
NORTHERN VIRGINIA TRANSPORTATION COMMISSION

# Advancing Bus Priority in Northern Virginia

July 2023

# Executive Summary

Traffic congestion is a problem experienced by all road users but can be somewhat mitigated for bus transit through the implementation of bus priority treatments. Seven bus operators serve Northern Virginia, highlighting the importance of bus to the region. The purpose of this report is to both better understand how the region's bus speeds are affected by congestion as well as find ways to prioritize the study and installation of bus priority treatments.

This study was primarily conducted using static general transit feed specification (GTFS) data, an expression of transit schedules. These data were used to estimate scheduled bus travel time and bus speeds. The analysis found that bus speed varied by time of day and geography. Excess delays caused by congestion follow similar patterns. The congestion-caused bus delays built into the region's transit schedules are estimated to cost the region $19 million per year.

The congestion-driven costs and delays could be mitigated using bus priority treatments. This report demonstrates different ways these treatments can be prioritized, including by location or bus route.

Overall, this evaluation has conservatively estimated the cost of congestion to transit agencies in Northern Virginia and provided ways to prioritize potential solutions. This work helps the region's transit by:

1. Identifying opportunities for improving speed and congestion issues
2. Facilitating more strategic funding solutions in the region
3. Leveraging the regional nature of Northern Virginia's bus to achieve shared benefits
4. Connecting to related work in the region

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## Acknowledgements

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# 1.0 Introduction

Congestion has a huge impact on travel. It can lengthen trips, make trips unreliable and increase costs. While this affects many modes of travel, it is particularly true for bus transit. Unlike trains, buses typically operate in mixed traffic, meaning they can get stuck in the same road congestion as cars. Unlike cars, buses can carry many more people, meaning a bus stuck in congestion typically affects more people than a car stuck in congestion. As the Washington, DC region is one of the most congested regions in the country[1], these congestion issues are of particular concern for Northern Virginia.

*Figure 1: Loudoun County Transit and Metro buses stuck in traffic*


The impacts of congestion on buses can be mitigated through a variety of bus priority treatments, including transit signal priority, priority bus lanes and queue jumps among others. These treatments are especially effective when used in concert, like with bus rapid transit (BRT) where specially designed infrastructure, policies and vehicles can help buses move more efficiently and reliably. However, while there are many benefits to implementing bus priority treatments, they require the use of limited resources including funding, political capital and roadway space.

The purpose of this report is two-fold. First, the report documents the existing speed and congestion issues for buses, giving insight into the severity of the congestion problem in the region. Second, the report provides a way to prioritize bus priority treatments by focusing on their financial impacts to agencies and jurisdictions. The financial evaluation will highlight where bus priority treatments could be considered, the scale of bus congestion concern and

[1] https://inrix.com/scorecard/#city-ranking-list

provide a way to compare multiple locations in the region. It also provides a justification for securing more funding for bus priority treatments in the region.

## 1.1 Evaluation Overview

Bus speed and congestion can be evaluated by using bus operational metrics like travel time, bus stop spacing and speed. With multiple bus operators in the region[2], including Arlington Transit (ART), Loudoun County Transit (LCT), OmniRide, DASH, Fairfax Connector and the Washington Metropolitan Area Transit Authority (Metro), evaluating bus operations in Northern Virginia provides an opportunity to observe differences in how congestion is incorporated into different bus operations. Further, the regional approach provides more variation in geography and route types, enabling a better understanding of how congestion varies. Finally, solutions to managing congestion may not be fully achievable within one jurisdiction or transit agency. A regional approach gives an opportunity to see where overlapping service areas and responsibilities could be leveraged to achieve regional transit goals. This report evaluates bus operations and congestion using regional summaries as well as an approximation of bus operational cost impacts.

The evaluation of regional bus begins with an overview of regional bus operations. This includes a variety of descriptive statistics and visuals for bus travel time, bus stop spacing and estimated bus speeds. The statistics and visuals can show how speeds and stop spacing vary across agencies, how bus speed varies through geographies and how trip times may vary throughout a day.

Transit agencies typically run multiple bus trips for a route throughout the day. However, bus trip times may vary because of anticipated congestion. For example, **Figure 2** gives a snapshot of the Metrobus 28A bus schedule. The route's first trip from King Steet starts at 5:05 a.m. and finishes at 6:17 a.m., a total travel time of 72 minutes. The last trip in the screenshot starts at 8:00 a.m., when traffic is heavier, and finishes at 9:36 a.m., a total of 96 minutes. Although both trips cover the same distance and serve the same stops the latter trip takes 24 minutes longer.

In a transit schedule, the smallest scheduled trip time typically represents when the least amount of congestion is expected. Thus, the difference between the smallest trip time and other trip times for the same route can often be attributed to congestion. This excess scheduled time can be aggregated to a year to get the annual operational impact of schedule variation. The cost of scheduled bus time variation can then be estimated by multiplying by a transit agency's average hourly operational costs. Consequently, the cost of scheduled bus time variation gives the potential opportunity cost of forgoing the implementation of bus priority treatments. This evaluation makes the case for where bus priority treatments could be implemented, how these treatments might be prioritized and where the cost of bus priority treatments could be shared across transit operators.

[2] Due to lack of data this analysis does not include the City of Fairfax City-University Energysaver (CUE)

*Figure 2: Snapshot of Metrobus 28A schedule (December 2022)*

**Westbound To Tysons station**

**Monday thru Friday — De Lunes a viernes**

| Route Number | King St-Old Town | Duke St. & Alexandria Commons Shopping Center | Duke St. (service road) & N. Jordan St | Seminary Rd. & Howard St. | Southern Towers (Stratford Bldg.) | Fillmore Ave. & Bisdorf Dr. (NVCC) | Columbia Pike & Carlin Springs Rd. | Leave Seven Corners Transit Center | East Falls Church | N. Washington St. & Park Ave. | West Falls Church | Leesburg Pike & Lisle Ave. | TYSONS (south side) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AM Service — Servicio matutino** | | | | | | | | | | | | | |
| **28A** | - | - | - | - | 4:18 | 4:22 | 4:29 | 4:43 | 4:48 | 4:53 | 5:01 | 5:08 | 5:12 |
| **28A** | - | - | - | - | 4:43 | 4:47 | 4:54 | 5:08 | 5:13 | 5:18 | 5:26 | 5:33 | 5:37 |
| **28A** | - | - | - | - | 5:03 | 5:07 | 5:14 | 5:28 | 5:33 | 5:38 | 5:46 | 5:53 | 5:57 |
| **28A** | 5:05 | 5:09 | 5:13 | 5:17 | 5:23 | 5:27 | 5:34 | 5:48 | 5:53 | 5:58 | 6:06 | 6:13 | 6:17 |
| **28A** | 5:25 | 5:29 | 5:33 | 5:37 | 5:43 | 5:49 | 5:58 | 6:14 | 6:20 | 6:26 | 6:35 | 6:43 | 6:48 |
| **28A** | 5:45 | 5:49 | 5:53 | 5:57 | 6:03 | 6:09 | 6:18 | 6:34 | 6:40 | 6:46 | 6:55 | 7:03 | 7:08 |
| **28A** | 6:00 | 6:04 | 6:09 | 6:14 | 6:23 | 6:29 | 6:39 | 6:55 | 7:03 | 7:11 | 7:21 | 7:29 | 7:34 |
| **28A** | 6:15 | 6:19 | 6:24 | 6:29 | 6:38 | 6:44 | 6:54 | 7:10 | 7:18 | 7:26 | 7:36 | 7:44 | 7:49 |
| **28A** | 6:30 | 6:34 | 6:39 | 6:44 | 6:53 | 6:59 | 7:09 | 7:25 | 7:33 | 7:41 | 7:51 | 7:59 | 8:04 |
| **28A** | 6:45 | 6:49 | 6:54 | 6:59 | 7:08 | 7:14 | 7:24 | 7:40 | 7:48 | 7:56 | 8:06 | 8:14 | 8:19 |
| **28A** | 7:00 | 7:06 | 7:11 | 7:16 | 7:24 | 7:30 | 7:39 | 7:55 | 8:02 | 8:09 | 8:19 | 8:30 | 8:36 |
| **28A** | 7:12 | 7:18 | 7:23 | 7:28 | 7:36 | 7:42 | 7:51 | 8:07 | 8:14 | 8:21 | 8:31 | 8:42 | 8:48 |
| **28A** | 7:24 | 7:30 | 7:35 | 7:40 | 7:48 | 7:54 | 8:03 | 8:19 | 8:26 | 8:33 | 8:43 | 8:54 | 9:00 |
| **28A** | 7:36 | 7:42 | 7:47 | 7:52 | 8:00 | 8:06 | 8:15 | 8:31 | 8:38 | 8:45 | 8:55 | 9:06 | 9:12 |
| **28A** | 7:48 | 7:54 | 7:59 | 8:04 | 8:12 | 8:18 | 8:27 | 8:43 | 8:50 | 8:57 | 9:07 | 9:18 | 9:24 |
| **28A** | 8:00 | 8:06 | 8:11 | 8:16 | 8:24 | 8:30 | 8:39 | 8:55 | 9:02 | 9:09 | 9:19 | 9:30 | 9:36 |

Finally, while bus routes and schedules are represented quantitatively as positions in space and time, they are the outcome of heuristic processes, the tweaking and adjustments by transit planners with knowledge and experience in the region. Thus, while the analysis is mostly quantitative, it is built off many years of experience in, and knowledge of, the region, capturing an understanding of regional travel variations that might not be clear in other resource-constrained data collection process, like traffic counts. Through these combined analyses, we hope to better understand how embedded congestion is in the region and how it affects scheduled transit services.

## 2.0 Data and Methodology

This evaluation uses publicly available data for all aspects of this analysis. All bus schedule data is sourced from General Transit Feed Specification (GTFS)[3] for each respective transit agency with bus operating data sourced from the Federal Transit Administration (FTA) National Transit Database (NTD). Data is described in more detail in Section 2.1.

Bus travel time, stop spacing, and average speeds each need to be estimated to produce descriptive statistics for regional bus operations. Descriptive statistics show how these metrics vary by transit agency, geography, and time. The second part of the analysis uses the

[3] https://developers.google.com/transit/gtfs

calculations for bus travel time, as well as estimated operating cost, to estimate the annual operating cost impact of variations in travel time. Each of these calculations are described in Sections 2.2 and 2.3.

## 2.1 Data

GTFS is a standard data format for transit schedules. It includes the geographic location of transit stops, the path a vehicle travels between stops, the timing and sequence of transit trips and the number of trips for each transit route. GTFS data can be used to obtain the physical location of bus stops on a bus route as well as the scheduled timing of buses at stops. All GTFS data were downloaded in February 2023.

FTA NTD estimates of operating cost per vehicle revenue hour were used to estimate costs. Due to some regional variations in bus productivity in 2021, 2020 FTA NTD data was used. As these numbers are lower than 2021, the cost estimates will be lower and more conservative than if more recent operational cost numbers were used.

## 2.2 Bus Operational Metrics

Three bus operational metrics are used in this evaluation: bus trip time, bus stop spacing and bus speeds. The former two are used to calculate the third. The calculation processes and assumptions for all three are described below.

### Step 1: Estimating Bus Trip Time

Bus trip time is the total of moving time, (the time in which the bus is traveling between bus stops) and bus stop delays (where a bus is preparing to stop or has stopped to service a bus stop). As **Table 1** shows, the components of bus travel time can be broken down into several categories.

It can be assumed some travel time components will be relatively constant throughout the day while some will vary based on demand to the transportation system. For example, neither acceleration nor deceleration will likely vary significantly through the day while congested time often increases during peak travel periods. Although there may be some variation to the time-of-day independent travel time components, we are assuming the variation is small enough that they do not significantly affect scheduled bus travel times. This assumption leaves congestion and dwell time as the two major components of travel time that vary through the day[4]. While both can vary significantly, depending on the time of day and the demand experienced by the transportation system, as **Table 1** shows, bus schedules account for these two times differently. Through using scheduled departure and arrival times, significant expected passenger delays can be somewhat accounted for separately to bus travel time. If passenger loading is small, dwell time is not expected to significantly influence

[4] Congestion delay contributes to up to 20-30% of bus travel time https://www.mwcog.org/documents/2011/04/01/bus-priority-treatment-guidelines-bus-bus-priority/

the scheduled bus time. Thus, considering these assumptions, for the purposes of this report, we are defining travel time as the difference between scheduled bus arrival time at one stop and scheduled bus departure time at the previous stop, as shown in **Appendix A**.

*Table 1: Composition of bus travel time*

| Travel Time Component | Description | Average Time[5] | Relatively constant through the day | Scheduled Time | |
|---|---|---|---|---|---|
| | | | | *Stop 1 Arrival to Stop 1 Departure* | *Stop 1 Departure to Stop 2 Arrival* |
| Travel time | Time when bus is driving between bus stops | > 1 minute | ✓ | | ✓ |
| Congestion | Excess delay caused by other vehicles | 0 to >1 minute | | | ✓ |
| Deceleration | Time spent slowing to a stop | 4.5 seconds (from 40 mph) | ✓ | | ✓ |
| Bus stop failure | Time spent waiting for other buses to unload | Up to dwell time and signal delay | ✓ | ✓ | |
| Boarding lost time | Time spent waiting for passengers to walk to the bus from the bus stop | 2.5 to 9 seconds | ✓ | ✓ | |
| Passenger service (dwell time) | Time for passengers to board and alight from bus | 10 to 60 seconds | | ✓ | |
| Traffic signal delay | Time spent waiting for a green light after passengers boarded | 0 to 70 seconds | ✓ | | ✓ |
| Re-entry delay | Time spent waiting for gap to reenter traffic | 0 to length of traffic signal green interval | ✓ | | ✓ |
| Acceleration | Time spent accelerating to travel speed | 5.5 seconds (to 25 mph) | ✓ | | ✓ |

### Step 2: Estimating Bus Stop Spacing

Bus stop spacing is the distance between a bus stop pair – how far a bus travels along its route between one bus stop and the next. A segment is one bus stop pair with a scheduled trip including multiple connected segments. **Appendix A** describes the estimation of distance.

[5] Kittelson & Associates, Inc, Parsons Brinckerhoff, KFH Group, Inc, Texas A&M Transportation Institute, ARUP. 2013. TCRP Report 165: Transit Capacity and Quality of Service Manual. Third edition.

The calculation process has two major steps. First, all bus stops are identified. While GTFS provides bus stop geographic locations, these locations might slightly differ when a bus stop is shared between multiple transit agencies, meaning they appear to be in slightly different locations in different GTFS files. To resolve this issue, a cluster analysis was used to group bus stops that are likely to be in the same geographic location, as described in **Appendix A**. As GTFS does not directly connect a bus stop's geographic location to the path a bus travels, the distance had to be estimated. This process is also described in **Appendix A**.

#### Step 3: Estimating Bus Speeds

The calculations of bus travel time and bus stop spacing can be used to estimate average bus speeds between stops. Equation 3 in **Appendix A** shows how speed is estimated. These bus speeds can be estimated for different trips through the day as well as for different bus operators. However, as there can be inconsistencies in GTFS data, some calculated speeds are not realistic. Thus, a two-phase cleaning process was employed. First, any speeds that were unreasonably large (scheduled faster than 70 mph) or small (scheduled less than 1 mph) were removed. Second, speed outliers[6] for a route segment were identified and removed. The process for calculating and cleaning speeds is described in **Appendix A**.

### *2.3 Estimating Annual Operational Cost Impacts*

Previous research[7] has demonstrated an agency's estimated bus cost per vehicle revenue hour can be used to estimate the potential operational cost impact of the variations in travel time. This is the sum of all differences between a segment's trip time and minimum trip time for all trips for a route in an average week multiplied by the bus cost per vehicle revenue hour. **Appendix A** shows how this can be calculated at both the bus route level as well as at the transit agency level. The number is annualized by multiplying by 52, the number of weeks in a year.

## 3.0 Results and Discussion

In Northern Virginia, bus speeds vary by geography, time and the type of bus operation. This section highlights these variations and gives some insight into how and why buses may slow down in the region. In addition, the evaluation of travel time costs indicates which operators may be most impacted by congestion and where the issues are particularly pronounced. The findings from both results are important for diagnosing where bus priority treatments might be useful.

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[6] 1.5 times the interquartile range

[7] Arias, D., Todd, K., Krieger, J., Maddox, S., Haley, P., Watkins, K.E. and Berrebi, S., 2021. Using GTFS to calculate travel time savings potential of bus preferential treatments. *Transportation Research Record*, 2675(9), pp.1643-1654.

## 3.1 Regional Bus Trends

Although speed limits legally govern bus speeds like all road vehicles, they are often not the primary speed limiter for buses. Road speed limits can sometimes be higher than a bus is able to safely maintain or reach due to other factors. **Table 2** summarizes some of the factors that may influence or restrict bus speeds. This section uses these factors to help explain regional trends in bus speeds resulting from the analyses described in the previous section. **Figure 3** shows box and whisker plots[8] for bus stop spacing trends by transit agency; **Figure 3** and **4** shows box and whisker plots for bus speed trends by transit agency; and **Figure 6** shows peak travel period bus speeds by geography.

*Table 2: Factors that influence bus speeds*

| Factor | Explanation |
|---|---|
| Speed limits | Legal limit for bus speeds. |
| Bus stop spacing | Bus stop spacing has been directly linked to bus speeds with increases in spacing reducing travel time and increasing speeds[9]. |
| Congestion | Recurring congestion (congestion caused by traffic typically associated with peak travel demand patterns[10]) can slow bus speeds. |
| High Occupancy Toll (HOT) lanes | Tolled express lanes that allow high occupancy vehicles, like buses, operate at higher speeds by avoiding traffic |
| Population and employment density | In addition to being more likely to have small bus stop spacing and more congestion, denser areas are more likely to have more multimodal conflicts, traffic signals and other interruptions to traffic flow. |
| Elevation | Bus speeds are more sensitive to increased elevation than cars. Consequently, increases in elevation may slow bus speeds. |

National guidance[11] for bus stop spacing recommends bus stops spacing be designed based on the goals of the route. Recommendations range from 800 feet for dense, local services to half a mile for rapid transit lines. A quarter mile is often assumed to be an accessible walking distance by transit planners. As mentioned earlier, greater spacing means buses can travel faster while smaller spacing can mean greater bus stop accessibility. Consequently, the design of bus stop spacing can be a tradeoff that is defined by the goals and needs of the route.

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[8] **Appendix B** explains how to interpret box and whisker plots. The axes in **Figure 3** and **4** were truncated to improve plot legibility. This means some outliers are not shown.
[9] El-Geneidy, A. M., Strathman, J. G., Kimpel, T. J., & Crout, D. T. 2006. Effects of bus stop consolidation on passenger activity and transit operations. Transportation Research Record, 1971(1), 32-41.
[10] https://ops.fhwa.dot.gov/program_areas/reduce-recur-cong.htm
[11] https://nacto.org/publication/transit-street-design-guide/transit-system-strategies/network-strategies/from-stops-to-stations/

*Figure 3: Bus agency stop spacing*

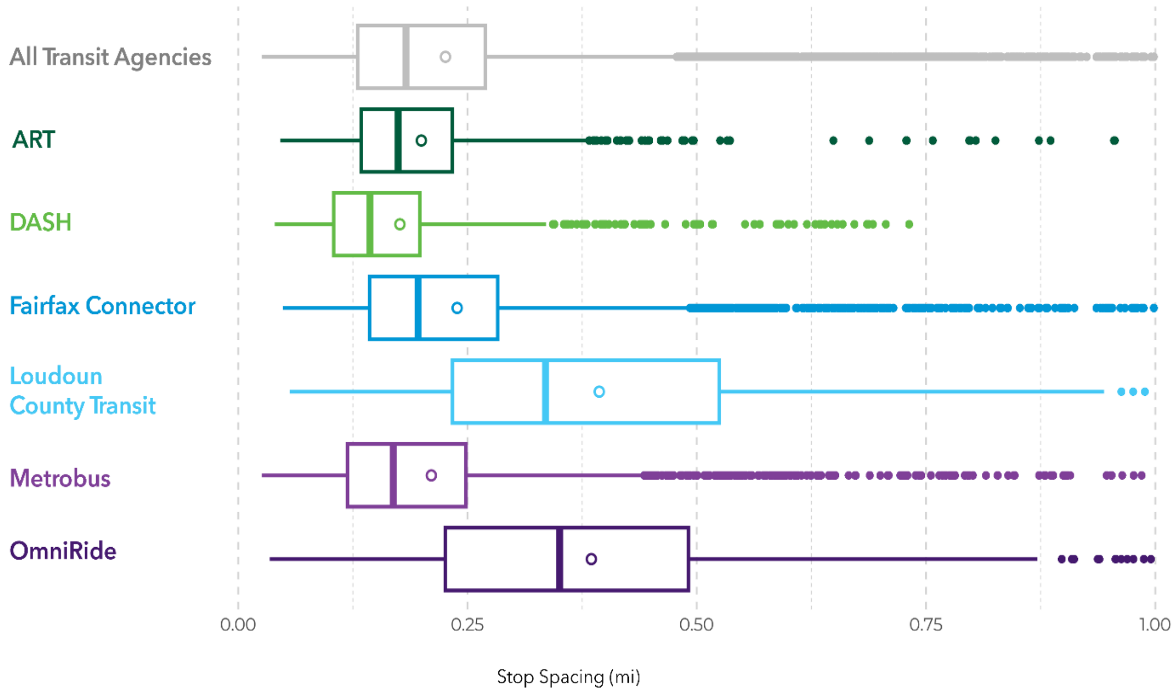
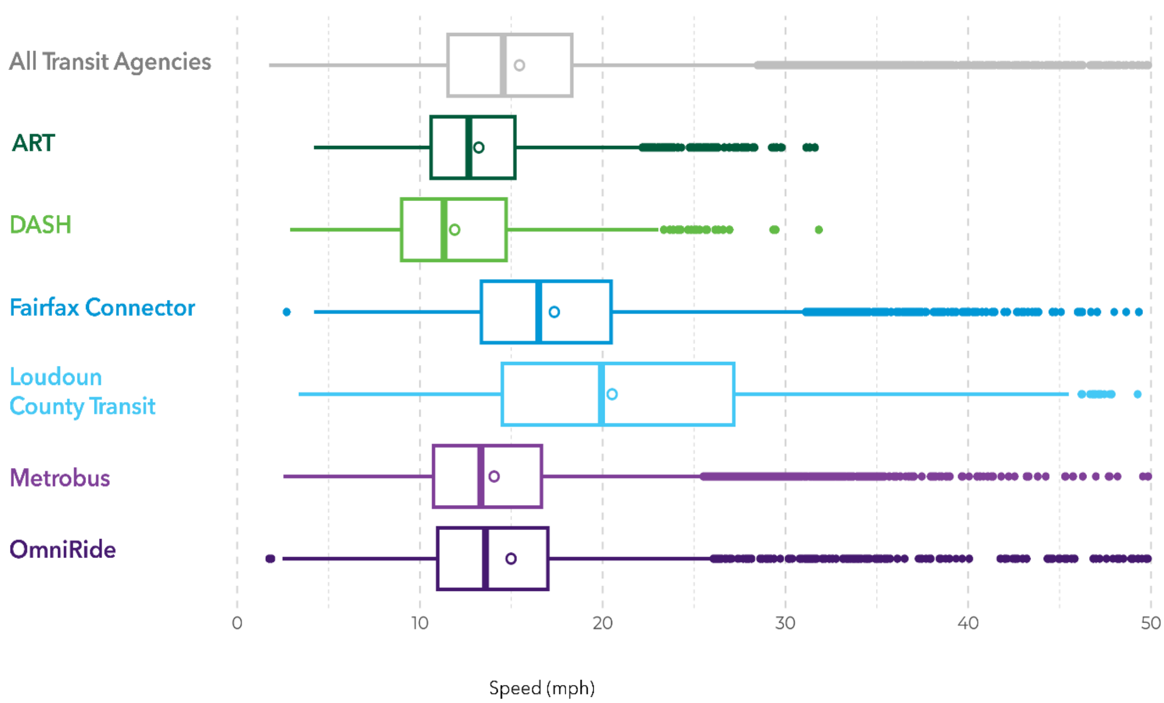



*Figure 4: Bus agency average segment speed*



As **Figure 3** shows, Northern Virginia bus stop spacing is typically less than a quarter mile, characteristic of bus stop spacing in the United States[12]. ART, DASH and Metro all have approximately 75% or more of their bus stops under a quarter mile. ART and DASH have the smallest interquartile ranges, indicating there is less variance around the stop spacing. Fairfax Connector and Metro have more variance in their spacing while LCT and OmniRide have the most. In all cases, the average is greater than the median, indicating there are a lot more smaller values than there are larger values (data is positively skewed).

The type of bus operations and operating environment have a large influence on bus stop spacing, as the national guidance cited earlier recommended. Both ART and DASH operate primarily local bus service in denser areas, explaining why there is less variance around their values. Fairfax Connector and Metro have more variety of services with some longer, regional routes and even some more commuter-oriented routes in their mix. This also helps explain why they have a larger interquartile range. Finally, both LCT and OmniRide, based in the less dense, outlying areas of Loudoun County and Prince William County, respectively, have significant commuter bus operations. Commuter bus operations typically have a cluster of stops in outlying areas and cluster of stops in dense employment centers. They also have "at least five miles of closed-door service[13]," meaning the bus stop spacing for part of the trip is greater than five miles. Thus, these agencies have greater ranges in bus stop spacing.

As mentioned earlier, bus stop spacing is related to bus speed, and comparisons of **Figures 3** and **4** mostly support this claim. However, while the spread in bus stop spacing and bus speeds are similar for most Northern Virginia agencies, there are some differences. This is largely because bus agency speeds are calculated for every trip while bus stop spacing has one observation for each stop pair. Thus, the spread in speed data in **Figure 4** is weighted towards bus routes with more service. This may help explain why Metro has slightly higher speeds than its bus stop spacing suggests. Metro has some Northern Virginia's of the highest frequency bus routes in Northern Virginia.

The starkest difference between stop spacing and bus speeds is seen with OmniRide's services. Although OmniRide and LCT have comparable average speeds at a trip level, bus speeds vary significantly at a segment level, as **Figure 4** shows. This is largely because the calculation of a simple average segment speed does not consider the segment length. For example, if a four-mile segment averaged 40 miles per hour, and a one-mile segment averaged 20 miles per hour, the simple average would be 30 miles per hour. However, when accounting for segment length, like with an average trip speed calculation, the average is closer to 33.3 miles per hour. An evaluation of LCT and OmniRide service gives some insight into how this is occurring. While LCT and OmniRide have similar types of services, and even similar proportions of services[14], the speed profiles for the three types of bus services are very

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[12] Pandey, A., L. Lehe, and D. Monzer. Distributions of Bus Stop Spacings in the United States. Transport Findings, 2021. https://doi.org/10.32866/001c.27373.
[13] https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary
[14] Both, for example, have local bus make up about 41% of all weekly trips

different. **Figure 5** shows how the speeds of the two agency's service types vary. As the figure shows, LCT's service speeds vary by service type while OmniRide's are more similar across services. As **Table 3** shows, average bus stop spacing also varies by service type. When combined, the different speed profiles are weighted by the different segment distances (bus stop spacing), resulting in different distributions of segment speeds for each agency.

When looking at bus speeds across geography, as seen in **Figure 6**, the role of density and congestion becomes particularly evident. During morning travel periods, bus speeds are slow around the region but slowest within the Beltway (I-495), especially in Arlington and Alexandria. This is expected given the location of bridge crossings towards Washington, DC's central business district as well as the larger density of employment centers in this area, meaning there is likely to be a greater traffic load on the road network in this area. These areas are also denser, meaning slower speed limits, more traffic signals and other interruptions to traffic flow.

*Figure 5: OmniRide and LCT bus speed comparisons*

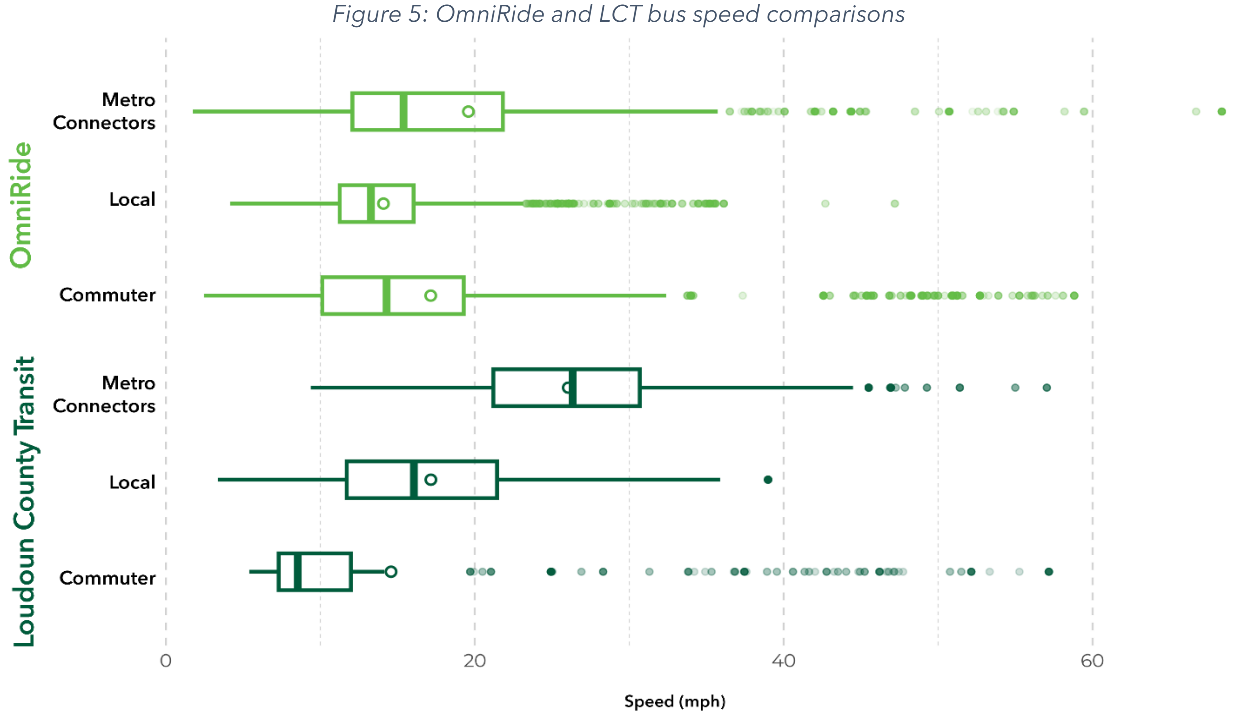
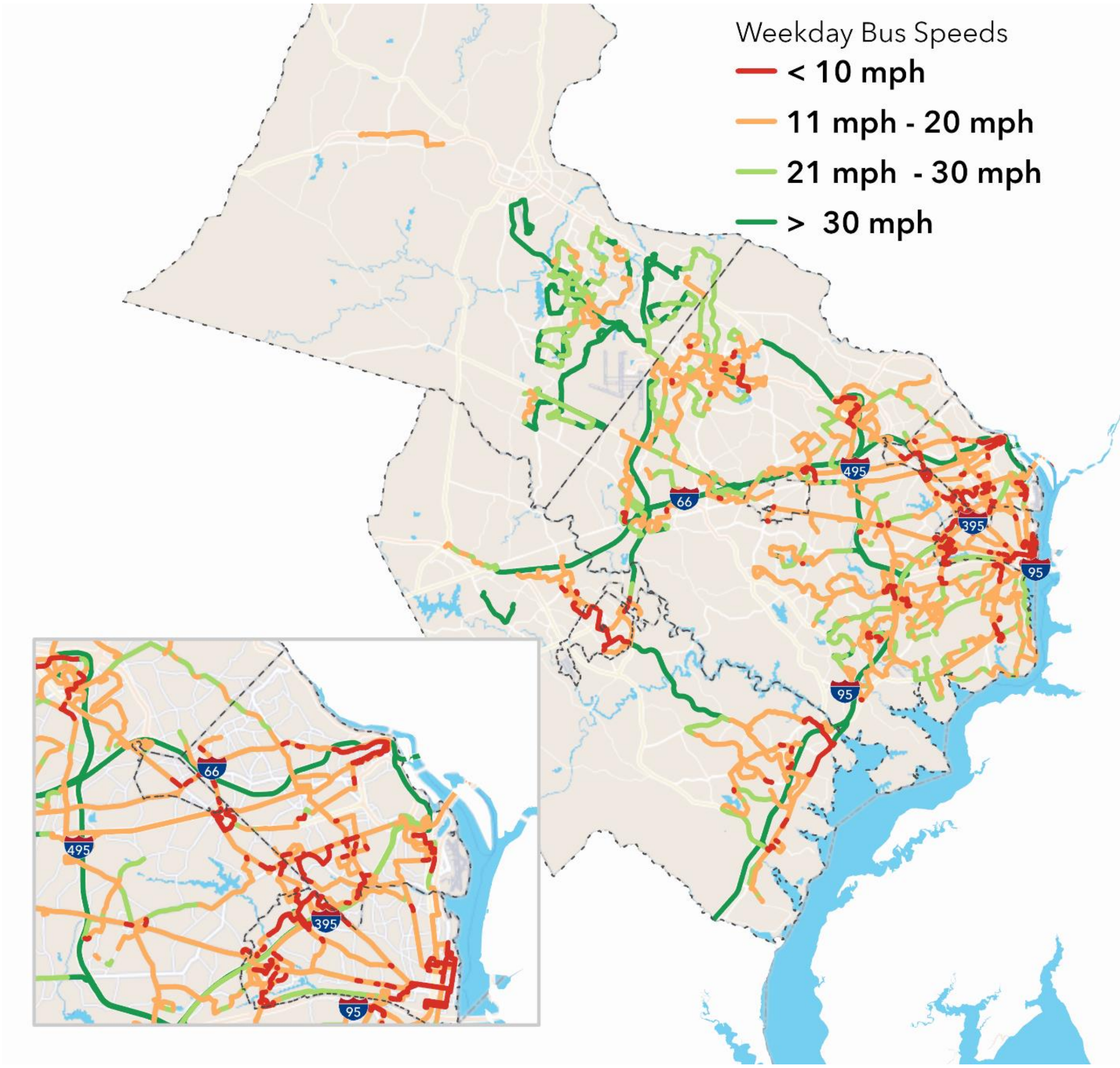



*Table 3: LCT and OmniRide average bus stop spacing (miles) by service type*

| Agency | Commuter | Local | Metro Connectors[15] |
|---|---|---|---|
| LCT | 4.5 | 0.4 | 1.8 |
| OmniRide | 3.6 | 0.4 | 1.6 |

[15] Metro Connectors are a category of bus service that take bus passengers to and from Metrorail stations all day. OmniRide calls this service Metro Express while LCT previously called them Metro Connection before they were replaced with Silver Line bus service.

*Figure 6: Northern Virginia average weekday peak period bus speeds (6 -9 a.m.)*




While major roads are labelled in **Figure 6**, HOT lanes could be identified anyway because of the mobility benefits they can provide to buses. I-95 on the south side of the map, for example, is one of the few roads in the region where buses average more than 30 mph. OmniRide commuter buses can use HOT lanes on I-95 for trips towards Washington, DC in the morning. This allows buses uninterrupted, higher-speed travel that avoids most of the congestion experienced on this notoriously congested roadway. This kind of benefit highlights the advantages of prioritized bus treatments like priority or express lanes.

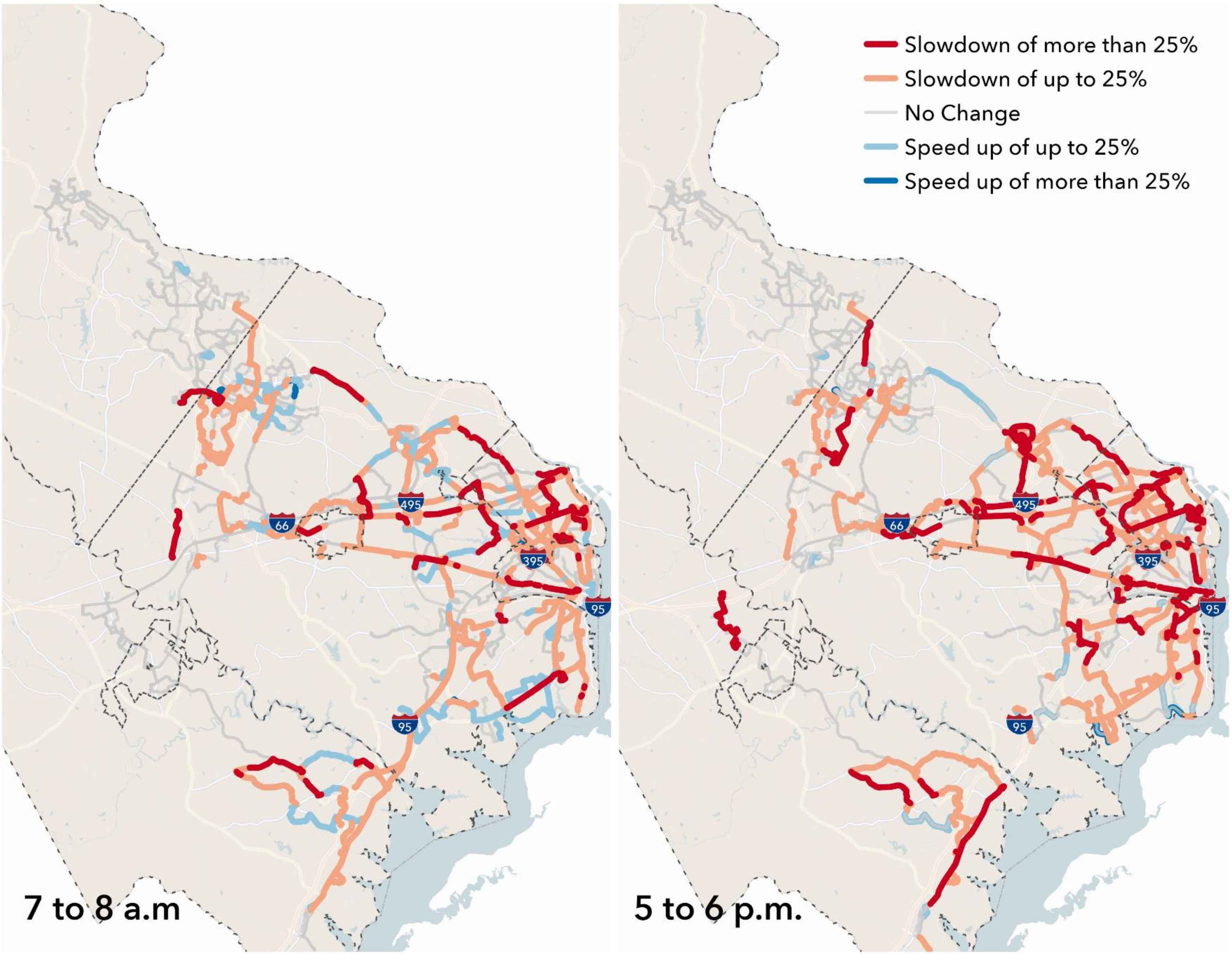
While **Figure 6** shows morning peak speeds, these speeds are not necessarily representative of the bus network's speeds through the day. **Figure 7** shows how bus speeds change between peak weekday periods and an off-peak period. In the morning peak, the more severe slowdowns are generally occurring within the Beltway, as previously discussed. However, there are still a multitude of other roads in the region that are slowing down, indicating the pervasiveness of the region's congestion. Evening peak congestion is even more glaring with road segments with bus speeds slowed by more than 25% scattered across the region. The evening pattern looks very different to the morning because of the more diffused travel patterns. In the morning, travel is concentrated towards the densest areas while in the evening travel is dispersed as people make their way home or to after work activities. **Figure 7** also shows some roads where bus speeds are faster in the peak periods. This is likely indicating roads where buses are traveling in an off-peak direction. For example, heading away from Arlington or Alexandria in the morning and towards these areas in the evening.

Overall, it is evident bus speeds can vary significantly throughout the day. These time-of-day travel time patterns are illustrated by Metro Route 28A in **Figure 8**. As the graph shows, trip travel time varies by both direction as well as time of day. For example, northbound buses take 54 minutes to complete their trip at the beginning of the day with trip time almost doubling in peak periods like the 5-6 p.m. hour. Weekday changes in bus speed can be substantial but can also be predictable.

In **Figure 7**, the roads with the greatest slowdowns are good potential locations for implementing bus priority treatments. Knowing where buses are predictably slowing down means there is a better chance that bus priority treatments can be effective. For example, additional study of one of these road segments might highlight an opportunity to build a red bus priority lane[16], or a location where queued traffic could be skipped using queue jumps[17] or even places where a bus slowed by traffic needs a little more green time at traffic signals[18]. However, with so many road segments that could potentially benefit from investment in bus priority treatments, and finite resources to do the work, implementation needs to be prioritized. The next section will elaborate on ways to triage bus priority.

[16] https://nacto.org/publication/transit-street-design-guide/transit-lanes-transitways/transit-lanes/
[17] https://nacto.org/publication/transit-street-design-guide/intersections/intersection-design/queue-jump-lanes/
[18] https://nacto.org/publication/transit-street-design-guide/intersections/signals-operations/active-transit-signal-priority/

*Figure 7: Peak period bus speeds (morning peak 7-8 a.m. and evening peak 5-6 p.m.) relative to off-peak periods (10-11 a.m.)*



## 3.2 Cost of Bus Delays

Slow buses are not only inconvenient for bus riders, but also result in a real cost to transit agencies and jurisdictions. While bus fares in Northern Virginia do not change through the day, the cost of operating a bus trip does change. Bus operators are compensated for their time driving, not for the number of trips they complete. Consequently, in congested times of the day when buses are slower, the cost of providing a transit trip can increase. As **Figure 8** demonstrated, in some cases the cost of operating the same trip can almost double in peak periods. As explained in Section 2.3, we can estimate the cost impact of these changes in bus speeds. **Table 4** summarizes the annual costs for each bus agency in Northern Virginia.

*Table 4: Bus agency potential operating cost impacts*

| Transit Agency | Average Bus Cost per Operating Hour^ | Potential Annual Cost Impact |
|---|---|---|
| **ART** | $111 | $774,000 |
| **DASH** | $108 | $592,000 |
| **Fairfax Connector** | $123 | $6,332,000 |
| **LCT** | $137 | $97,000 |
| **Metro** | $222 | $10,133,000 |
| **OmniRide** | $220 | $1,051,000 |
| **Total** | | **$18,979,000** |

*^Annual operating cost divided by annual vehicle revenue miles*

As **Table 4** shows, reoccurring congestion potentially costs the region almost $19 million a year in bus delays. This does not account for the cost of delay for passengers on buses caught in congestion[19], meaning $19 million is a conservative estimate of the cost of congestion to Northern Virginia bus transit. Although this is a fraction of total transit operating costs in the region, it is a considerable annual loss to transit incurred by traffic congestion. While the potential cost impact is correlated with the amount of bus service provided by each agency, there is also a spatial element to the distribution of costs. **Figure 9** shows how the cost of congestion is distributed through the region.

[19] Personal delay time is estimated at $19.64 per hour per person. This is a conservative number estimated using national Bureau of Labor Statistics median hourly wage rates.
https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2021-appx-c.pdf

*Figure 8: Metrobus Route 28A weekday changes in trip time*

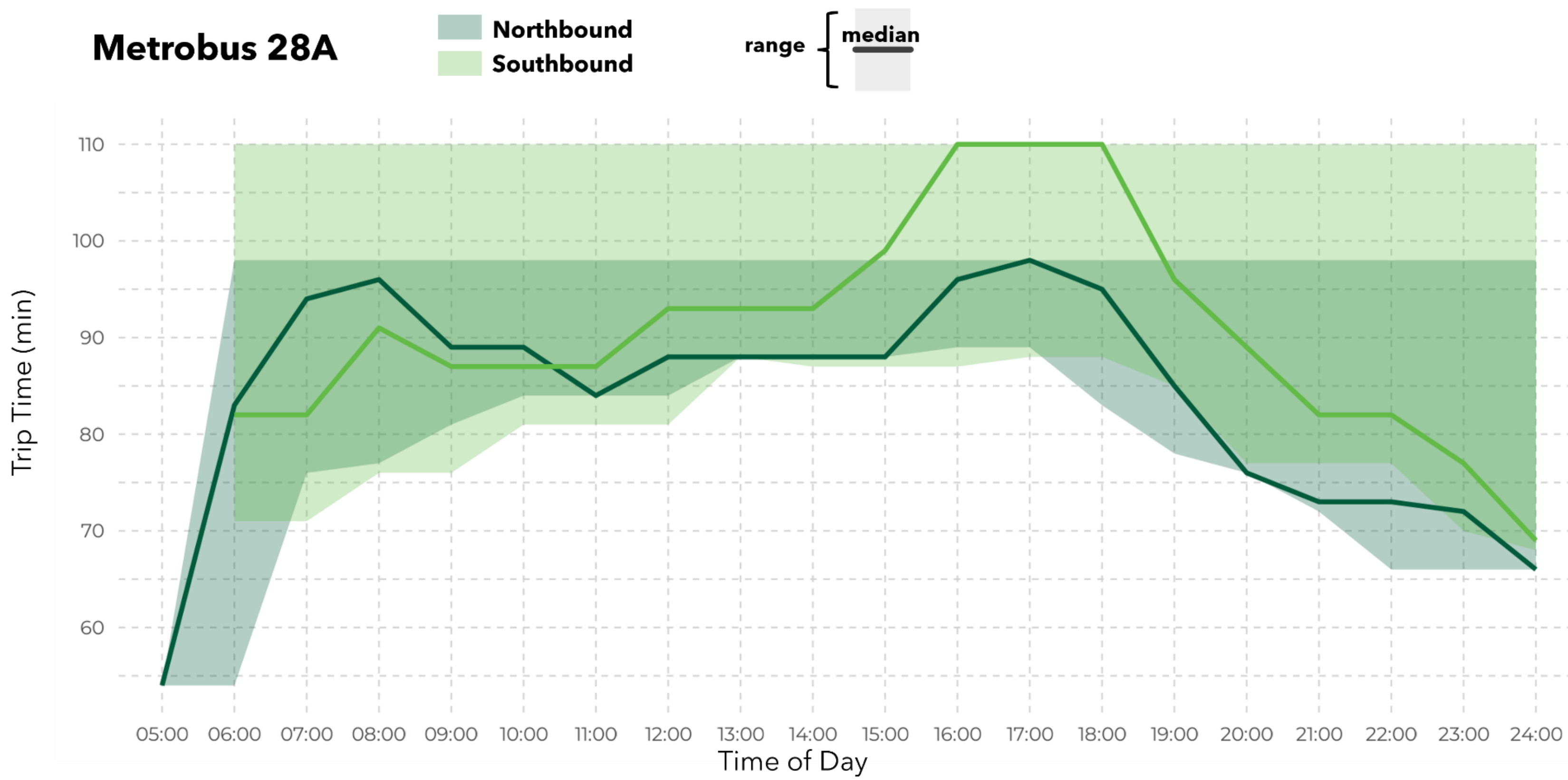
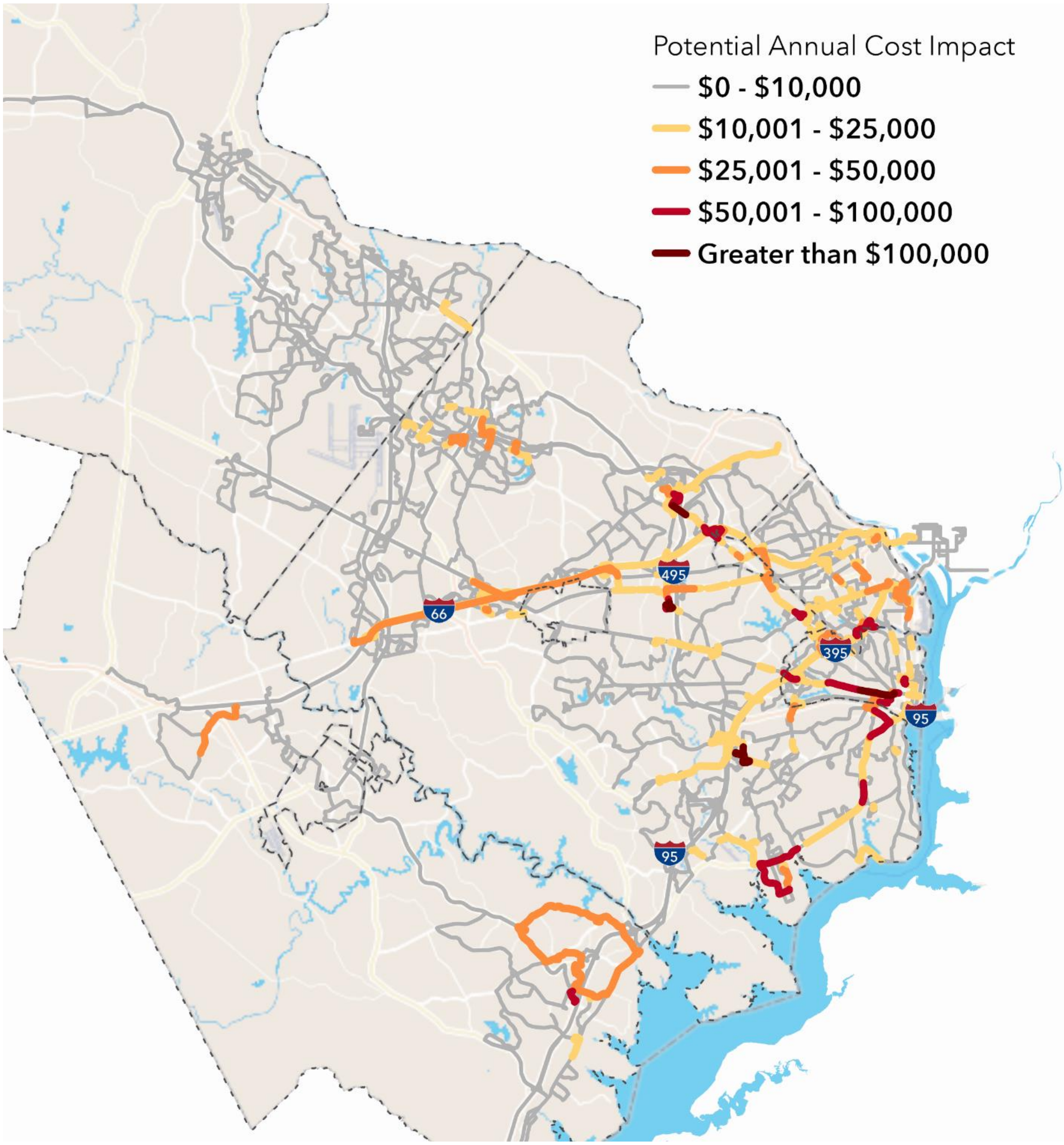


*Figure 9: Potential bus cost impacts caused by congestion*




As **Figure 9** shows, the road segments with the highest potential cost are correlated with the road segments with the greatest slowdowns in **Figure 7**. Again, roads within the Beltway are some of the most impacted. However, high-cost segments are not limited to this area with potentially high operating cost impacts also observable in some of the more suburban areas of Prince William County, where OmniRide operates, as well as Fairfax County. Lower cost segments are scattered across every Northern Virginia jurisdiction, providing opportunities for every jurisdiction in the region to work towards reducing congestion-related bus cost impacts. The potential cost impacts of different road segments provide a way to prioritize which parts of the regional bus network could be prioritized for implementing bus priority treatments. Through the investment in capital improvements that prioritize buses, like transit signal priority or queue jumps, operating costs could potentially be saved. This may make it easier for transit agencies to provide more service without increasing operating costs.

While focusing on high-cost road segments is one potential way to advance bus priority implementation, it is not the only way. Because bus priority treatments work best when deployed together, an alternative way to prioritize treatments is by prioritizing entire bus routes. Implementing multiple bus priority treatments in concert on one corridor provides the infrastructure backbone needed for bus rapid transit (BRT). BRT is a type of high-quality bus transit system where buses benefit from multiple bus priority policies and infrastructure[20]. Even without implementing full BRT, the deployment of multiple bus treatments benefits a bus route more than isolated bus priority treatments. **Table 5** gives the estimated congestion-imposed cost impacts for the 20 most impacted bus routes. The table ranks routes by overall cost, cost per mile and cost per person as each agency's goals might prioritize a route in different ways.

As the results show, the different ranking strategies generally prioritize different routes. Metro Route 28A is an exception, ranked first in each of the three ranking methods. The route operating cost methodology employed here is somewhat validated when considering some of the most impacted bus routes are already being studied as BRT corridors, as seen in **Table 5**. For example. Metro Route 28A travels along the corridor studied for the Envision Route 7 BRT[21] and Metro's REX and Fairfax Connector's route 171 both travel along the corridor where The One BRT[22] is planned.

A key characteristic of Northern Virginia transit is its multi-agency and multijurisdictional nature. Within the NVTC geographic area, there are three counties, three cities, and seven bus transit providers. Consequently, a third way to prioritize bus priority treatments is by considering the overlapping nature of bus service in the region. There are multiple roads in Northern Virginia where bus routes overlap or buses from different transit agencies overlap. Given the resource constrained environment of transit, congested roads shared by multiple providers or multiple routes could be prioritized because of the opportunity to pool resources and help multiple bus routes with geographically targeted solutions. For example, if two agencies have buses that travel through the same problem intersection, they could tackle the problem together, splitting the costs, rather than having the full cost of implementation fall onto one agency or jurisdiction. **Figure 10** provides three examples in the region where multiple transit agencies and multiple bus routes overlap. These kinds of locations would be good candidates for shared bus priority solutions.

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[20] https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/
[21] https://novatransit.org/programs/route7/
[22] https://www.fairfaxcounty.gov/transportation/richmond-hwy-brt

*Table 5: Top 20 bus routes with greatest potential cost impact*

| Agency | Route | Annual Cost | Rank | Cost per Mile | Rank | Cost per Person~ | Rank |
|---|---|---|---|---|---|---|---|
| Metro | 28A | $2,331,000 | **1** | $131,600 | **1** | $29.20 | **1** |
| Fairfax Connector | 401 | $1,085,000 | **2** | $59,100 | **4** | $24.60 | **2** |
| Metro | 1A | $966,000 | **3** | $73,200 | **2** | $17.80 | **3** |
| Fairfax Connector | 402 | $783,000 | **4** | $42,900 | **10** | $17.50 | **5** |
| Metro | REX | $740,000 | **5** | $50,000 | **7** | $14.80 | **6** |
| Fairfax Connector | 171 | $641,000 | **6** | $41,400 | **11** | $14.10 | **7** |
| Metro | 10B | $602,000 | **7** | $53,700 | **5** | $7.80 | **12** |
| Metro | 29N | $514,000 | **8** | $32,800 | **17** | $8.40 | **11** |
| Fairfax Connector | 950 | $465,000 | **9** | $60,000 | **3** | $17.50 | **4** |
| Metro | 10A | $440,000 | **10** | $43,600 | **9** | $7.00 | **15** |
| Metro | 7A | $372,000 | **11** | $35,500 | **14** | $4.70 | **34** |
| Metro | 1C | $368,000 | **12** | $27,800 | **24** | $10.80 | **8** |
| OmniRide | WoodLoc | $353,000 | **13** | $22,000 | **30** | $9.70 | **9** |
| Metro | 29K | $342,000 | **14** | $22,100 | **29** | $5.80 | **21** |
| Metro | 23T | $319,000 | **15** | $24,500 | **27** | $5.10 | **29** |
| Metro | 16A | $316,000 | **16** | $28,300 | **22** | $5.30 | **27** |
| Fairfax Connector | 151 | $311,000 | **17** | $25,600 | **26** | $7.50 | **13** |
| ART | 41 | $296,000 | **18** | $53,600 | **6** | $4.70 | **35** |
| DASH | 30 | $281,000 | **19** | $31,900 | **18** | $5.40 | **26** |
| Fairfax Connector | 321 | $281,000 | **20** | $14,700 | **36** | $6.20 | **18** |

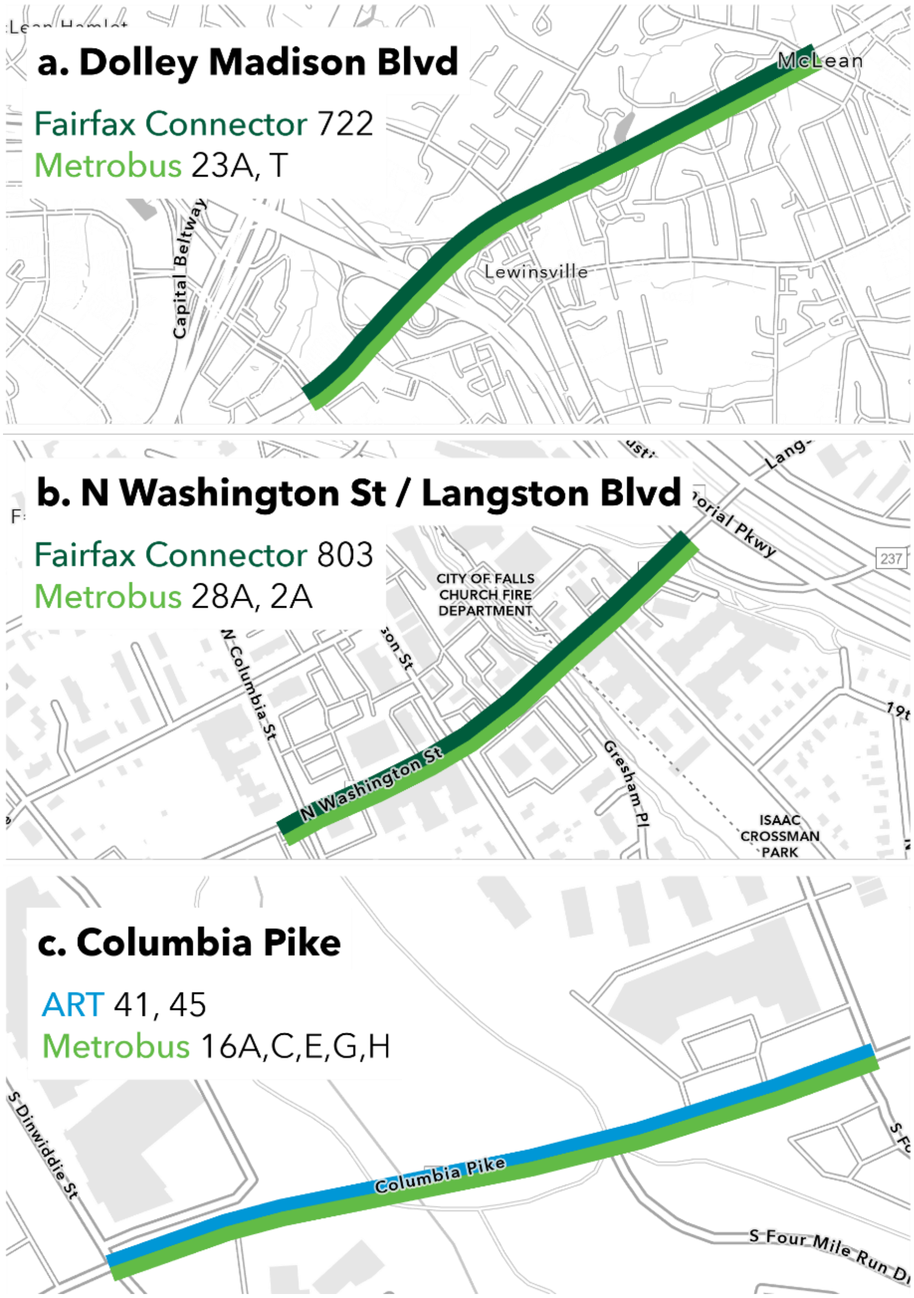
*~Per person is defined as the estimated population within a quarter mile of the bus route. Route-level ridership data was not available but this exercise could also be calculated with ridership data.*

## 4.0 Conclusions

Traffic congestion is a problem experienced by all road users but can be somewhat mitigated for bus transit through the implementation of bus priority treatments. The purpose of this report was to both better understand how bus speeds are affected by congestion as well as to find ways to prioritize the study and installation of bus priority treatments.

This report has demonstrated that bus speeds are affected by a variety of factors, including the types of bus services operated as well as each bus agency's operating environment. Importantly, this report has also demonstrated that not only do the region's buses slow down (sometimes substantially) during peak travel periods, but they do so reliably enough that the region's transit planners can account for the changes in their schedules. These slowdowns potentially cost transit agencies in Northern Virginia $19 million a year. Fortunately, the evaluation of changes in bus speeds also provides a candidate list of locations that can be used to further evaluate whether bus priority treatments could help.

*Figure 10: Overlapping transit segments with shared bus priority needs*




Transit is a resource constrained industry that does not have all that is needed to fix every problem. However, transit congestion problems need to be prioritized. Using estimates of operating cost impact, this report demonstrated three potential ways candidate bus priority locations could be prioritized for further study or evaluation. Prioritization could focus on the highest cost locations, the highest cost routes, or locations where issues affect multiple routes or transit agencies.

Overall, traffic congestion affects more than just cars. This evaluation has conservatively estimated the cost of congestion to transit agencies in Northern Virginia and provided ways to prioritize potential solutions.

## *5.1 Key Takeaways*

This report has four key takeaways for Northern Virginia transit professionals. Specifically, this work helps the region's transit by doing each of the following:

1. **Identifies opportunities for improving speed and congestion issues**

This report has emphasized that congestion issues are pervasive in Northern Virginia. However, through relatively simple methods, this report has identified opportunities for studying bus priority treatment candidate locations. These candidate locations could be prioritized by the magnitude of the potential cost impact, the number of agencies or routes that overlap in a segment, or by the magnitude of the cost to a specific route. Through this last analysis, this report has further justified the study of existing BRT corridors and potentially uncovered new potential BRT corridors.

2. **Facilitates more strategic funding solutions in the region**

Identifying where bus priority treatments could be implemented is just part of what is needed to help improve bus speeds in the region. Once an identified segment has been further studied, and the appropriate bus priority treatment chosen, financial resources are needed to plan and implement the recommended solutions. However, transit funding is limited. The different priority treatments discussed above can help determine which roads or bus routes could be prioritized given the severity of congestion issues. The analyses in this report also provide justification for packages of projects that together target a congested road corridor. These packages of projects have a level of empirical justification that could support going after funds from organizations like the Virginia Department of Rail and Public Transportation (DRPT) or the Northern Virginia Transportation Authority (NVTA).

This work also provides financial justification for strategic investment in bus infrastructure. Capital investments in bus infrastructure and technology have the potential to save operating dollars for bus operators. As operating funds are generally more difficult to obtain for bus operators, capital investment could give transit agencies more flexibility with their more limited operating funds.

3. **Leverages the regional nature of Northern Virginia's bus to achieve shared benefits**

The regional nature of Northern Virginia transit makes bus transit unique in this part of the country. With six jurisdictions and seven bus operators, coordination and cooperation are particularly important. A regional analysis of bus operations, like the one in this report, provides a holistic understanding of how street congestion affects bus operations. Understanding how congestion changes over different parts of the region can facilitate the coordination and cooperation needed to make bus a success.

In addition, bus services overlap in many places through the region. This means congestion hot spots can sometimes impact more than one transit agency. These shared issues provide an opportunity to pool resources to help overcome issues. As already mentioned, transit funding can be limited and combining resources provides an opportunity to reduce the financial impact to any one bus operator.

4. **Connects to related work**

Finally, this work highlights the important role of bus in the Northern Virginia region while providing opportunities for improving bus quality. The findings in this report complement other ongoing efforts in the region achieving these shared bus goals. This includes the NVTC Regional Bus Analysis[23], the Metro Better Bus Network Redesign[24], and the NVTA BRT Preliminary Deployment Plan[25].

[23] https://novatransit.org/uploads/presentations/NVTC_RegionalBus_Presentation_XJH.pdf
[24] https://www.wmata.com/initiatives/plans/Better-Bus/about-the-project.cfm
[25] https://thenovaauthority.org/wp-content/uploads/2023/04/BRT-PDP-RFP-Final-v1.pdf

# Appendix A: Calculation Processes

### *Process for Calculating Time Between Stops*

*Equation 1: Segment travel time*

$$T_{i,y-x} = T_{i,y} - T_{i,x}$$

Where,

- $T_{i,x\text{-}y}$ is the segment time for trip, i and sequential stops x and y
- $T_{i,y}$ is the scheduled stop time for stop y on trip i
- $T_{i,x}$ is the scheduled stop time for stop x on trip i

1. Identify all possible stop pairs for each agency, route, and trip and create a segment id for each unique segment.
    a. The segment id is the previous stop_id and the current stop_id connected with a hyphen (e.g., "ART112-ART92").
2. Calculate the difference between scheduled bus arrival time at one stop and scheduled bus departure time at the previous stop using scheduled stop times in GTFS.
    a. Join the GTFS stop_times and trips file.
    b. Subtract departure time of the previous row from arrival time of the current row.
    c. Filter out NA values and any times less than 0.
3. Combine all the time data from each agency into one file.

### *Bus Stop Cluster Analysis*

1. In ArcGIS, create a spatial file that joins bus stops from all Northern Virginia bus agencies.
2. Project the stops from geographic coordinate system (WGS 1984) to projected coordinate system (NAD 1983 State Plane Virginia North FIPS 4501 (US Feet)).
3. Use the Density-based Clustering tool[26] with a 20 ft buffer (20 ft was determined by manual exploration of the data). Join the output of the cluster analysis with the stop layer by Source ID and Object ID. Then export as shapefile to R.
4. In R, create Novastop_id value for shared bus stops.
    a. Note: Cluster IDs above -1 indicate a "cluster" or a shared stop.

[26] https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/densitybasedclustering.htm

### *Estimating Bus Stop Spacing*

*Equation 2: Segment travel distance*

$$D_{i,y-x} = D_{i,y} - D_{i,x}$$

Where,

- $D_{i,x-y}$ is the segment bus distance traveled for trip, i and sequential stops x and y
- $D_{i,y}$ is the bus distance traveled for stop y on trip i
- $D_{i,x}$ is the bus distance traveled for stop x on trip i

1. In Python, use the gtfs-segments module[27] to find distance between all stops. Run the code for each individual bus agency using GTFS data. Export as csv to R.
2. In R, clean the segment file:
    a. Create segment_id from bus stop_id1 and stop_id2.
    b. Remove Metrobus routes that do not enter Virginia.
    c. Convert from meters to miles.
3. Join the cleaned segments file with the stop cluster data described earlier. Join first using the stop_id1 from the segments file. Then join again, this time with stop_id2. This is necessary because the stop clusters file just list stop_ids while the segments file includes two columns of different stop_ids. Joining to both columns ensures the stop_ids from the segments file are linked to the stop clusters.

### *Bus Speed Data*

*Equation 3: Segment bus speed*

$$S_{i,y-x} = \frac{D_{i,y-x} \cdot 60}{T_{i,y-x}}$$

Where,

- $S_{i,x-y}$ is the segment speed for trip, i and stops x and y
- $D_{i,x-y}$ is the segment bus distance traveled for trip, i and stops x and y
- $T_{i,x-y}$ is the segment time for trip, i and stops x and y

[27] https://pypi.org/project/gtfs-segments/

### ***Bus Speed Data Cleaning Process***

1. Join the segment and time files by both the segment_id and route_id. For each row, calculate speed (distance/speed)
2. Filter speeds larger than 70 mph and less than 1 mph. Through inspection of the data, it was determined that any speed outside of this range is due to either an error in the GTFS stop_times file or the segment file.
3. To remove any remaining outliers, calculate 1.5 times the upper and lower interquartile range and filter out any rows that lie outside this range.

### ***Cost of Bus Congestion***

*Equation 4: Estimated cost of bus congestion (route level)*

$$C_{r,s,\overline{w}} = H_{a,r} \cdot \sum_{r,s,\overline{w}} \left(T_{r,s} - min(T_s)\right)$$

*Equation 5: Estimated cost of bus congestion (agency level)*

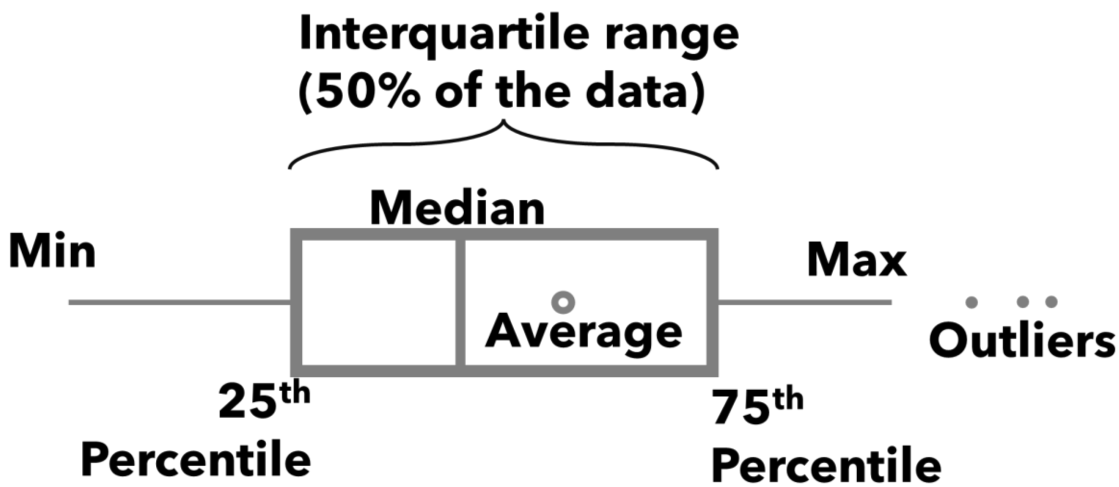
$$C_{a,s,\overline{w}} = H_a \cdot \sum_{a,s,\overline{w}} \left(T_{a,s} - min(T_s)\right)$$

Where,

- C is the average weekly cost for agency
- H is the bus cost per vehicle revenue hour
- T is the trip time for segment
- $s$ is a bus trip segment between two consecutive stops
- $r$ is a route
- $a$ is an agency
- $\overline{w}$ is an average week

*Equation 4 and 5 calculates the costs for an average week but can also be used to estimate an annual cost when multiplied by 52, the number of weeks in a year.*

# Appendix B: Interpreting Box and Whisker Plots




- **Median** (50th percentile) – the midpoint in a dataset with an even number of values greater than and less than this value
- **Average** (mean) – the sum of all values divided by the count of all values
- **25th Percentile** – 25% of all values are below this number
- **75th Percentile** – 75% of all values are below this number
- **Interquartile range** – The difference between the 75th percentile and the 25th percentile
- **Min** – defined as 1.5 times below the interquartile range
- **Max** – defined as 1.5 times above the interquartile range
- **Outliers** – any data points that are below the min or above the max