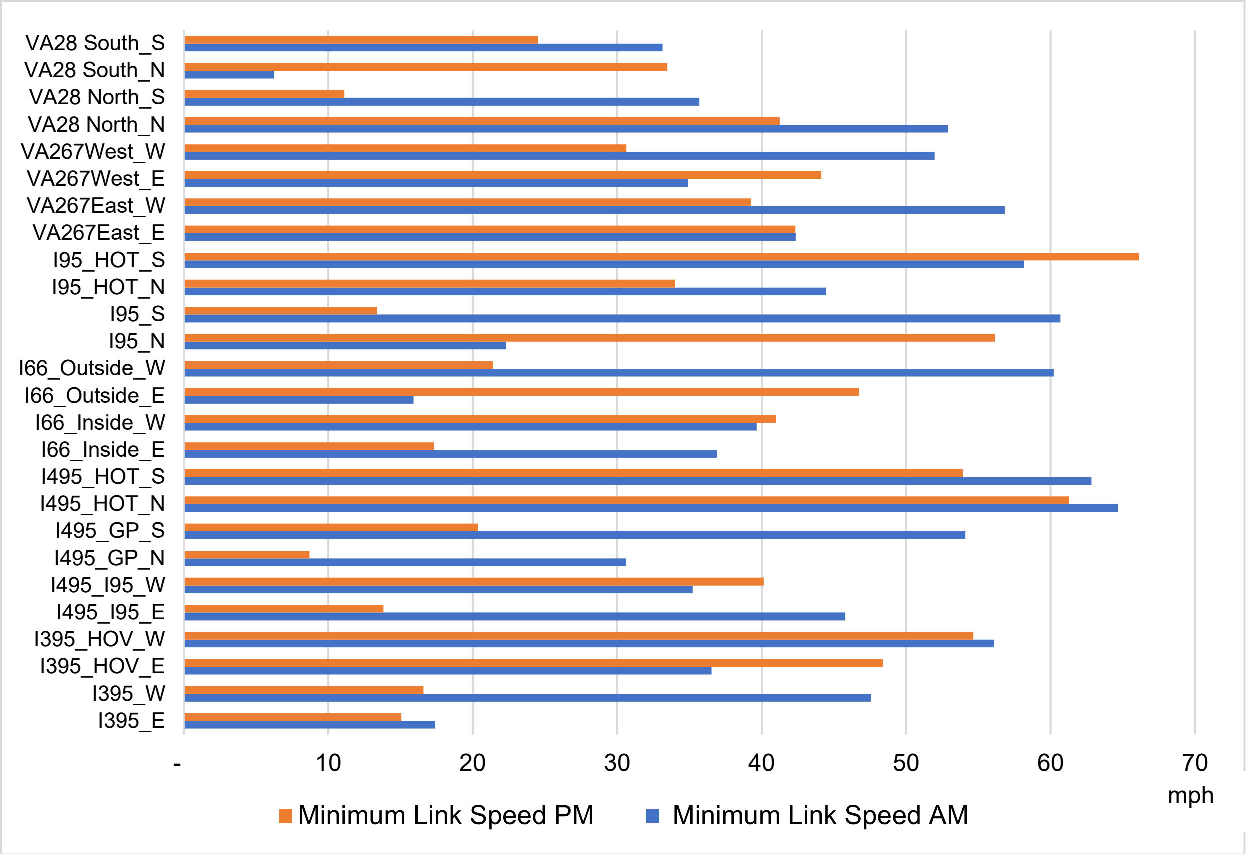


Figure 47 Minimum Link Speed for Priority Corridor Segments: Arterials

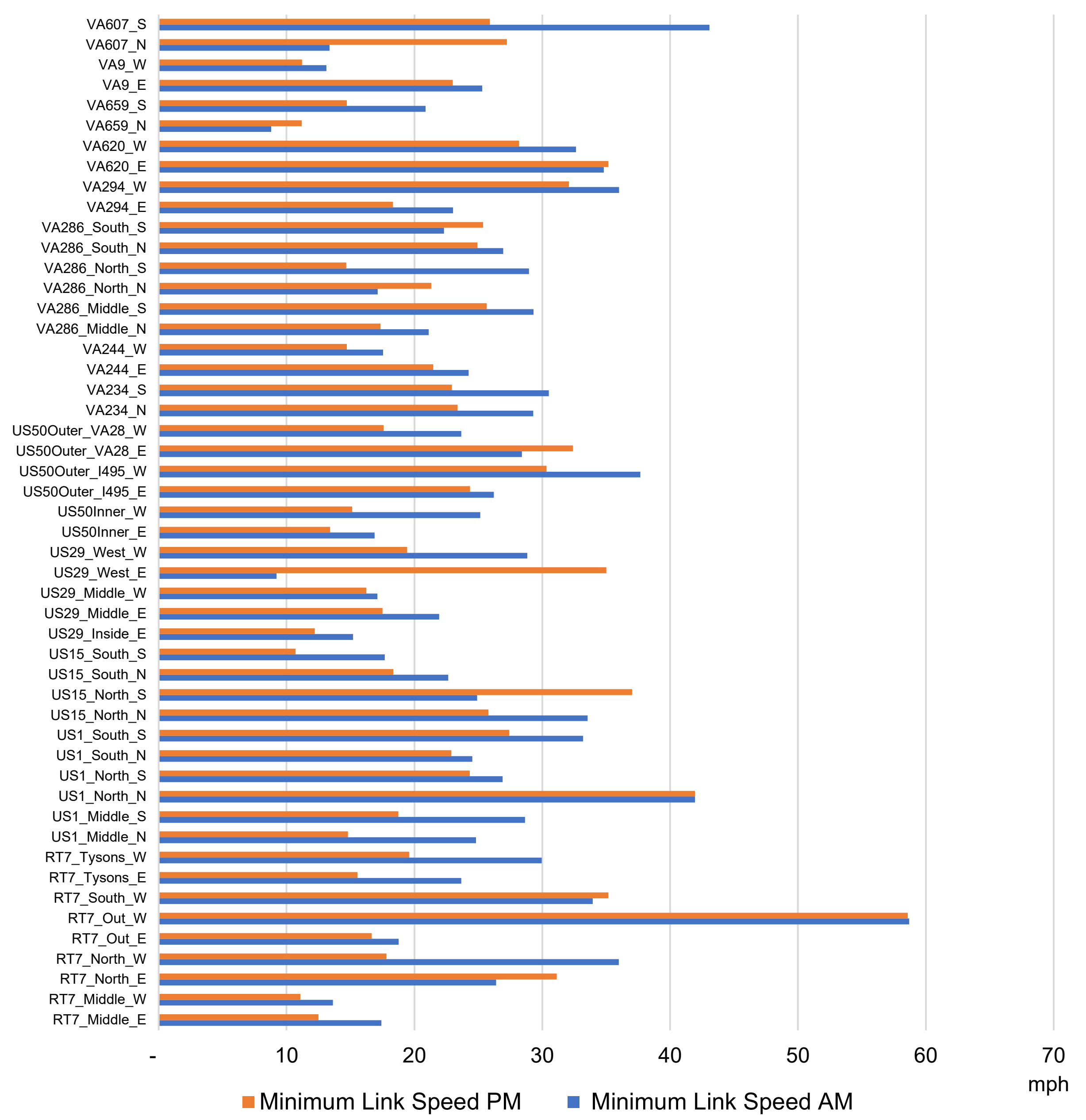


Figure 48 Speed Profiles for I-395 (Southbound)

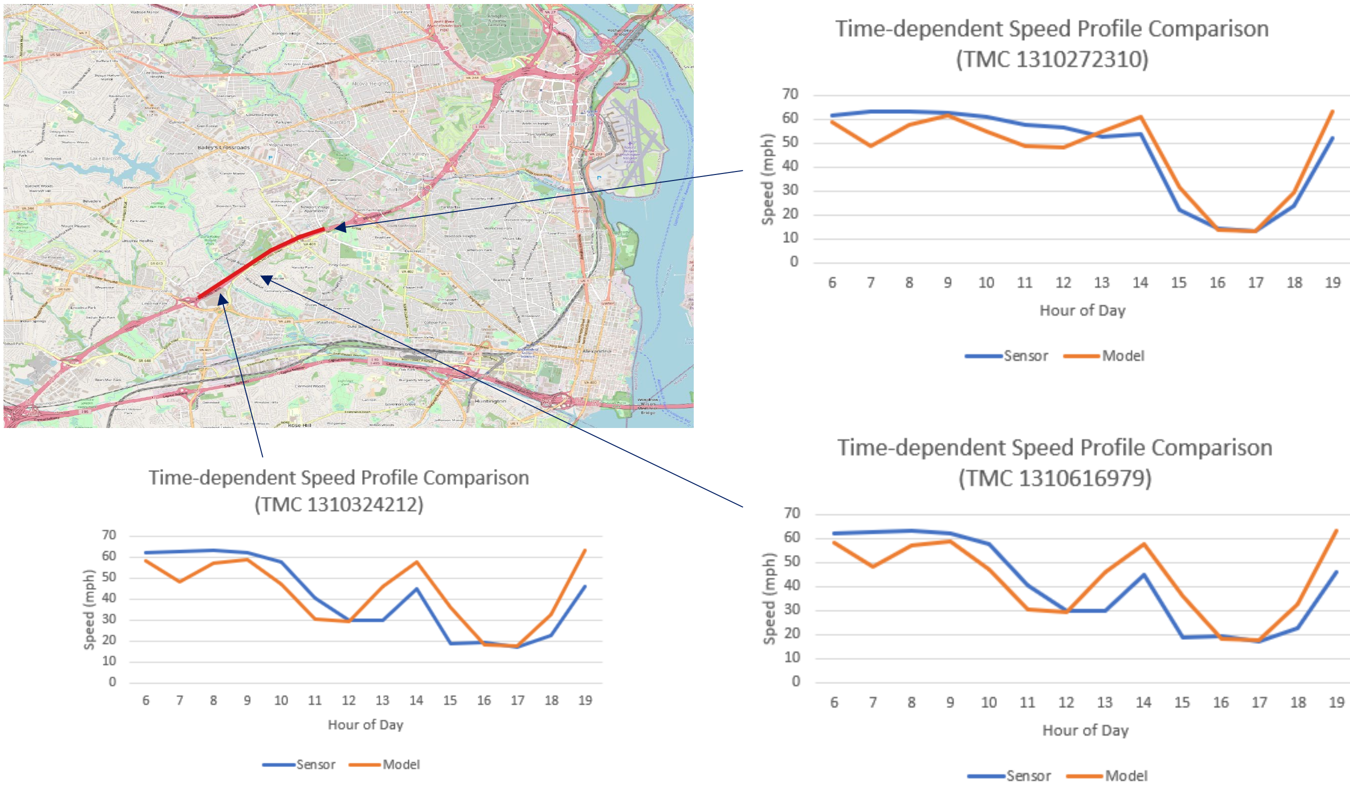


Figure 49 Speed Profiles for I-495 (Eastbound)

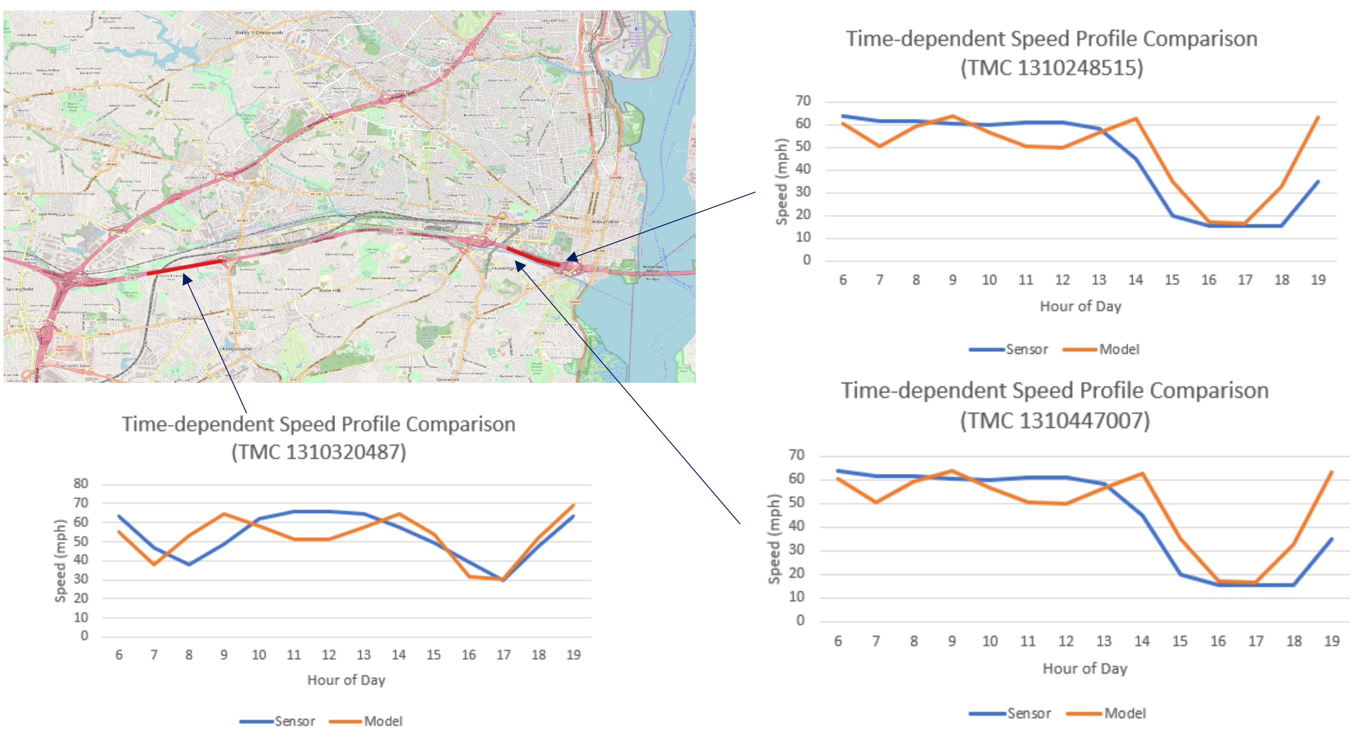


Figure 50 Speed Profiles for I-495 (Westbound)

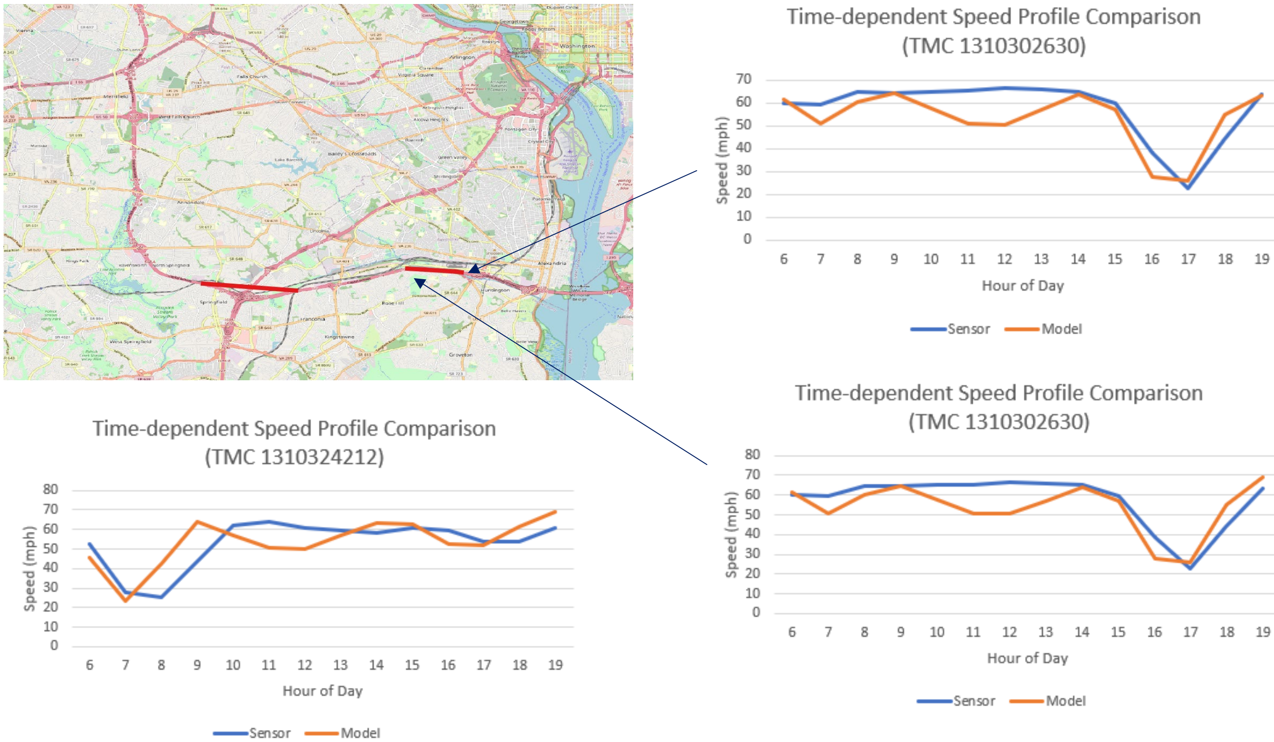


Figure 51 Speed Profiles for I-495 (Northbound)

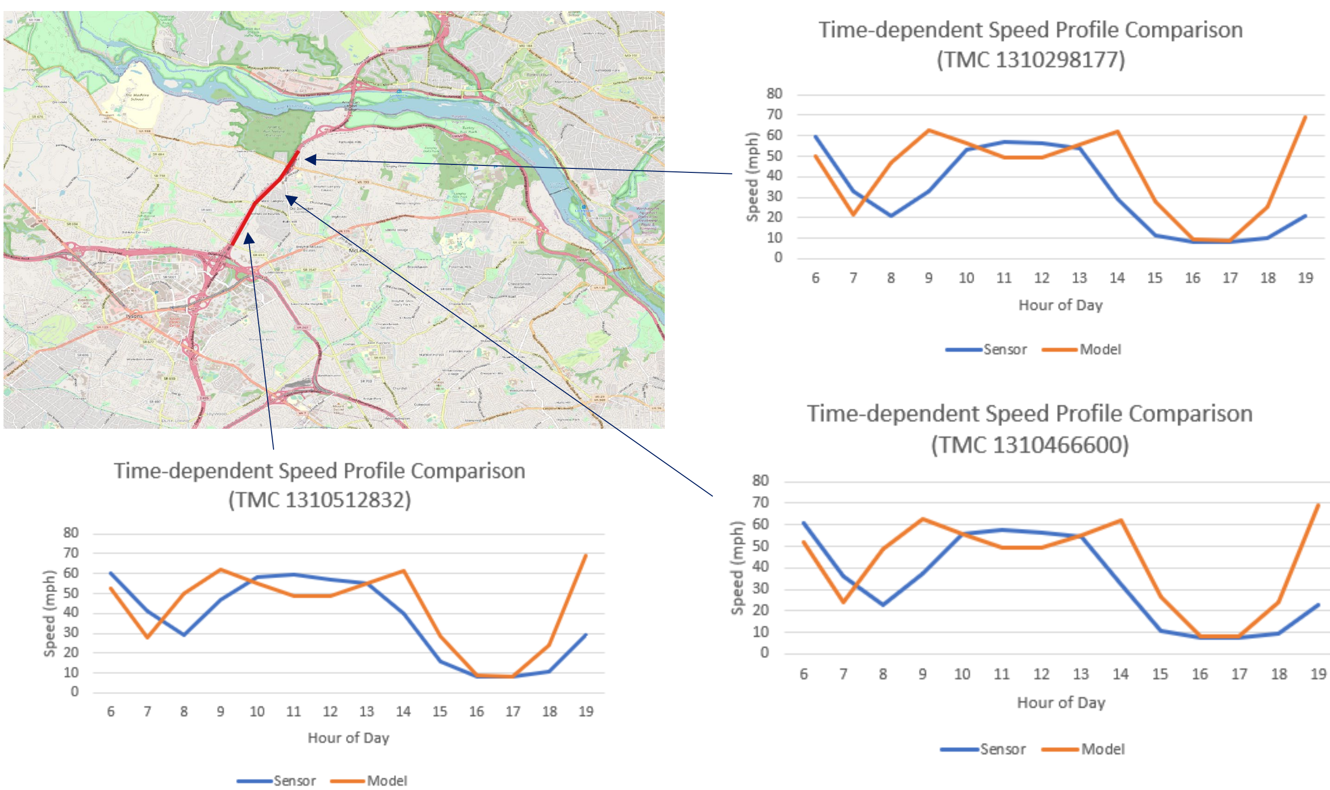


Figure 52 Speed Profiles for I-495 (Southbound)

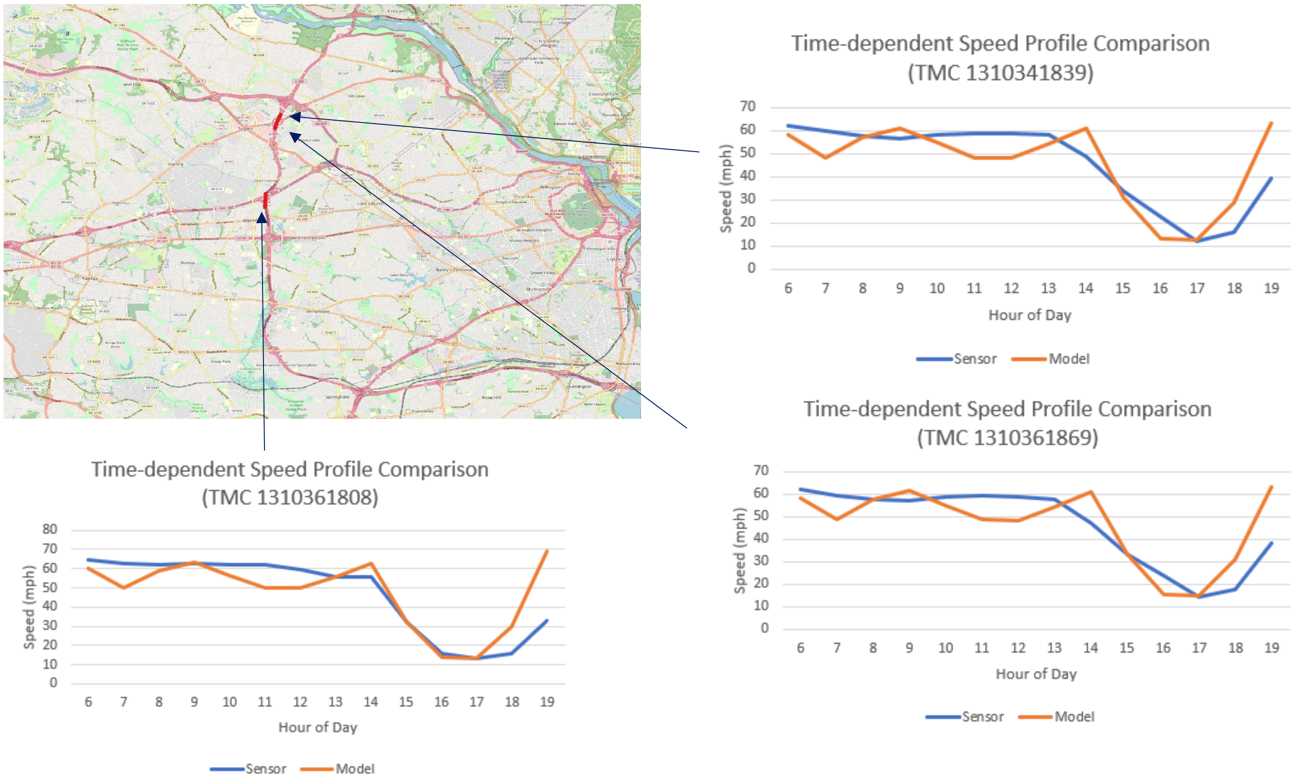


Figure 53 Speed Profiles for I-66 Inside (Eastbound)

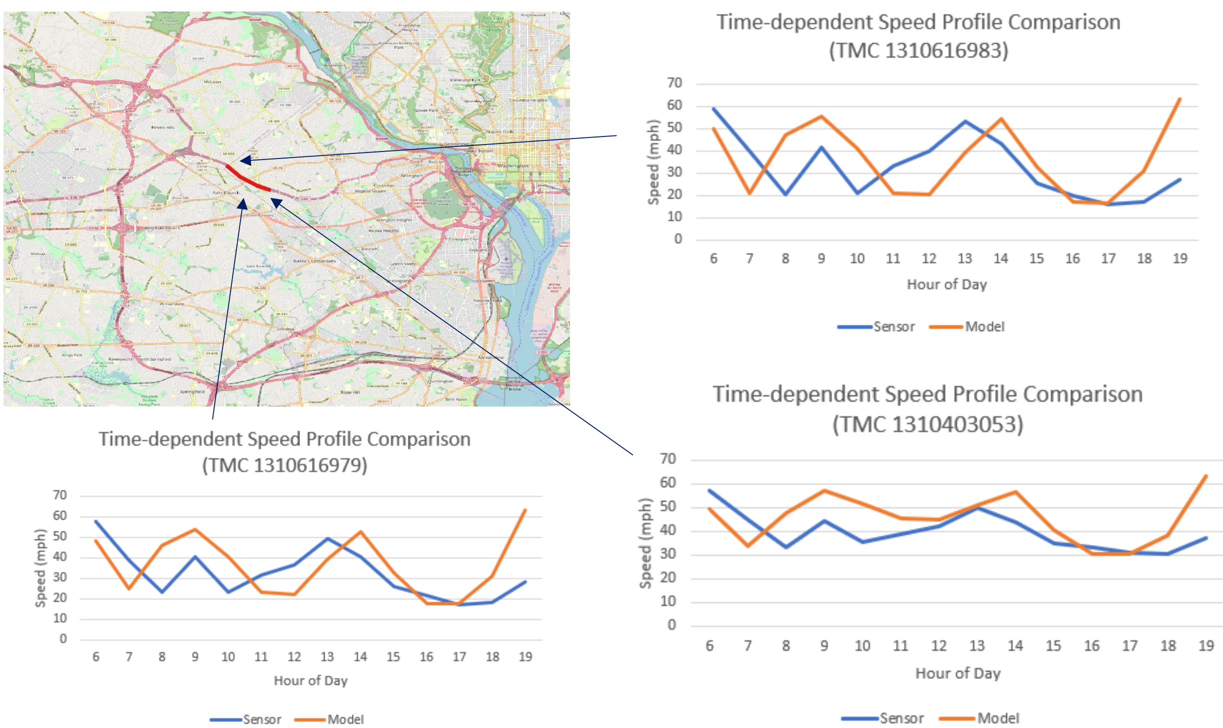


Figure 54 Speed Profiles for I-66 Inside (Westbound)

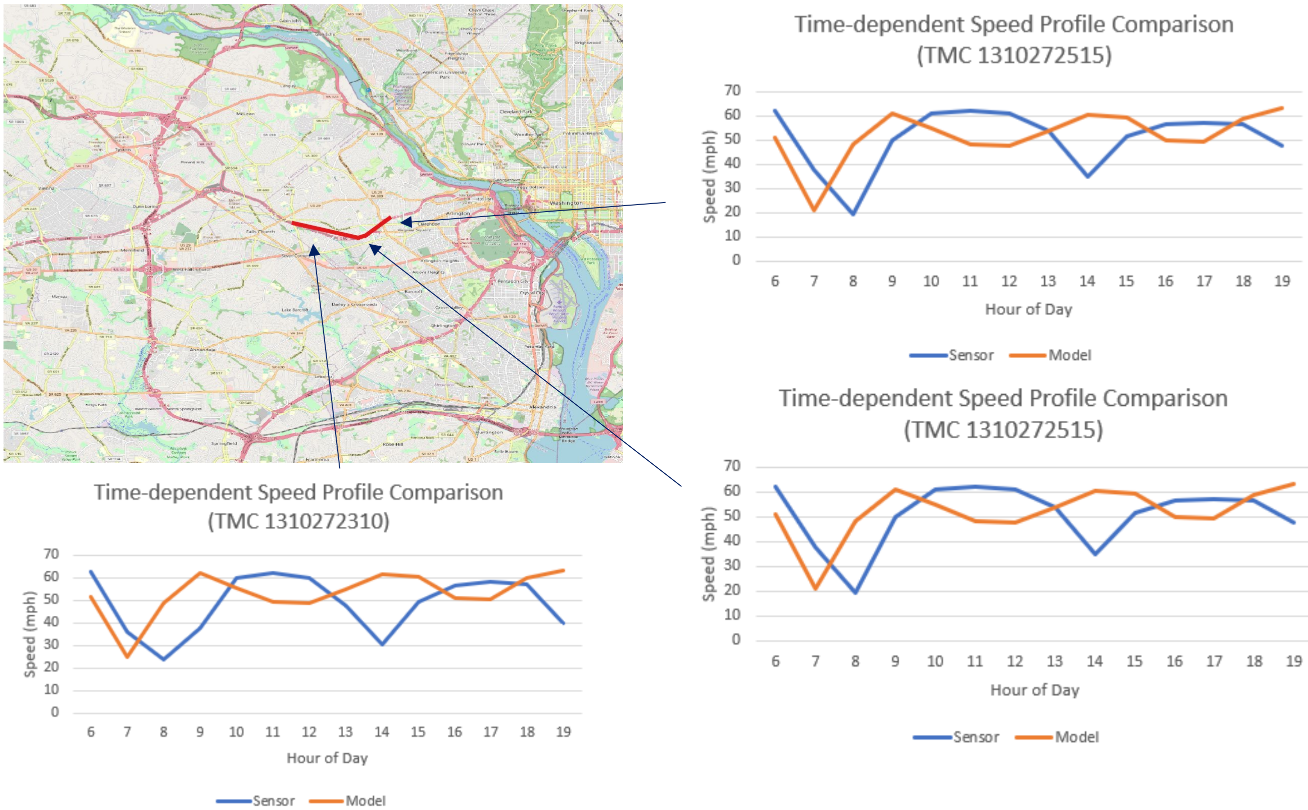


Figure 55 Speed Profiles for I-66 Outside (Eastbound)

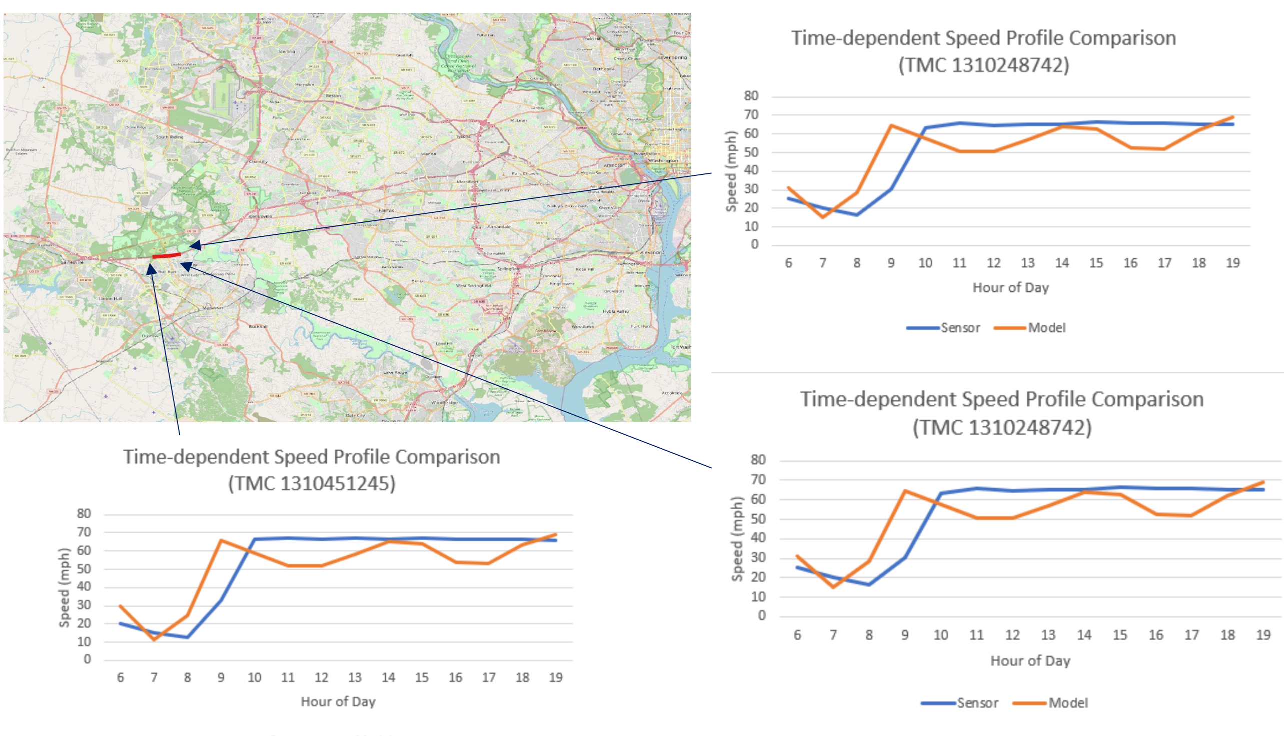


Figure 56 Speed Profiles for I-66 Outside (Westbound)

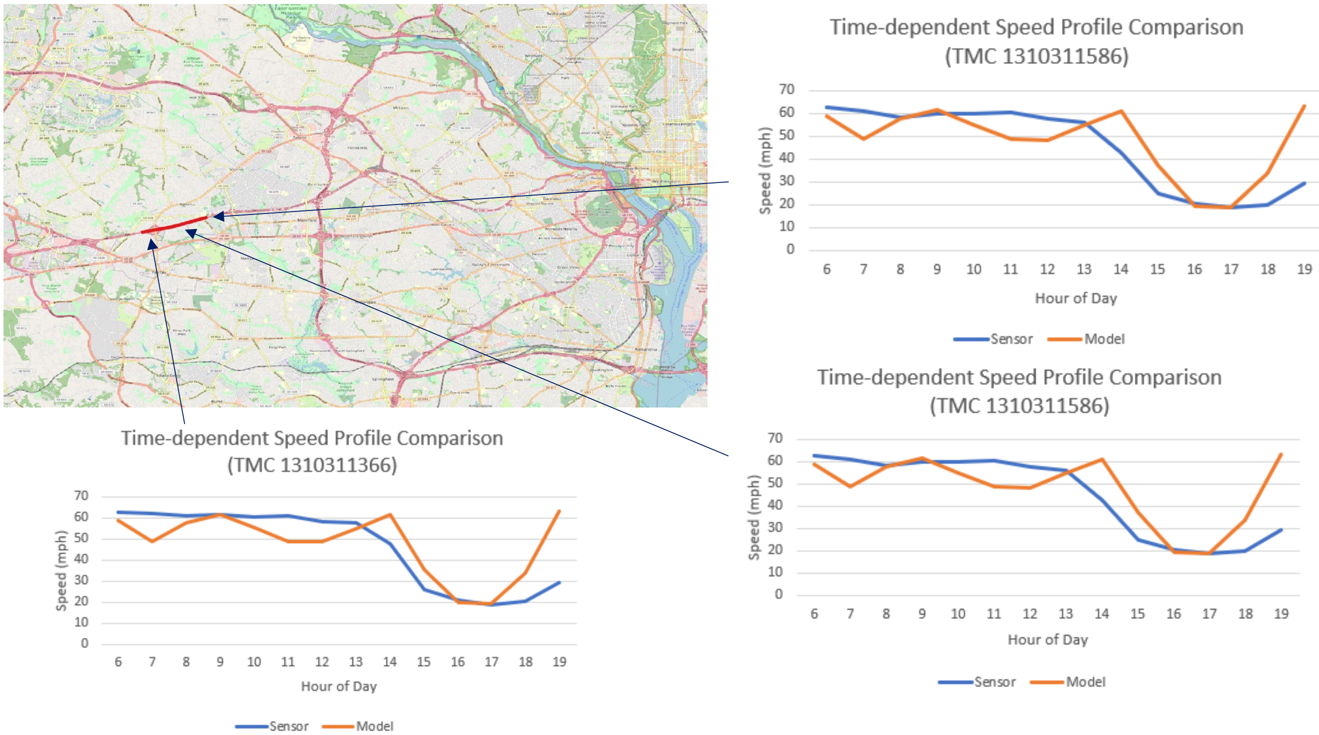


Figure 57 Speed Profiles for I-95 (Northbound)

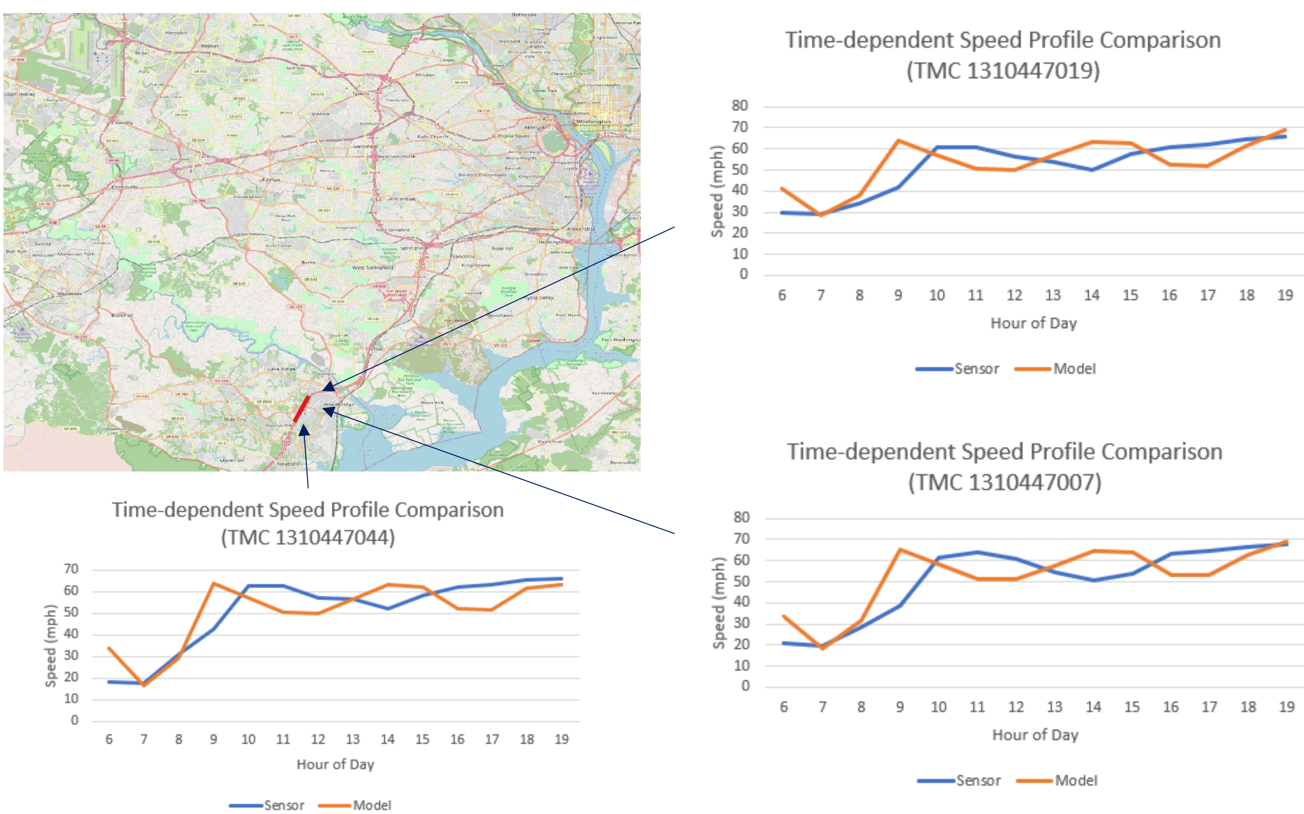


Figure 58 Speed Profiles for I-95 (Southbound)

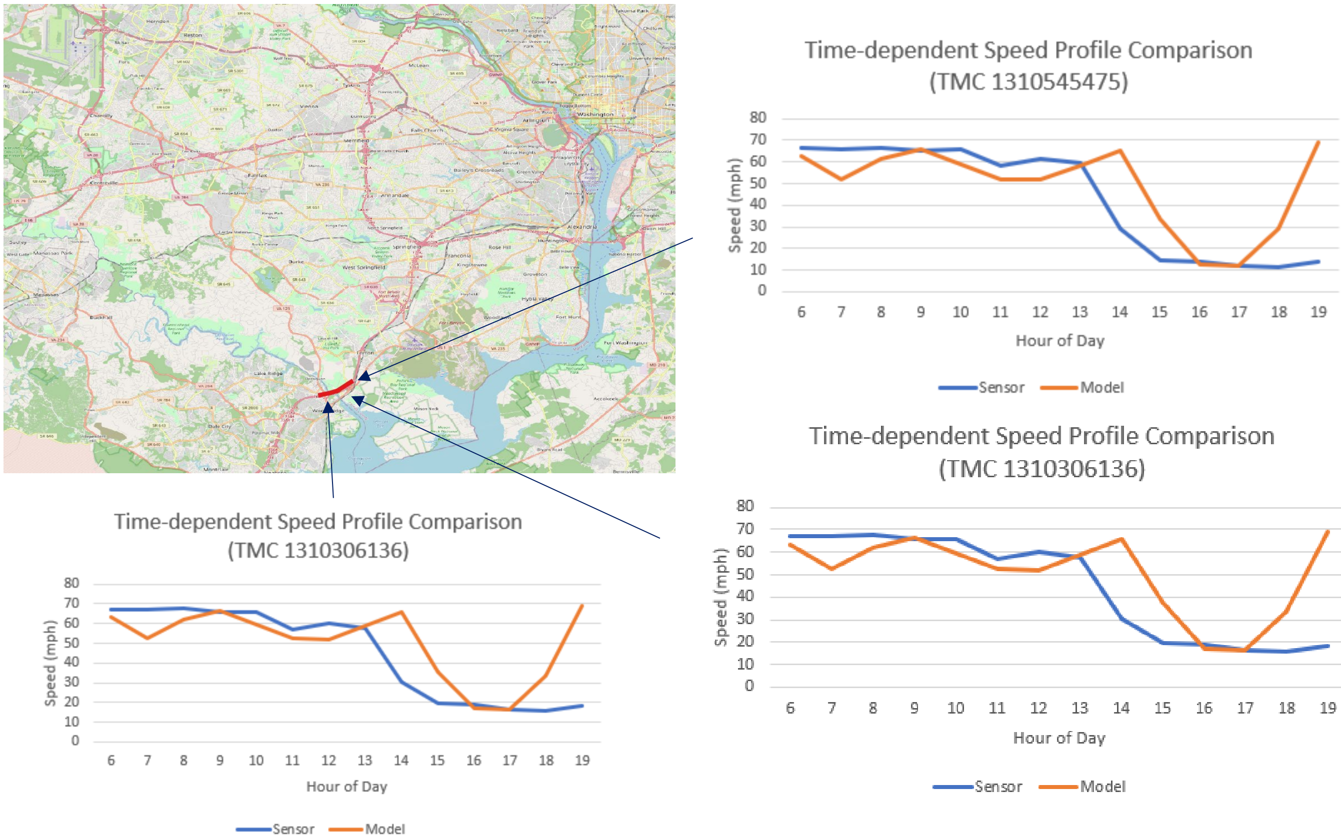


Figure 59 Speed Heatmaps for Southbound Traffic along I-395

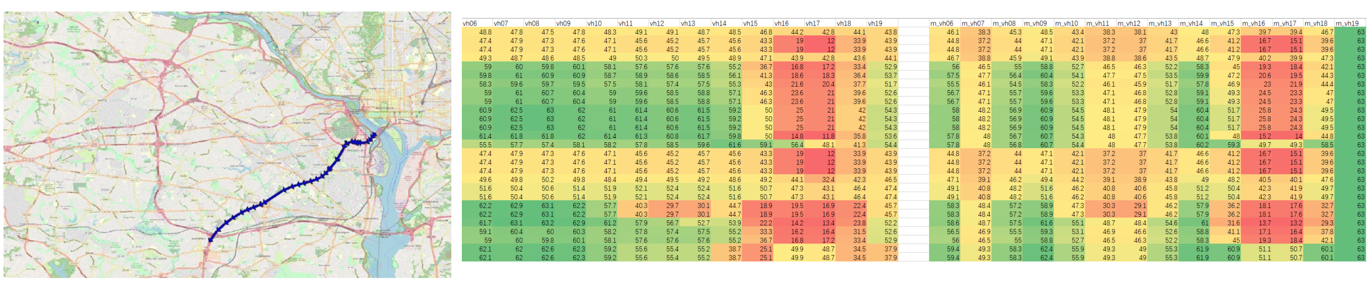


Figure 60 Speed Heatmaps for Eastbound Traffic along I-495

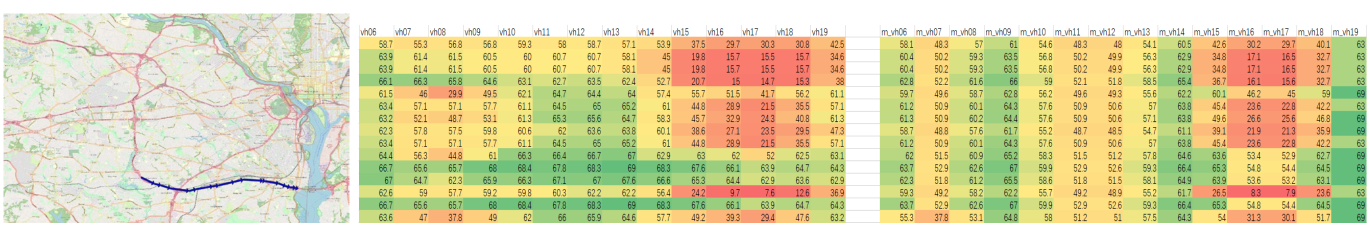


Figure 61 Speed Heatmaps for Westbound Traffic along I-495

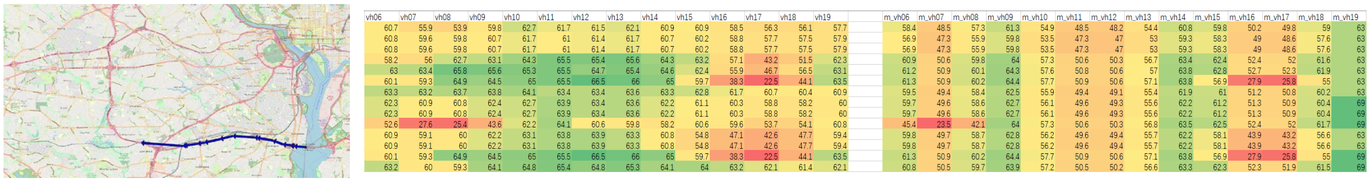


Figure 62 Speed Heatmaps for Northbound Traffic along I-495

Figure 63 Speed Heatmaps for Southbound Traffic along I-495

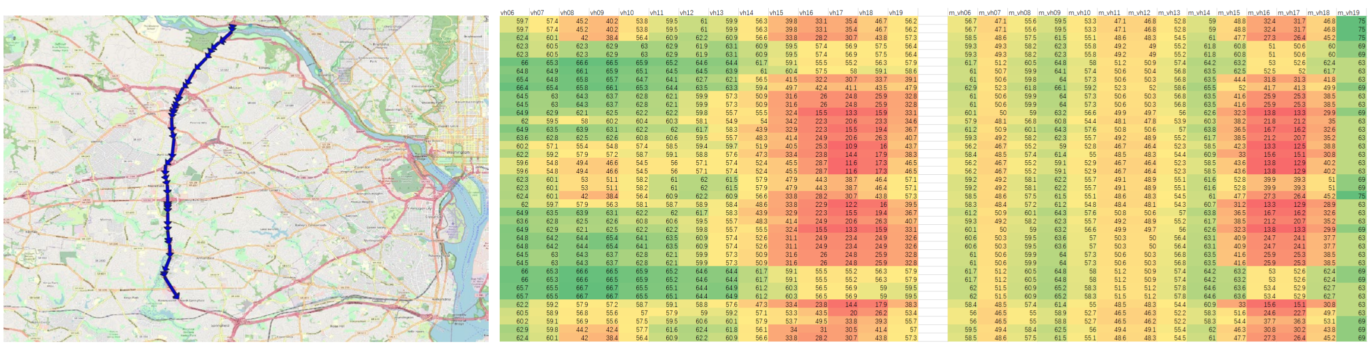


Figure 64 Speed Heatmaps for Eastbound Traffic along I-66 (Inside)

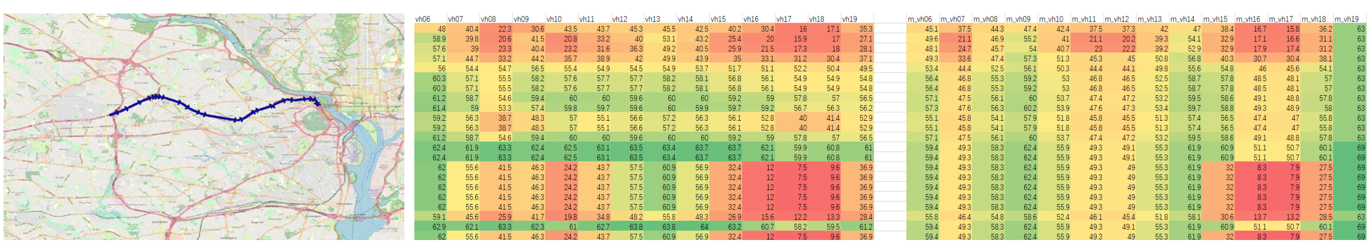


Figure 65 Speed Heatmaps for Westbound Traffic along I-66 (Inside)

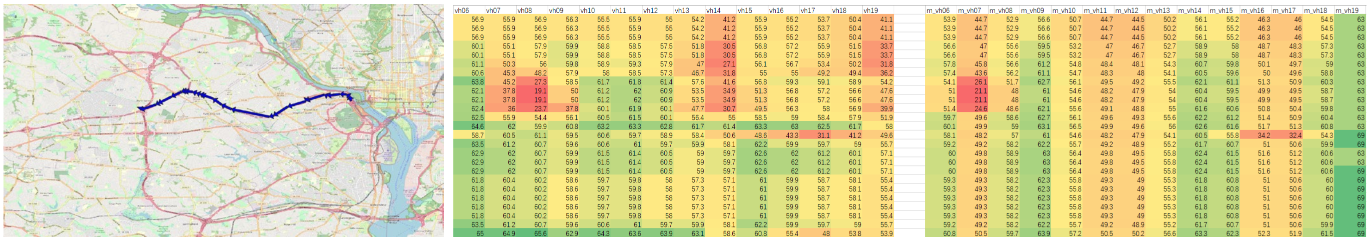


Figure 66 Speed Heatmaps for Eastbound Traffic along I-66 (Outside)

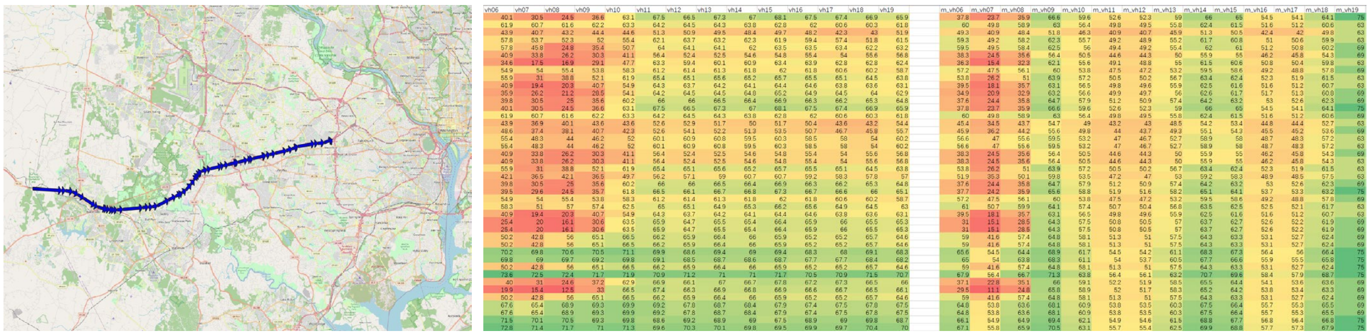


Figure 67 Speed Heatmaps for Westbound Traffic along I-66 (Outside)

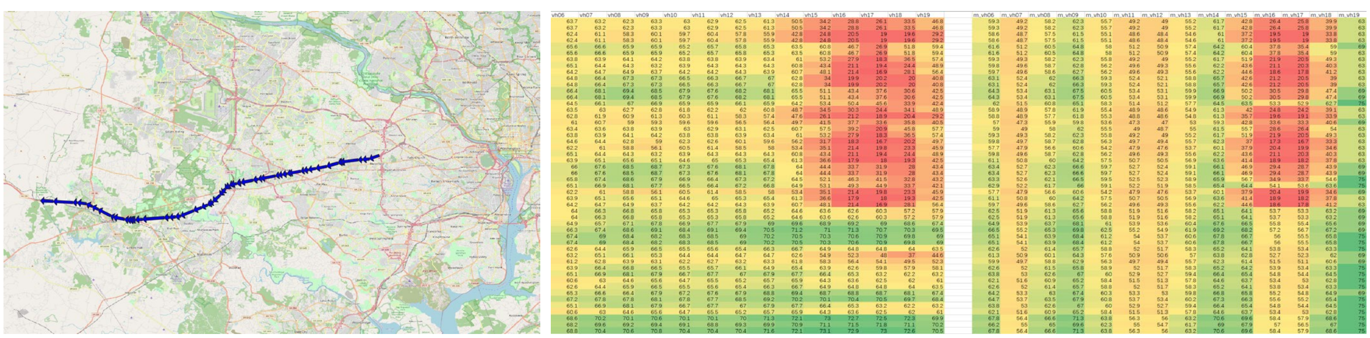


Figure 68 Speed Heatmaps for Northbound Traffic along I-95

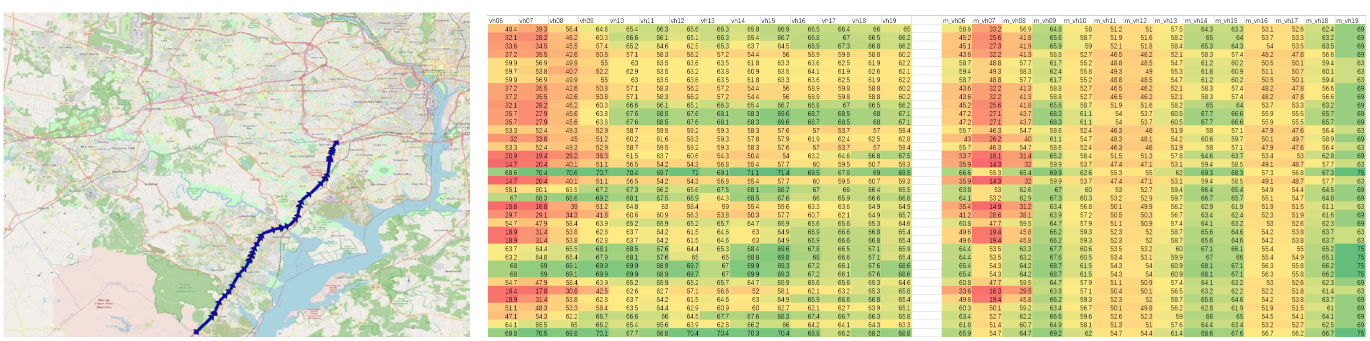
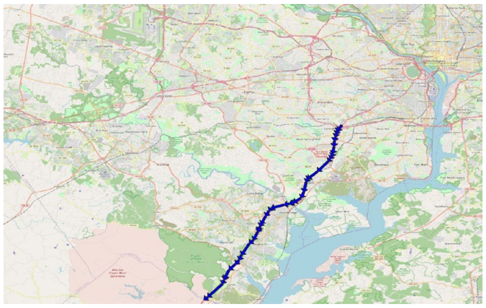


Figure 69 Speed Heatmaps for Southbound Traffic along I-95



vh06	vh07	vh08	vh09	vh10	vh11	vh12	vh13	vh14	vh15	vh16	vh17	vh18	vh19
66.2	65.5	63.6	65.9	65.4	64.4	64.9	64.2	57.8	47.5	43.3	34.4	48.1	54.5
66.5	66	64	66.3	66.1	65	65.3	64.8	57.9	48.9	43.9	35.7	46.4	53.7
68.6	68.9	68.3	68.4	67.3	66.3	66.3	65.7	58.1	48	30.3	23.1	23.2	42.5
68.6	68.9	68.3	68.4	67.3	66.3	66.3	65.7	58.1	48	30.3	23.1	23.2	42.5
67.3	67.5	64.2	63.4	61.6	65.6	71.5	73.1	74.1	73.2	71.1	69.9	70.5	69.8
67.3	67.5	64.2	63.4	61.6	65.6	71.5	73.1	74.1	73.2	71.1	69.9	70.5	69.8
66.7	66	66.6	65.4	65.7	58.4	61.6	59.5	29	14.3	13.9	11.9	11.4	14
67.3	67	67.9	65.8	66	56.9	60.1	57.9	30.1	19.3	18.6	16.4	16	18.2
65.9	67.6	67.6	67.9	66.9	66	65.9	64.9	57.9	37.6	20.9	16.8	17.6	30.2
65.8	64.2	61.5	66.3	66.9	65.9	66.1	65.3	60.1	53.4	42.7	33.9	40	52.4
64.7	59.9	57.5	64.5	66.9	66.6	66.1	66.4	60.4	51.3	37.1	28	33	49.3
65.2	66.2	66.5	65.9	65.4	64.4	64.4	63.8	59	47.1	28.7	22.6	21.9	37.1
66.9	65.6	63.9	65.7	65.1	64	64.5	64.2	58.6	50.9	45.5	36.7	51.1	56.3
64.6	61.9	61.4	62.6	62.3	61.5	61.2	60.9	56.7	53.2	49.2	41.6	51.8	54.3
66.6	66.3	63.7	66.6	66.8	65.1	65.6	64.7	58.6	51.5	44.4	36.7	44.1	53.6
63.4	62.1	63.1	61.6	59.8	55.5	57.7	55.5	44	40.9	40.8	36	37.5	37.6
67.4	67.6	68.1	68.6	67.9	67	66.8	66.6	66.1	64	58	50.1	57.1	58.1
70.5	71.7	72	71.2	69.1	70.6	71.3	72.2	71.1	53	35.8	43	61.8	67.4
69.2	69.7	70.5	70.3	69.2	69.7	69.3	68.5	68.7	67.6	64.9	62.6	65.1	65
69.9	69.6	70.7	70.7	69.9	69.4	69.4	68.2	68.7	68.7	66.1	63.3	65.7	63.8
69.4	66.4	69.1	68.8	69.1	68.2	68.4	69.5	66.6	67.2	63.8	61.3	63.2	65
69.4	66.4	69.1	68.8	69.1	68.2	68.4	69.5	66.6	67.2	63.8	61.3	63.2	65
67.9	67	68.6	69.7	70.2	69.1	69.7	69.6	68.8	66.1	60.8	59.2	65	64.7
66.7	67.1	67.3	67.9	68.5	68	68.4	69.2	68.6	62	53.3	54.8	62.7	64.5
69	67.5	69.1	68.8	68.8	67.6	68.3	68.7	67	66.1	63.3	58.4	60.8	61
67.9	67	68.6	69.7	70.2	69.1	69.7	69.6	68.8	66.1	60.8	59.2	65	64.7
67.4	67.6	68.1	68.6	67.9	67	66.8	66.6	66.1	64	58	50.1	57.1	58.1
69.2	69.7	70.5	70.3	69.2	69.7	69.3	68.5	68.7	67.6	64.9	62.6	65.1	65
67.3	67	67.9	65.8	66	56.9	60.1	57.9	30.1	19.3	18.6	16.4	16	18.2
67.3	67	67.9	65.8	66	56.9	60.1	57.9	30.1	19.3	18.6	16.4	16	18.2
69.1	69.5	70	69.9	68.6	68.7	68.9	68.4	68.6	67.1	64.9	62	64.4	64
66.5	67.3	68.2	67.7	66.9	65.2	66.7	66.2	65.5	64.8	63.4	56.7	58.5	56.4
65.3	65	65.6	65.9	64.6	63.1	64.3	63.5	61.4	60	57.5	50.4	54.9	56
66.5	67.3	68.2	67.7	66.9	65.2	66.7	66.2	65.5	64.8	63.4	56.7	58.5	56.4
67.9	67	68.6	69.7	70.2	69.1	69.7	69.6	68.8	66.1	60.8	59.2	65	64.7

m_vh06	m_vh07	m_vh08	m_vh09	m_vh10	m_vh11	m_vh12	m_vh13	m_vh14	m_vh15	m_vh16	m_vh17	m_vh18	m_vh19
62.8	52.2	61.7	66	59.1	52.2	51.9	58.5	65.4	58.4	37.8	36.5	56.5	63
63.1	52.4	61.9	66.2	59.3	52.3	52.1	58.7	65.7	55.5	37.5	36.6	53.4	63
64.2	53.3	63	67.5	60.4	53.3	53	59.8	66.9	47.9	22.8	22	44.5	69
64.2	53.3	63	67.5	60.4	53.3	53	59.8	66.9	47.9	22.8	22	44.5	69
68.3	56.7	67.1	71.8	64.2	56.7	56.4	63.6	71.1	70	58.8	58.3	69.1	69
68.3	56.7	67.1	71.8	64.2	56.7	56.4	63.6	71.1	70	58.8	58.3	69.1	69
62.6	52	61.5	65.8	58.9	52	51.7	58.3	65.2	33.7	12.5	12	29.2	69
63.1	52.4	62	66.3	59.4	52.4	52.1	58.8	65.7	37.4	16.9	16.4	33.4	69
62.8	52.2	61.7	66	59.1	52.2	51.9	58.5	65.4	37.6	16.3	15.7	33.6	69
62.3	51.7	61.1	65.4	58.6	51.7	51.4	58	64.9	56.4	36.4	35.3	54.4	63
62	51.5	60.9	65.2	58.3	51.5	51.2	57.8	64.6	50.3	27.6	26.6	47.5	69
61.4	51	60.3	64.6	57.8	51	50.7	57.2	64	46	22.2	21.3	42.7	69
63.5	52.8	62.4	66.7	59.7	52.7	52.4	59.1	66.1	61.4	41.6	40	59.8	63
60.4	50.2	59.3	63.5	56.8	50.2	49.9	56.3	62.9	59.7	45	43.9	58.4	63
62.6	52	61.4	65.8	58.9	52	51.7	58.3	65.2	56.7	38.7	37.8	54.8	63
60.1	50	59	63.2	56.5	49.9	49.7	56	62.6	44.7	34.8	34.4	42.4	69
63.1	52.4	61.9	66.3	59.3	52.4	52.1	58.8	65.7	64.7	54.3	53.8	63.8	69
67.4	56	66.2	70.8	63.4	56	55.7	62.8	70.2	61.6	38.5	37	59.5	75
65.8	54.7	64.6	69.1	61.9	54.6	54.3	61.3	68.5	67.5	56.6	56.2	66.6	75
65.6	54.5	64.4	69	61.7	54.5	54.2	61.1	68.4	67.3	56.5	56	66.4	69
64.4	53.5	63.2	67.6	60.6	53.5	53.2	60	67	66	55.4	54.9	65.1	75
64.4	53.5	63.2	67.6	60.6	53.5	53.2	60	67	66	55.4	54.9	65.1	69
65	54	63.8	68.3	61.1	54	53.7	60.5	67.7	66.6	55.9	55.5	65.7	75
64.3	53.4	63.1	67.5	60.5	53.4	53.1	59.9	67	65.9	55.3	54.9	65	75
64.5	53.6	63.4	67.8	60.7	53.6	53.3	60.1	67.2	66.2	55.5	55.1	65.3	75
65	54	63.8	68.3	61.1	54	53.7	60.5	67.7	66.6	55.9	55.5	65.7	75
63.1	52.4	61.9	66.3	59.3	52.4	52.1	58.8	65.7	64.7	54.3	53.8	63.8	69
65.8	54.7	64.6	69.1	61.9	54.6	54.3	61.3	68.5	67.5	56.6	56.2	66.6	63
63.1	52.4	62	66.3	59.4	52.4	52.1	58.8	65.7	35.7	16.9	16.4	33.4	69
63.1	52.4	62	66.3	59.4	52.4	52.1	58.8	65.7	37.4	16.9	16.4	33.4	69
64.9	53.9	63.7	68.1	61	53.9	53.6	60.4	67.5	66.5	55.8	55.3	65.6	63
63.8	53	62.6	67	60	52.9	52.7	59.4	66.4	65.4	54.8	54.4	64.5	69
61.4	51	60.2	64.5	57.7	50.9	50.7	57.1	63.9	62.9	52.8	52.4	62.1	69
63.8	53	62.6	67	60	52.9	52.7	59.4	66.4	65.4	54.8	54.4	64.5	69
65	54	63.8	68.3	61.1	54	53.7	60.5	67.7	66.6	55.9	55.5	65.7	69