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# The Impact of Phase 1 of the Silver Line on the Northern Virginia Transportation System

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**PAMELA MURRAY-TUITE**
**Associate Professor**
**Department of Civil and Environmental Engineering**
**Virginia Tech**

**SHANJIANG ZHU**
**Assistant Professor**
**Department of Civil, Environmental, and Infrastructure Engineering**
**George Mason University**

**AMAL P. CHACKO**
**Graduate Research Assistant**
**Department of Civil and Environmental Engineering**
**Virginia Tech**

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VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

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| Author(s): Pamela Murray-Tuite, Shanjiang Zhu, and Amal P. Chacko | | | | |
| Performing Organization Name and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903 | | | | |
| Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219 | | | | |
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Abstract:

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The study used geographic information systems to visualize transit demand and regression and the Mann-Whitney U test to identify patterns, estimate new transit demand, and determine whether road changes were significant. Some, but not all, Silver Line ridership appeared to be drawn from the Orange Line, resulting in traffic pattern changes between the two lines. This finding was supported by the ridership on the two lines and changes at intersections in the south of Reston and intersections near the West Falls Church Metro Station.

The regression analysis showed that the Silver Line attracted approximately 20,000 new rider trips (trip ends counting both exits and entrances separately) on a typical weekday. Ridership at the Wiehle-Reston East Station showed a strong pattern of commuting traffic, with a detectable morning and afternoon peak for entries and exits, respectively. Changes in the intersection counts in Reston supported this pattern. However, the numbers of entries and exits during the same time period for the other four stations were more balanced. Ridership supported reverse commuting with the Silver Line. Some mode or route shifts appeared to occur in the Reston area, suggested by improved travel times on VA-267 between Route 28 and Hunter Mill Road in the AM peak and in the Tysons Corner area, suggested by improved travel times on I-495 between I-66 and Route 7 and intersection count changes at Chain Bridge Road and International Drive. Another travel pattern shift in the Tysons Corner area appeared to be the avoidance of the interchange of Route 7 and Chain Bridge Road, particularly suggested by changes at the intersection just west of this interchange. The majority of the road data suggested general growth in the region, which hid some of the benefits of the Silver Line. The new ridership allowed for some accommodation of new traffic and traffic rebalancing across routes.

**FINAL REPORT**

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**Pamela Murray-Tuite**
**Associate Professor**
**Department of Civil and Environmental Engineering**
**Virginia Tech**

**Shanjiang Zhu**
**Assistant Professor**
**Department of Civil, Environmental, and Infrastructure Engineering**
**George Mason University**

**Amal P. Chacko**
**Graduate Research Assistant**
**Department of Civil and Environmental Engineering**
**Virginia Tech**

*VTRC Project Managers*
Michael D. Fontaine, Ph.D., P.E., and Cathy C. McGhee, P.E.
Virginia Transportation Research Council

Virginia Transportation Research Council
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Each contract report was peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report were performed by the contractor.

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## INTRODUCTION

As measured by annual ridership, according to data from the National Transit Database, the Washington Metropolitan Area Transit Authority (WMATA) operates the second largest Metro system in the United States. It is second only to the New York City Transit Authority. On July 26, 2014, the 11.7 miles of the Silver Line Phase 1 began service. As illustrated in Figure 1, the Silver Line splits from the existing Orange Line between the East and West Falls Church stations; stretches westward through the Tysons Corner area in Fairfax, Virginia; and ends at the Wiehle-Reston East Station. Phase 1 of the Silver Line contains five new stations: Wiehle-Reston East, Spring Hill, Greensboro, Tysons Corner, and McLean. Phase 2 of the Silver Line project will extend further westward for another 11.5 miles to Loudoun County via Washington Dulles International Airport. This is the first major expansion of the Metro system in the metropolitan Washington, D.C., area since the existing five lines were largely completed in 2001. The Silver Line serves the rapidly expanding business and commercial development in the Northern Virginia suburban area.

According to the Metropolitan Washington Council of Governments' financially constrained long-range transportation plan, transit is currently carrying 23% of commuter trips and 7% of all trips (NCRTPB, 2015). The share for transit for the region as a whole is not expected to change significantly in the near future. Despite this, the Silver Line and the related changes of other transit services could have significant impacts on the corridors they serve. The areas the Silver Line serves, including the I-66 and Route 7 corridors and the Tysons Corner area, are among the most congested areas in the region. Therefore, the changes in travel demand as a result of the Silver Line also have a significant impact on the road network managed by the Virginia Department of Transportation (VDOT).

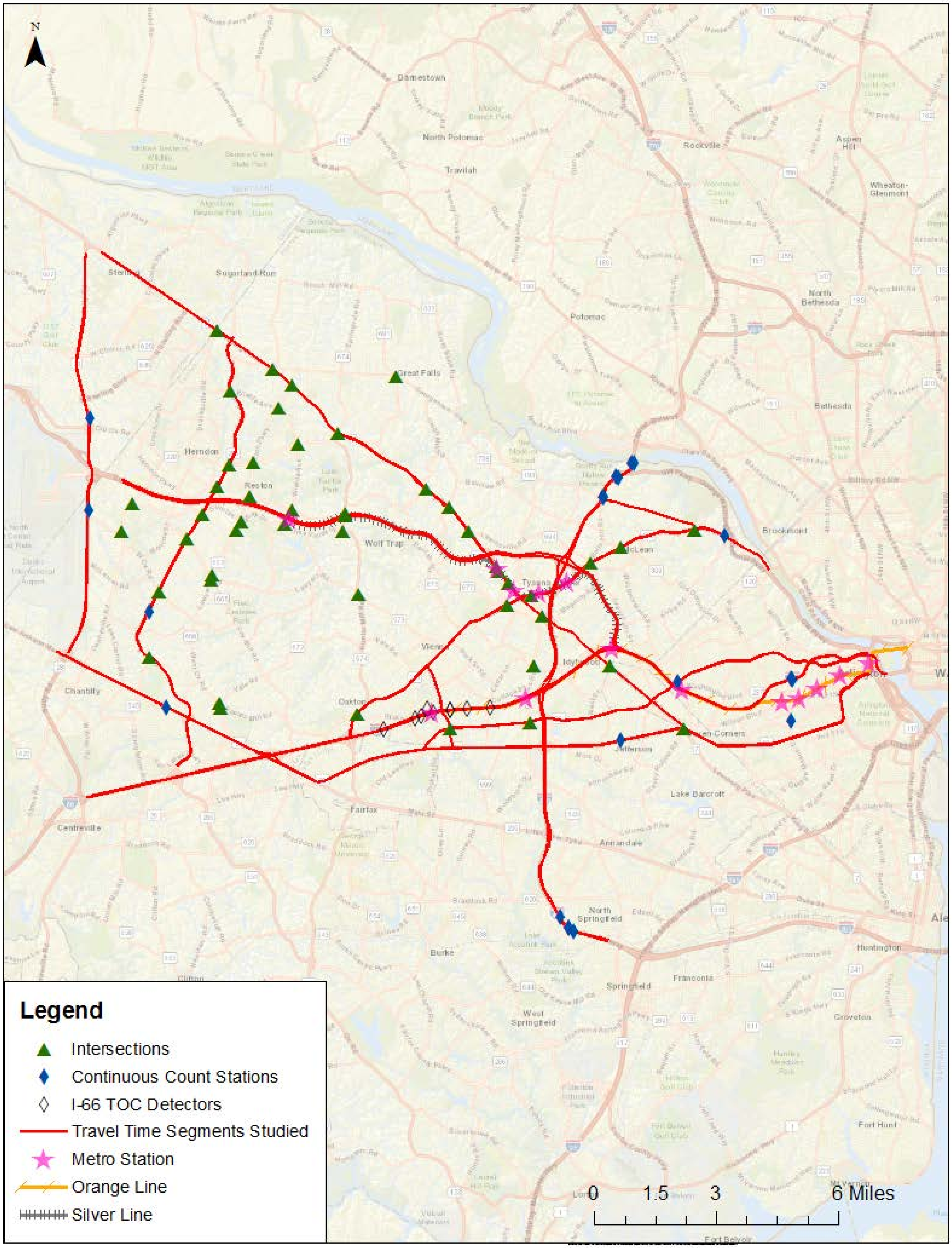


**Figure 1. Location of Phase 1 of Silver Line and Key Study Locations**

Major transportation infrastructure projects are relatively rare in well-developed, urbanized areas. The Metropolitan Washington, D.C., area has taken on the unique challenge and chosen to build the new Silver Line. To manage the potential impact better and to prepare VDOT for similar projects in the future, including Phase 2 of the Silver Line, this study evaluated the impact of the opening of Phase 1 of the Silver Line on the regional transportation network using empirical data. The overall purpose of this study was to determine the impact that the Silver Line had on existing transportation system performance and mode use.

## PURPOSE AND SCOPE

The purpose of this study was to support VDOT's mission of managing a regional surface traffic network in response to travel demand and traffic pattern shifts after a major transit service opened. The findings of this study will help VDOT understand traffic pattern changes on the surface network after the Silver Line opened and prepare for Phase 2 of the Silver Line project, which will bring more changes to regional traffic patterns.

This study investigated the aggregate impact that the opening of the first phase of the Silver Line had on traffic, turning movements at intersections relevant to the study area, volumes on arterials, Metrorail Orange Line users, Metrorail ridership, and aggregate bus ridership for Metro Bus, Fairfax County Connector, and Loudoun County Transit. The aggregate data and related analyses allowed the research team to evaluate the transit line's impact on overall mobility through measures related to vehicle counts, travel times and reliabilities, and transit ridership. The surface network analyses focused on mid-week traffic between 6:00 AM and 20:00 (8:00 PM) in the months of September/October and April/May. The comparisons were between the year before the Silver Line opened and the two years afterwards. The Metro SafeTrack project, a series of accelerated track work plans that involve either continuous single-track operations or complete shutdown of a line segment, started in June 2016 and will continue into June 2017. This study did not include any data from the SafeTrack period to avoid a major confounding factor that may significantly affect the Silver Line ridership, Metro ridership in general, and the surface transportation conditions. Another potentially confounding factor was the implementation of an active traffic management system on I-66 in September 2015 (Chun and Fontaine, 2016). This was after the first year of the Silver Line operation. Although data are presented in this report for two years after the Silver Line opened, traffic changes near I-66 should be considered with more emphasis on the first year's comparison to help separate the Silver Line's and active traffic management system's effects.

The geographic scope of the study is shown in Figure 1. The specific roads and intersections examined in this study are highlighted in this figure, and included Route 28, parts of Centreville Road, Reston Parkway, Wiehle Avenue, Sunset Hills Road, Sunrise Valley Drive, Route 7, Baron Cameron Avenue, State Road (SR) 123, SR-243 (Nutley Street), VA-267, US-29, US-50, I-66, and I-495. The transit provider data examined pertained to WMATA, Fairfax County Connector, and Loudoun County Commuter Bus. Parking facility usage at Metro stations was also considered based on WMATA reports.

# METHODS

This study used a variety of data to investigate different aspects of the Silver Line's impacts on the transportation system. The data and the analysis methods are outlined here. The transit aspects are presented first to provide context for the road-based analyses.

## Transit Analysis

### Transit Data

It is critical to understand that multiple transit service providers operate in the Northern Virginia area, but this study focused on aggregate ridership data from major transit agencies whose services, based on geographic information system (GIS) analysis and inputs from the VDOT technical team, have direct connections with the Silver Line. These providers included Metro Bus, Fairfax County Connector, and Loudoun County Commuter Bus.

Ridership for the year prior to the opening of the Silver Line and the duration of the study was collected to establish baselines and assess ridership changes. Data for the period beyond the scope of this study were also collected whenever they were readily accessible and were helpful for this study. Major constraints for further extending the analysis period were data availability and confounding factors. For example, WMATA only collects complete Metro origin-destination (OD) matrices every May for planning purposes. After the opening of the Silver Line, WMATA also collected the OD data in October. There was a major Metro fare increase in the fiscal year 2014. The Metro SafeTrack project, a major confounding factor for Metro ridership, started in June 2016. After weighing all these factors, the data sets used for this study included the following:

- the number of entries and exits by station, by time of the day, and by day of the week (weekday, Saturday, or Sunday) for all Metro stations west of Rosslyn (01/2014–06/2016)
- monthly transit ridership of the entire Metro system (01/2002-03/2016)
- the Metro OD matrix based on smart card data for selected months (05/2012, 05/2013, 05/2014, 10/2014, 05/2015, and 10/2015)
- average monthly ridership by route of the 12 Metro Bus lines that serve either the Silver Line stations or Orange Line stations (01/2010-05/2016)
- average monthly weekday ridership by route of the Fairfax County Connector System (07/2005-06/2016)
- daily ridership by route of the Loudoun County Commuter Bus Service (07/2012–03/2016).

**Transit Analysis Methods**

After transit data collection, cleaning, and integration, the data were used in GIS and statistical analyses.

The Silver Line joins the existing Orange Line at the East Falls Church Station and the two lines share track and station platforms from this point and continue to downtown Washington, D.C. The Silver Line and Blue Line also serve the same set of stations starting from the Rosslyn Station and ending at the Largo Town Center; this allows for ease of transfer between these lines. At overlapping stations, Metro riders are likely to board the first train that comes and serves their desired destination station. Therefore, only riders at the five new Silver Line stations were labeled as new Silver Line riders; among them, some may have been using the Orange Line prior to the opening of the Silver Line. Line switching was considered in this study.

WMATA automatically documents the total number of entries and exits at each station through their smart card system. For privacy protection, these data are collected only at the aggregate level so no entries and exits can be linked in their monthly ridership data. WMATA typically re-groups the data into five time periods:

1. AM Peak = 5:00 to 9:30
2. Midday = 9:30 to 15:00 (3:00 PM)
3. PM Peak = 15:00 to 19:00 (3:00 PM-7:00 PM)
4. Evening = 19:00 to 24:00 (7:00 PM-12:00 AM)
5. Late-Night Peak = Friday and Saturday nights only, midnight to closing.

The late-night data were irregular; therefore, only data for the first four periods were provided. The data are further split by weekdays, Saturdays, and Sundays. In this study, the research team focused on patterns of the total weekday daily ridership, with more analysis whenever a noticeable pattern for a specific time period or station existed.

*Trends in Silver Line Ridership*

To investigate trends in Silver Line ridership, a time series analysis based on the Seasonal Auto Regressive Integrated Moving Average model was conducted using STATA, a commercial software package for statistical analysis (StataCorp LP, 2016). The analysis of the aggregated monthly ridership helped determine if the total Silver Line ridership stabilized two years after opening and the overall long-term trend of Metro ridership. Strong seasonal effects were expected in the Metro ridership (e.g., winter versus summer). The time series analysis could help to exclude the seasonal effects using the differencing method. However, only two years of Silver Line ridership data were available, which challenged the obtainment of meaningful results. The research team also analyzed the ridership data for all Northern Virginia Silver and Orange Line stations located west of the Rosslyn Station, incorporating additional pre-Silver Line years and increasing the total number of months available from 24 to 42, which is still too few for the obtainment of meaningful results using the Seasonal Auto Regressive Integrated Moving Average approach. For this reason, discussions of the time series analysis results are not included in this report but are available from the authors upon request.

In addition to the total number of riders, the research team analyzed ridership patterns station by station using GIS. The locational difference between the five new Silver Line stations could have contributed to diversity in rider types at each unique station, which could explain differences in ridership patterns.

*Detecting Substitution Effects*

To determine whether Silver Line riders were new Metro users or diverted from other lines, aggregate ridership data were used to develop a linear regression model of the form in Equation 1.

$$y_j = \beta_0 + \gamma S_j + \sum \beta_{ij} x_{ij} + \varepsilon \qquad (1)$$

where

$y_j$ is the total number of Silver Line and Orange Line riders for all stations west of the Rosslyn Station in month $j$

$S_j$ is a dummy variable with the value 0 before the Silver Line opened and 1 afterwards

$x_{ij}$ is a series of variables that help to control the impacts of external factors ($i$ represents different variables), including month-to-month changes in overall economy, employment, gas price, and weather conditions in the study area

$\varepsilon$ is a random error.

If the Silver Line did not attract any new riders, all riders at the stations west of the Rosslyn Station would be original Orange Line riders, regardless of which lines they were riding after the Silver Line opened. Therefore, the total number of riders, $y_j$, would follow the same pattern before and after the Silver Line opened. In this case, the coefficient $\gamma$ would not be significant after all external factors were controlled. In contrast, if the Silver Line did attract new riders, the total number of riders, $y_j$, would be higher after the Silver Line opened, with all confounding factors controlled. The magnitude of $\gamma$ captured the number of new riders brought by the Silver Line, all else being equal.

At the metropolitan level, most socioeconomic factors are reported only annually. The only variable with monthly data was gas price. To control other confounding factors, the monthly Metro ridership for the rest of the network (all stations excluding the ones west of the Rosslyn Station) was used. If the Silver Line did not generate any new riders, the total number of riders for stations west of the Rosslyn Station would fluctuate in the same way as the rest of the Metro network and the coefficient $\gamma$ would not be significant. Without monthly socioeconomic data, this method allowed the research team to test the hypothesis that all ridership previously used other lines by using the ridership of other Metro lines as control variables. This approach assumes ridership patterns did not vary geographically in a relatively short period of time. This method also helped to control the strong seasonal effects without introducing a series of month dummy variables or applying the differencing method with 12-month lags.

One commonly cited factor in the news about Metro ridership decline is the issue of reliability (Ashe, 2015; Siddiqui and Powers, 2016). The method used in this study controls for this factor since the reliability issue should affect ridership on other Metro lines the same way as the ridership of the Silver Line. The period during the SafeTrack project, which started in June 2016, was not included in this analysis.

*Trends in Metrorail OD Patterns*

The Metro OD data could be derived by comparing the swipe-in and swipe-out stations of Metro riders who use the smart card (about 99% of riders, according to WMATA). WMATA does not provide Metro OD data on a continuous basis but does survey the OD patterns once or twice a year for planning purposes. With the help of WMATA, six Metro OD matrices were obtained to provide additional insights on Silver Line riders' destinations. One hypothesis was that the Silver Line provided an effective travel mode for reverse-commuters; those commuters who live in Washington, D.C., or Arlington but work in the Tysons Corner area or further west along the Route 7 corridor. With the Metro OD data, the research team tracked the total number of such riders over time by graphing the data and using GIS analysis.

*Trends in Bus Ridership*

A clear understanding of Silver Line riders' connecting modes could lead to a better understanding of the impact on the surface network. For example, if many riders came to the Silver Line stations through buses, they could add traffic to the network around the Silver Line stations. Unfortunately, no transfer data were available. Major bus operators in the study area include the Metro Bus, Fairfax County, and Loudoun County Bus systems and they collect transit ridership data by line. The only exception is that the Metro Bus used the Automatic Passenger Counting system to collect ridership by stop. In this study, the research team first conducted GIS analysis to identify all bus lines that served Silver Line stations and then analyzed graphically the ridership changes of the bus lines.

## Road-Based Data

The road-based data included (1) INRIX's travel times, collected by probe vehicles; (2) intersection counts recorded using loop detectors on single or multiple lanes at intersection approaches (provided by VDOT); (3) counts recorded at continuous count stations, monitored by the VDOT Traffic Engineering Division and used for reporting average daily travel (Asare et al., 2015); and (4) I-66 Traffic Operations Center (TOC) detector data, which support VDOT's freeway operations decisions. Data types 1 and 4 were obtained from the website of the Regional Integrated Transportation Information System (RITIS). Types 2 and 3 were obtained directly from VDOT. INRIX's travel time data included a confidence score, which is an index indicating the nature of the data: "10" meant overnight non–real time data based on the reference speed, “20” was non–real time daytime data imputed based on historic averages, and “30” indicated purely real time data. The aggregate data were obtained in 15-minute increments.

Previously, traffic data from Tuesday, Wednesday, and Thursday had little to no statistically significant variation (Rakha and Van Aerde, 1995). For this study, visual inspection and Mann-Whitney U statistical tests (Siegel, 1956) confirmed this finding so these days were combined to increase the number of observations for statistical comparisons.

The timeframe for the data set used for the study was composed of September and October 2013-15 and April and May 2014-16. Within a given month group (September/October or April/May), the travel behavior and data were expected to exhibit consistent patterns during the weekdays since (1) school was in session; (2) there was a lack of major school holidays during this time frame (except for spring break in April); and (3) these month groups were the least affected by weather changes in Northern Virginia. The data set for September/October (fall) 2013 and April/May (spring) 2014 was defined as the base year data, and the changes in the subsequent years were studied with respect to these data sets.

## Data Processing

### *Travel Time Data*

INRIX relied on the presence of vehicle probes to report travel time data. For time periods with an insufficient number of probes traversing a particular road section (traffic message channel or TMC), the provider reports travel time based on historic data. However, these historical data were not useful in this study. The 1-minute data were aggregated automatically into 15-minute intervals, which was the data resolution obtained for this study. The corresponding confidence score was an average of the confidence scores reported for the 1-minute intervals. It was moderately rare to obtain 100% real time data within a 15-minute time period; i.e., all the data points at 1-minute resolution within a 15-minute time period had “30” as the corresponding confidence score. Past VDOT studies have shown that a good real time score can be assumed if 85% of the 1-minute scores report a confidence score of “30” (Hu et al., 2016). This would translate to a minimum confidence score of “28.5” during the day and “27” during the night for the 15-minute timestamps. The time period used for the analysis was from 6:00 AM to 20:00 (8:00 PM). Therefore, only the TMC-codes with confidence scores greater than 28.5 were used for the analysis.

Relatively short TMCs were combined to form manually defined longer segments, terminated at major roads and at possible travel change locations (e.g., ramps providing an opportunity to change routes). The combinations were based on simple addition of travel times and reflect “instantaneous” travel times. However, in many instances one or more of the TMCs that make up the manually defined segment did not have data with a minimum confidence score of “28.5” at a particular timestamp. If the total number of TMCs within a manual segment reported real time data with a confidence score greater than “28.5” for at least 85% of the segment corridor length for a given time stamp, then historic data from the remaining TMCs were used to generate the travel time for the entire corridor.

*Intersection Volume Count Data*

If multiple sets of detectors were available for the same turning movement at an intersection, due to higher accuracy, system detectors were used. Only during the instances of poor data quality in system detectors were local detectors used. Detectors reporting "0" counts for all of the study months were eliminated from the study and those reporting "0" counts for an entire month group were not included in that month-group analysis. When a detector reported consistent "0" counts for one of the months but not the other, individual months (rather than the month group) were used in the comparisons. The 15-minute volume count data provided by VDOT were in the form of data scaled to 1 hour to save the data in the format (vehicle volume / hour) to be used by the Management Information System for Transportation. Therefore, the volume count data were divided by 4 to get the count for the 15-minute interval.

## Surface Transportation Network Analysis

The analysis procedure for travel time and vehicle counts consisted of four basic steps. First, the data were graphed to determine whether combining the months into month groups was logical based on visual inspection. Second, the combinability of the *months* within a month group was tested with the Mann-Whitney U test (Siegel, 1956). If the months were combinable, the process proceeded with the combined data; otherwise, the process continued with the months treated separately. In the third step, the post-Silver Line opening data were compared to the pre-Silver Line data using the Mann-Whitney U test. If the data sets were statistically different, the relevant times of day were recorded and the process continued to step four. In the fourth step, the magnitude of change and the relative percent change were calculated.

Travel times on VA-267, I-66, and I-495 were further evaluated for reliability using four metrics: travel time window, percent variation, travel time percentiles (80th, 85th, 90th, and 95th), and planning time index. The travel time window spanned between the values that are a standard deviation less than the average travel time and a standard deviation more than the average travel time. The variability in travel time within a particular timeframe was measured using this statistic (Lomax and Margiotta, 2003). Percent variation was the ratio of standard deviation to the average travel time of a segment (see Equation 2), measuring the dispersion in travel time data for a segment (Lomax and Margiotta, 2003). This measure was equivalent to the coefficient of variation multiplied by 100. The pth percentile (80th, 85th, 90th, and 95th) was the value of travel time for which at most p percent of the times had a smaller value (Freund et al., 2010). The planning time index was computed as the 95th percentile travel time divided by free flow travel time (Lyman, 2007). The free-flow travel time was assumed to be the length of the segment divided by posted speed limit (PSL) – 55 mph on I-66. A value close to 1 indicated that vehicles travelled at free flow travel speed.

$$Percent\ Variation = \frac{Standard\ deviation}{Average\ travel\ time}\ x\ 100\ \% \qquad (2)$$

*Mann-Whitney U Test*

Travel times and volumes can be affected by traffic incidents as well as temporary detector errors. These events are inconsistent across years and could affect the comparisons, especially if using statistics based on the mean or based on the assumption of a normal distribution. Unlike the Student *t*-test, which is based on the mean and assumes a normal population distribution, the Mann-Whitney U test compares the medians of two data sets. The Mann-Whitney U test (Siegel, 1956) is a non-parametric test for differentiating between two distributions that does not require the underlying data to be normally distributed. The test is also ideal for unequal sample sizes. However, the probability that the non-parametric test correctly rejects the null hypothesis is lower than that of parametric tests. This means that nonparametric tests typically require larger sample sizes to be able to draw conclusions with the same degree of confidence (Day et al., 2012), which is why the data analysis was limited to the mid-week days and months were combined if possible.

The null hypothesis for the Mann-Whitney U test is the two data samples come from populations with the same distribution. The alternative hypothesis is the data samples are significantly different from each other.

This test operates by combining the samples and then assigning ranks to each of the observations, allocating the rank 1 to the smallest, 2 to the next smallest, and so on. Under the null hypothesis, it would be expected that the two samples would be spread randomly in the rank ordering and the sums of the ranks computed for each sample would be similar to each other. However, if there is a significant difference between the two samples, then the sum of the ranks would be dissimilar and one sample would contribute values to the upper part of the rank list, while the other sample would contribute values to the lower part. Thus, the rank sums would be considerably different. The Mann-Whitney U test quantifies this difference in the rank sums.

The test involves calculation of a U statistic for each group of data. These statistics have a unique distribution under the null hypothesis identified by Mann and Whitney (Mann and Whitney, 1947) for different sample data sizes (Nachar, 2008). Mathematically the U statistic is defined for each data group under comparison as follows:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \qquad (3)$$

$$U_2 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_2 \qquad (4)$$

where

$n_1 = number\ of\ observations\ in\ sample\ data\ group\ 1$
$n_2 = number\ of\ observations\ in\ sample\ data\ group\ 2$
$R_1 = sum\ of\ the\ ranks\ assigned\ to\ the\ data\ group\ 1$
$R_2 = sum\ of\ the\ ranks\ assigned\ to\ the\ data\ group\ 2.$

If the number of observations $n_1$ and $n_2$ is larger than eight, the sampling distribution of the U statistic approaches the normal distribution (Mann and Whitney, 1947) with the mean shown in Equation 5, standard deviation in Equation 6, and test statistic in Equation 7.

$$\mu_U = \frac{n_1 n_2}{2} \qquad (5)$$

$$\sigma_U = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} \tag{6}$$

$$z = \frac{U - \mu_U}{\sigma_U} \tag{7}$$

The test statistic is a measure of the number of standard deviations the value of the performance measure is away from its mean. This test statistic and the p-value are used to make a decision whether to reject the null hypothesis or not. The p-value is the probability of obtaining a test statistic value that would be the same as or more extreme than the observed test statistic value when the null hypothesis is true (Devore, 2000); in other words, p represents the probability of incorrectly rejecting the null hypothesis. In this study, a p-value less than 0.05 was considered statistically significant (Fisher, 1934), indicating that the two samples were significantly different.

## RESULTS AND DISCUSSION

The transit aspects are presented first to provide context for the road-based analyses. The tables for this study are extensive, and most are provided in supplemental files as to not interrupt the flow. The contents of these files are outlined in Table 1. These files are available from the authors upon request.

**Table 1. Content of the Supplemental Files**

| Supplemental File | Content |
|---|---|
| A | Intersection Vehicle Count Changes Near Reston |
| B | Intersection Vehicle Count Changes Near Reston and Orange Line Stations |
| C | Travel Time Changes on SR-286 |
| D | Travel Time Changes on Rt-28 |
| E | Travel Time Changes and Reliabilities on VA-267 |
| F | Travel Time Changes on Rt-7 |
| G | Intersection Vehicle Count Changes on Rt-7 |
| H | Travel Time Changes on SR-123 |
| I | Intersection Vehicle Count Changes on SR-123 |
| J | Travel Time Changes on SR-193 |
| K | Travel Time Changes on SR-243 |
| L | Travel Time Changes on US-29 |
| M | Intersection Vehicle Count Changes on US-29 |
| N | Travel Time Changes on US-50 |
| O | Travel Time Changes and Reliabilities on I-66 |
| P | Vehicle Count Changes at I-66 Detectors |
| Q | Travel Time Changes and Reliabilities on I-495 |
| T | Additional Transit Analyses |

## Silver Line Ridership

### Trends in Monthly Average Ridership

Figure 2 shows the average daily weekday entries, exits, and totals for the five new Silver Line stations since it opened on July 26, 2014. The total number of entries and exits on a typical weekday were almost the same (lower line in Figure 2), indicating highly symmetric ridership. Strong seasonal effects were apparent, as the total number of riders was lower in winter, and higher in late spring and early summer. Overall ridership stabilized after two years and did not show strong momentum in the second year. The ridership in 2016 was lower than the same period in 2015. This decrease in ridership may be related to external factors such as gas price changes and service reductions due to maintenance, although this study did not contain data after SafeTrack began.

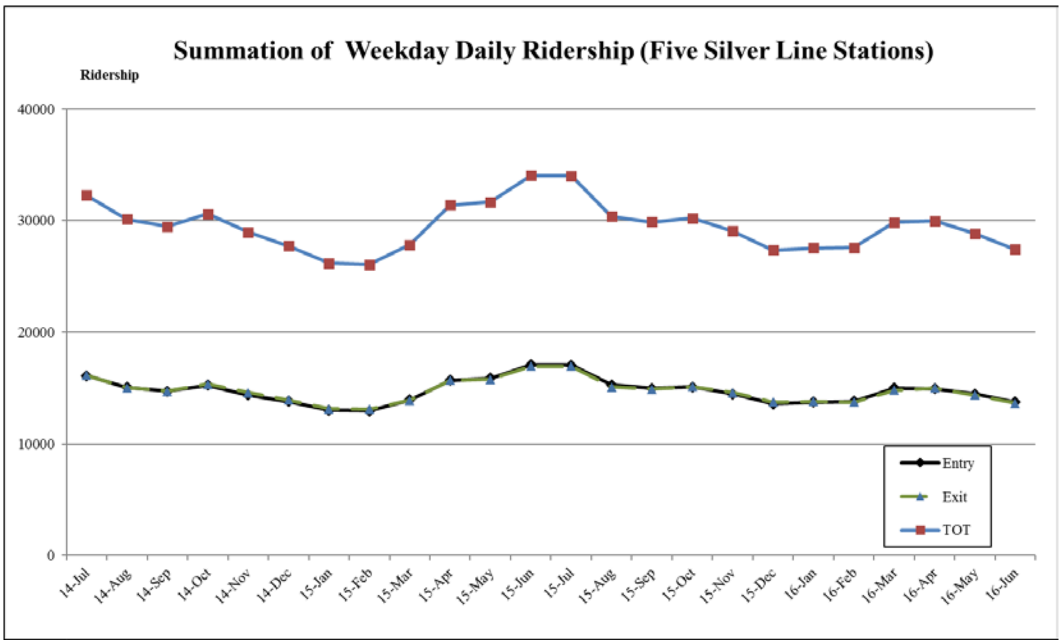


**Figure 2. Average Workday Daily Number of Entries, Exits and Sum for the Five New Silver Line Stations (the number of entries and exits are overlapping for most months)**

Table 2 summarizes the entries and exits for the five Silver Line stations in May 2015. May was selected by WMATA to represent typical travel patterns. After almost one year after the opening of the Silver Line Phase 1, with approximately 31,700 passengers served on a typical weekday, demand should have stabilized. The average ridership for the five Silver Line stations (entries and exits combined) on a typical Saturday and Sunday was about 16,600 and 12,000, respectively (see Tables 3 and 4). The weekday ridership for May 2016 declined by 8.9% compared to May 2015. May 2015 is shown here since some of the ridership decline may have been due to several high-profile incidents in the Metro system in the following year.

**Table 2. Silver Line Average Weekday Ridership in May 2015**

| Station Name | Type | Time of Day | | | | Total |
|---|---|---|---|---|---|---|
| | | AM | MID | PM | EVN | |
| MCLEAN | ENTRY | 732 | 292 | 549 | 96 | 1,669 |
| | EXIT | 434 | 237 | 643 | 275 | 1,589 |
| TYSONS CORNER | ENTRY | 559 | 573 | 1,270 | 739 | 3,141 |
| | EXIT | 874 | 918 | 1,125 | 378 | 3,294 |
| GREENSBORO | ENTRY | 291 | 184 | 469 | 126 | 1,071 |
| | EXIT | 378 | 228 | 322 | 127 | 1,055 |
| SPRING HILL | ENTRY | 539 | 270 | 439 | 157 | 1,406 |
| | EXIT | 383 | 255 | 529 | 236 | 1,404 |
| WIEHLE-RESTON EAST | ENTRY | 5,226 | 1,378 | 1,604 | 380 | 8,588 |
| | EXIT | 1,063 | 1,066 | 4,596 | 1,729 | 8,455 |

**Table 3. Silver Line Average Saturday Ridership in May 2015**

| Station Name | Type | Time of Day | | | | Total |
|---|---|---|---|---|---|---|
| | | AM | MID | PM | EVN | |
| MCLEAN | ENTRY | 77 | 248 | 135 | 87 | 547 |
| | EXIT | 83 | 123 | 157 | 183 | 546 |
| TYSONS CORNER | ENTRY | 189 | 648 | 880 | 931 | 2,648 |
| | EXIT | 210 | 1,137 | 896 | 443 | 2,685 |
| GREENSBORO | ENTRY | 38 | 137 | 111 | 83 | 369 |
| | EXIT | 51 | 110 | 114 | 81 | 356 |
| SPRING HILL | ENTRY | 125 | 355 | 170 | 124 | 774 |
| | EXIT | 107 | 194 | 229 | 193 | 722 |
| WIEHLE-RESTON EAST | ENTRY | 718 | 1,943 | 948 | 461 | 4,071 |
| | EXIT | 421 | 848 | 1,279 | 1,323 | 3,870 |

**Table 4. Silver Line Average Sunday Ridership in May 2015**

| Station Name | Type | Time of Day | | | | Total |
|---|---|---|---|---|---|---|
| | | AM | MID | PM | EVN | |
| MCLEAN | ENTRY | 53 | 206 | 93 | 48 | 400 |
| | EXIT | 26 | 102 | 149 | 107 | 384 |
| TYSONS CORNER | ENTRY | 81 | 453 | 733 | 546 | 1,813 |
| | EXIT | 112 | 899 | 567 | 205 | 1,783 |
| GREENSBORO | ENTRY | 26 | 103 | 81 | 50 | 260 |
| | EXIT | 18 | 92 | 95 | 50 | 255 |
| SPRING HILL | ENTRY | 83 | 253 | 128 | 88 | 552 |
| | EXIT | 41 | 152 | 185 | 136 | 514 |
| WIEHLE-RESTON EAST | ENTRY | 417 | 1,647 | 702 | 318 | 3,083 |
| | EXIT | 150 | 731 | 1,260 | 816 | 2,957 |

## Patterns in Ridership of Individual Stations

As shown in Table 2, the ridership for the terminal station of Phase 1, Wiehle-Reston East, exhibited a strong pattern of commuting travel. Most riders entered the station in the morning and exited during the afternoon (PM) peak. The other four stations did not exhibit similar patterns. On weekdays, a higher proportion of travelers arrived at the Tysons Corner Station during the middle of the day or PM peak and left in the evening. Ridership at the other three stations was much smaller comparatively. This is illustrated in Figures 3 and 5 and in Table 2 for 2015.

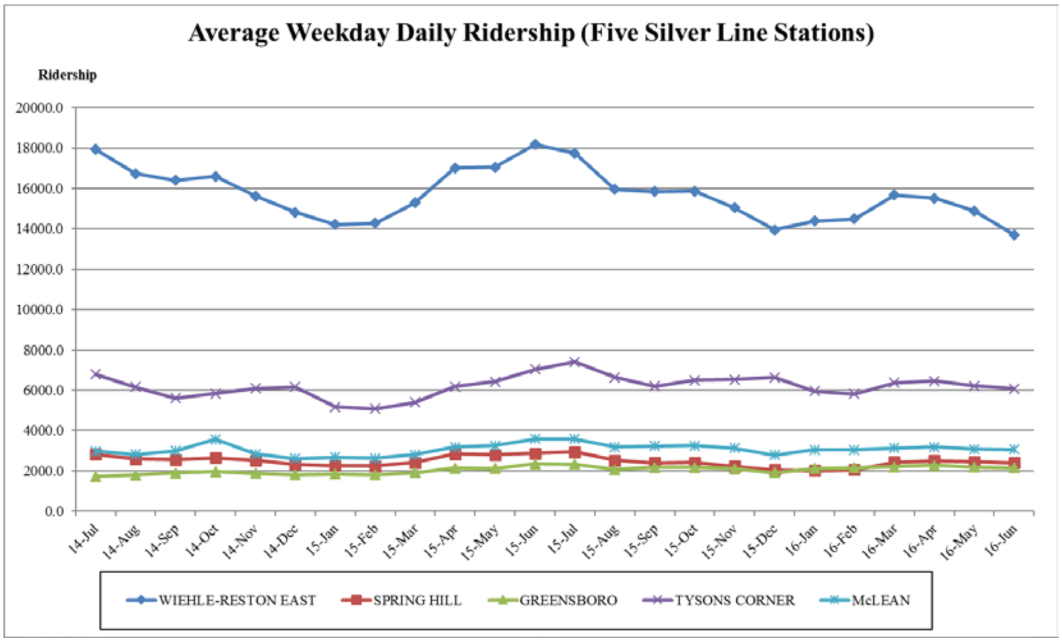


**Figure 3. Average Weekday Daily Ridership (Entries and Exits Combined) by Station for the Five New Silver Line Stations**

These differences in travel patterns between stations may be partially explained by different degrees of multimodal integration and different land use patterns at these stations. Many commuters living further west than the Wiehle-Reston East Station could have transferred to the rail system through bus, park-and-ride, or kiss-and-ride to avoid the congestion on the surface network. The terminal station for Phase 1, Wiehle-Reston East, is the only station among the five where a park-and-ride garage was provided. The park-and-ride garage had 2,306 spaces, with 253 reserved spaces. The price for a reserved space was $65 a month. Therefore, it is not surprising that most commuters chose the Wiehle-Reston East Station.

The Tysons Corner region has numerous office buildings, restaurants, and retail stores. No additional public parking lots were built in the area for the Metro stations. Therefore, Tysons Corner likely attracted shopping and recreation trips, the peak of which occurs later in the day than commuting traffic. Table 2 showed that ridership at the Tysons Corner Station was low during the morning peak, but higher in the afternoon and in the evening.

Figures 4 and 5 present the average May weekday ridership (sum of entries and exits) at the Orange Line stations west of Rosslyn for 2014 and 2015, respectively. By comparing these figures, the impact of the Silver Line on the ridership at existing Orange Line stations can be detected. On a typical weekday, the impact of the Silver Line on the ridership of the Vienna Station (the terminal station of the Orange line) was undetectable. The ridership at the Dunn Loring Station dropped slightly. The largest drop in ridership was seen at the West Falls Church Station, which previously was the Metro access point for many commuter buses from Reston and

Loudoun County. For other eastward stations where the Orange Line and the Silver Line share track and platforms, the impact of the opening of the Silver Line was moderate. The pattern on weekends was similar to that of the weekdays (figures for the weekend ridership are available from the authors upon request).

**Regression Model for Substitution Effect**

Figure 1 showed that the Silver Line and the Orange Line split only between the East and West Falls Church stations in Virginia. Both lines stretch to the west, with the Silver Line running north of the Orange Line. Figure 6 shows the number of entries and exits recorded by the smart card system at the Orange Line stations and the aggregated number of riders for both the Orange Line stations and the five new Silver Line stations on a typical workday. The difference between the two sets of curves represents the number of entries and exits at the five new Silver Line stations. The pattern on weekends is similar to that of the weekdays, and figures of the weekend ridership changes are available from the authors upon request. Figure 6 illustrates that without including the riders of the five Silver Line stations, the total number of riders for stations west of Rosslyn decreased since July 2014. However, during the same time period, if Silver Line riders are included, the total number of riders entering and exiting all Metro stations west of the Rosslyn Station (the last stop before crossing the Potomac River) increased.

To separate new demand from riders who simply switched lines and stations after the Silver Line opened, a rigorous statistical analysis was needed. As described in the Methods section, to overcome data challenges, the research team used total ridership for all stations west of the Rosslyn Station as the dependent variable and the total ridership for the rest of the Metro system as one of the independent variables. If all riders at the five new Silver Line stations were old Metro riders who simply switched lines, the total ridership for stations west of the Rosslyn Station (including both Orange Line stations and new Silver Line stations) would fluctuate consistently with the ridership on the rest of the Metro system. It would also be affected by external factors such as the economy and demographics that were common for the entire Metro system (recall that SafeTrack started after the study period). However, if the opening of the Silver Line in July 2014 attracted new demand, the pattern of total ridership for stations west of Rosslyn would differ from the rest of the Metro system, which could be captured by a dummy variable reflecting the opening of the Silver Line.

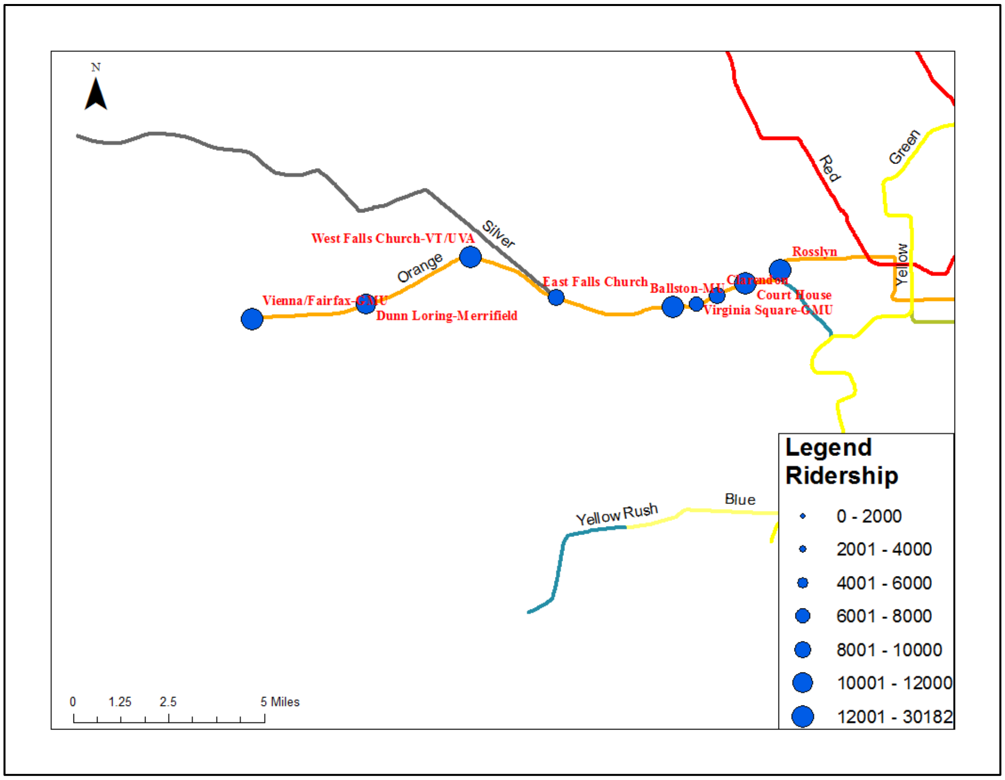


**Figure 4. Orange Line Ridership Comparison for Weekdays of May 2014**

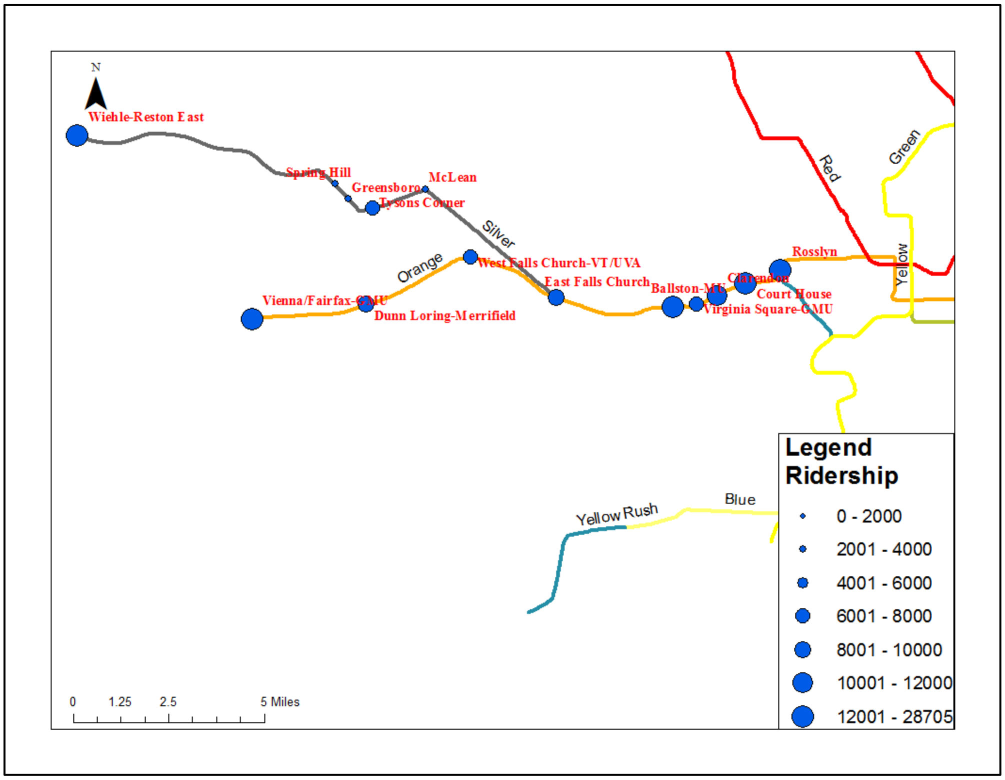


**Figure 5. Ridership Comparison for Weekdays of May 2015**

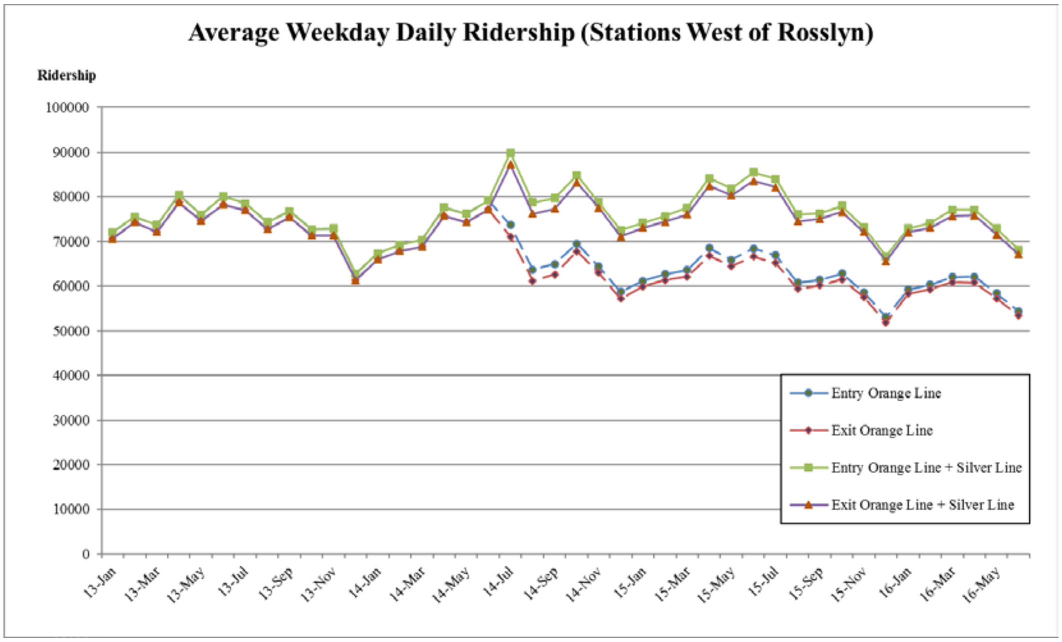


**Figure 6. Average Weekday Daily Ridership for Stations West of Rosslyn**

The results of the regression analysis are summarized in Table 5. Monthly ridership data and gas prices were used, starting with January 2013. There were 42 data points. The model shown in Table 5 had an adjusted R-squared value of 0.81. All coefficients were significant and consistent with expectations. The number of users for all stations west of Rosslyn was positively correlated with the ridership changes on the rest of the Metro system, as both would be affected by the same external factors. The decrease in gas prices during the study period diminished Metro ridership; a $1 reduction in gas prices resulted in a loss of 7,656 riders for all stations west of Rosslyn. With all other factors controlled, the opening of the Silver Line brought in about 20,215 additional rider trip ends (entrances and exits combined for about 19,174 new one-way trips).

**Table 5. Regression Model for Weekday Ridership (Entrances and Exits Combined) of All Stations West of Rosslyn**

| Variable | Beta | t | P |
|---|---|---|---|
| Total Ridership for the Rest of the Metro System | 0.0022665 | 5.7 | 0 |
| Gas Price | 7656.444 | 3.33 | 0.002 |
| Silver Line Dummy | 20215.1 | 8.49 | 0 |
| Constant | 38749.27 | 5.09 | 0 |

## OD Analysis and Reverse Commuting

Figure 7 shows the number of riders who traveled westward during the AM peak and exited at the five Silver Line Stations in October 2014, May 2015, and October 2015. This is based on WMATA's complete OD matrices for the Metro system during these periods. The top five origin and destination stations for riders entering and exiting the five new Silver Line stations during AM peak hours in May 2015 were identified using the OD matrices WMATA provided. Not surprisingly, during the AM peak, most Silver Line riders were going to downtown Washington, D.C. The top five destinations for Metro riders boarding at the five Silver Line stations included Farragut West (11.4%), McPherson Square (7.0%), Foggy Bottom-

GWU (5.7%), Metro Center (5.6%), and Union Station (5.1%), all of which are in downtown Washington, D.C. In contrast, the top five origins for Metro riders going to the five Silver Line stations included Wiehle-Reston East (5.0%), Ballston-MU (6.1%), and Court House (3.4%) in Northern Virginia, and McPherson Square (3.4%) and Foggy Bottom-GWU (2.8%) stations in Washington, D.C. The top origin stations also implied that the Silver Line served reverse commuting traffic coming from Arlington. Smart card data also showed that many riders who boarded the train at the Wiehle-Reston East Station stayed within the Silver Line corridor.

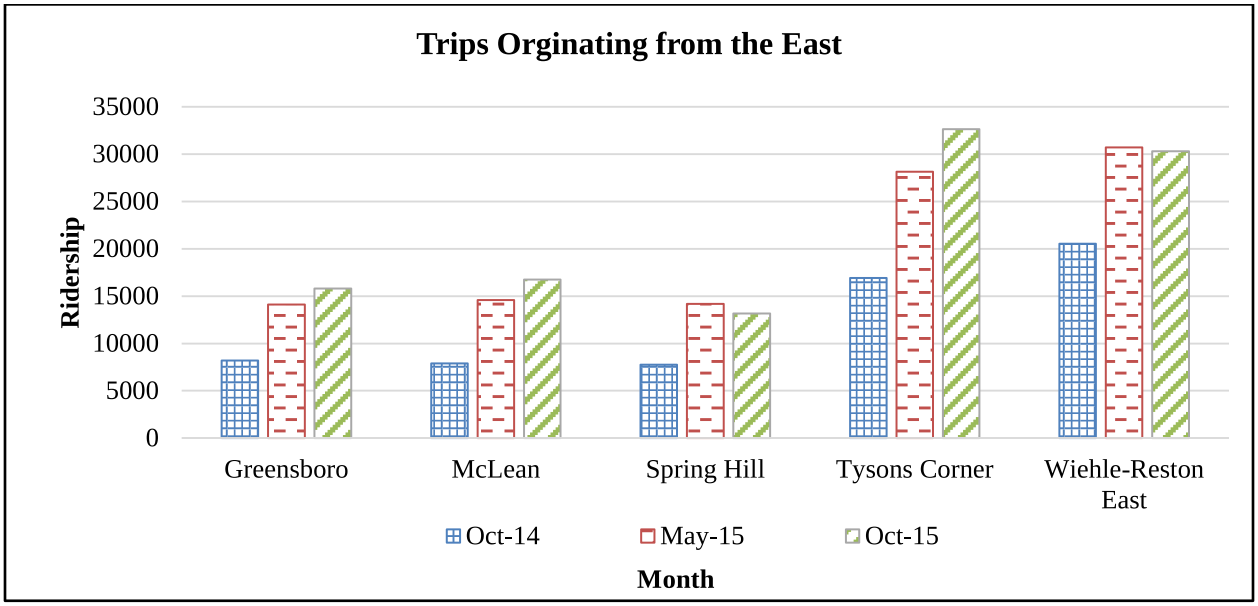


**Figure 7. Number of Riders Traveling Westward During AM Peak That Exited at the Five Silver Line Stations**

The top five destination and top five origin stations for riders entering and exiting the five new Silver Line stations during PM peak hours were also identified using May 2015 OD matrices WMATA provided. The top destination was the Navy-Yard Metro Station (5.6%), which served a large number of people going to the Nationals Park stadium. Other top destinations during the PM peak included Ballston (4.3%) in Arlington, Foggy Bottom-GWU (3.3%) and McPherson Square (3.0%) in Washington, D.C., and the Wiehle-Reston East Station (3.6%), the terminal station of the Silver Line in Northern Virginia. The top five origins during the PM peak were all major Metro stations in the downtown area (Farragut West, 9.7%; McPherson Square, 5.9%; Metro Center, 5.6%; Foggy Bottom-GWU, 5.5%; and Union Station, 4.6%), implying that most riders were commuters going home. The OD matrices that were available for other months yielded similar patterns.

Finally, Figure 8 showed the aggregated patterns of Silver Line users (riders boarding or exiting at the five new Silver Line stations) using data from October of 2014. Among riders who originated from the five Silver Line stations, 70.3% of them crossed the Potomac River to reach their destinations. Another 10.3% of them stayed within the five stations, and the remaining riders went to the areas between the West Falls Church and Rosslyn stations.

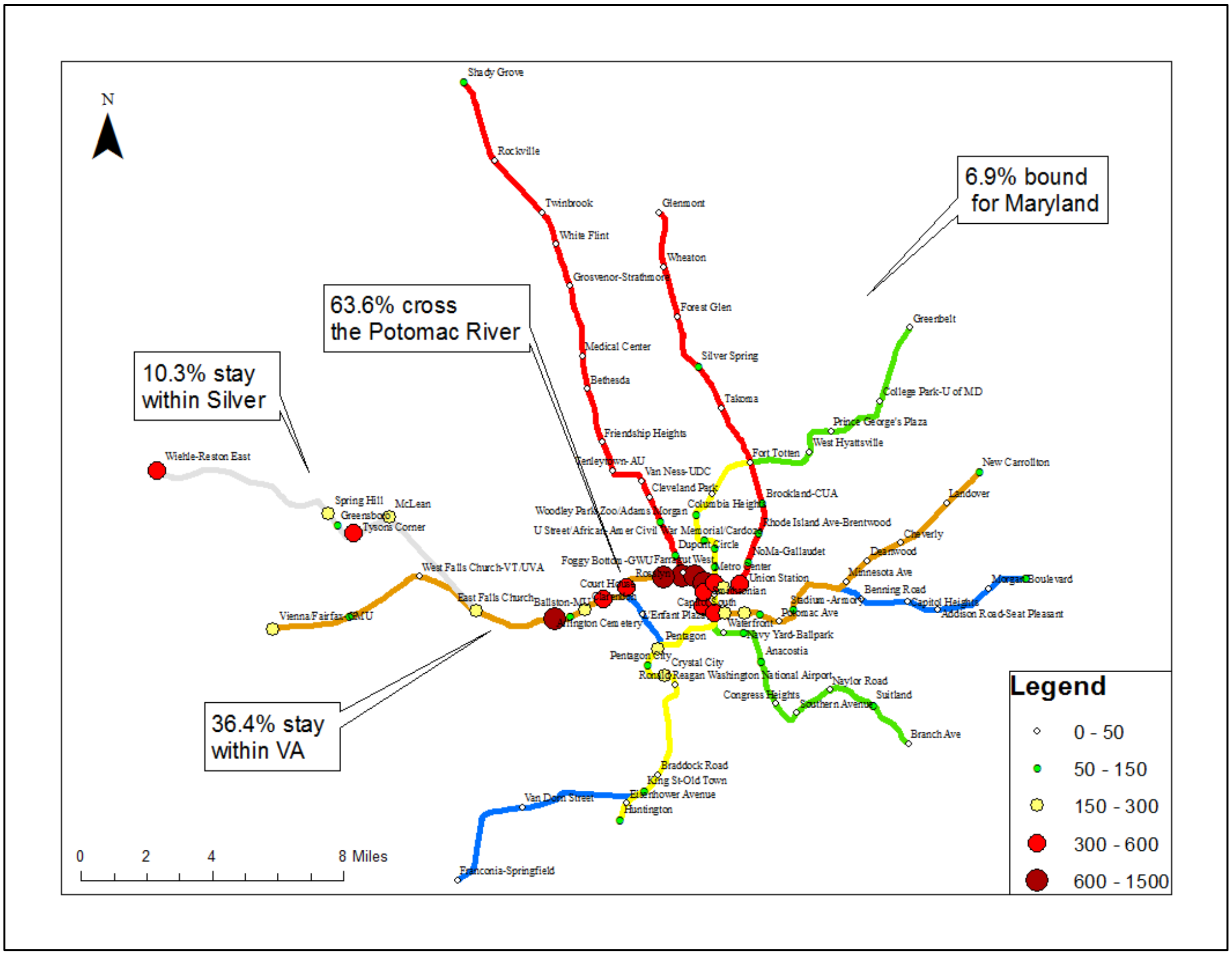


Figure 8. Patterns of Silver Line Riders Using Data From October 2014

## Impact on Regional Bus Services

The bus and rail systems affect each other. Changes in bus routes, particularly those that previously accessed the West Falls Church Metro Station, affected the rail ridership to/from some stations. The expansion of the Metro system also shaped regional bus services. Many Metro riders used regional bus services for connections. A better understanding of these dynamics could help both parties improve their services in the future, especially with Phase 2 of the Silver Line being imminent.

### Impact on Metro Bus Ridership

WMATA is the largest bus operator in the region and many of their bus lines served routes now serviced by the Silver Line. Buses operated by WMATA are equipped with an automatic ridership recording system using data from the fare box. This system allowed for an investigation of the geographic distribution of bus ridership by boarding stop. However, the numbers of passengers getting off the bus at each stop are not recorded. WMATA has also started to equip their buses with an automatic passenger detection system, which could record both boarding and alighting. However, data from that system have not been validated and were not available for this study.

The GIS analysis of bus ridership data showed that nine Metro Bus routes served the corridor of the Silver Line between the Wiehle-Reston East and East Falls Church stations. One route (23T: Mclean to Crystal City) did not begin service until March 2014. Two other bus routes (15M, which linked George Mason University and Tysons Corner, and 28X, which linked Mark Center and Tysons Corner) stopped service in June 2015.

Figure 9 shows the total monthly ridership of the nine Metro Bus routes serving the Silver Line stations. After the Silver Line opened, the total ridership dropped gradually, possibly implying that some bus riders have switched to the Silver Line. As a comparison, Figure 9 also showed the monthly ridership of the entire Metro Bus system. These data were obtained from the National Transit Database. As indicated in previous sections, the total ridership of the transit system in the region decreased slightly in 2015 and 2016. However, the gap in ridership between the Metro Bus lines serving the Silver Line stations and the entire Metro Bus system expanded over time, implying a possible negative impact of the Silver Line. The Silver Line provides a more convenient link between the Tysons Corner area and the commercial corridor (along Wilson Boulevard) in Arlington County. This suggests that some bus riders may have switched to the Silver Line after it opened. However, without individual level data (such as a survey or bus transfer data), it is hard to establish any causal relationship.

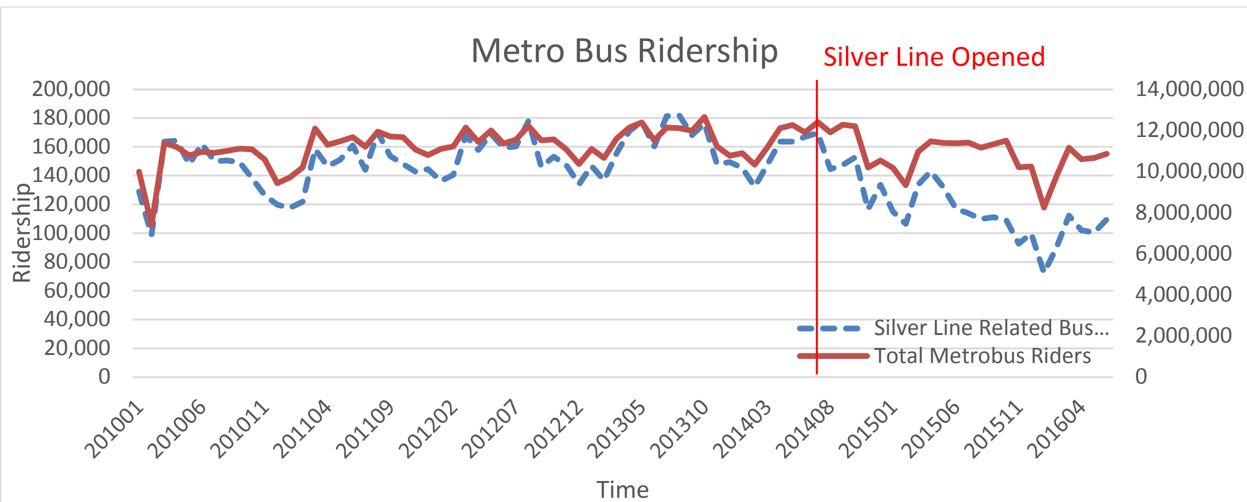


**Figure 9. Monthly Ridership of the Nine Metro Bus Routes Serving the Silver Line Stations in Comparison With the Total Metro Bus Ridership**

Similar patterns were also observed for bus lines operated by the Fairfax County Connector system. GIS analysis showed that among the 86 bus lines in the Fairfax County Connector system, 28 overlapped with the Silver Line to some extent. For the routes that served the Silver Line corridors, the total ridership dropped gradually after the Silver Line opened. In comparison, the total ridership of the entire Fairfax County Connector system did not decrease, although the month-to-month fluctuation expanded over time.

The existing network of both Metro Buses and Fairfax County Connector system had significant overlap with the Silver Line system. However, the Loudoun County bus system was not specifically designed to serve Silver Line areas before the Silver Line opened. After the Silver Line opened, a Metro bus sub-system was created to serve mainly the Wiehle-Reston East Station, as well as the other Silver Line stations (14 lines). Figure 10 shows the ridership of this sub-system as compared with the Loudoun County Commuter Bus Lines that served the downtown Washington, D.C., area. Bus ridership to the Silver Line stations was stable after the Silver Line opened in July 2014. Stop level data were unavailable for the Loudoun County bus systems; thus, it cannot be determined how many bus riders transferred to the Silver Line.

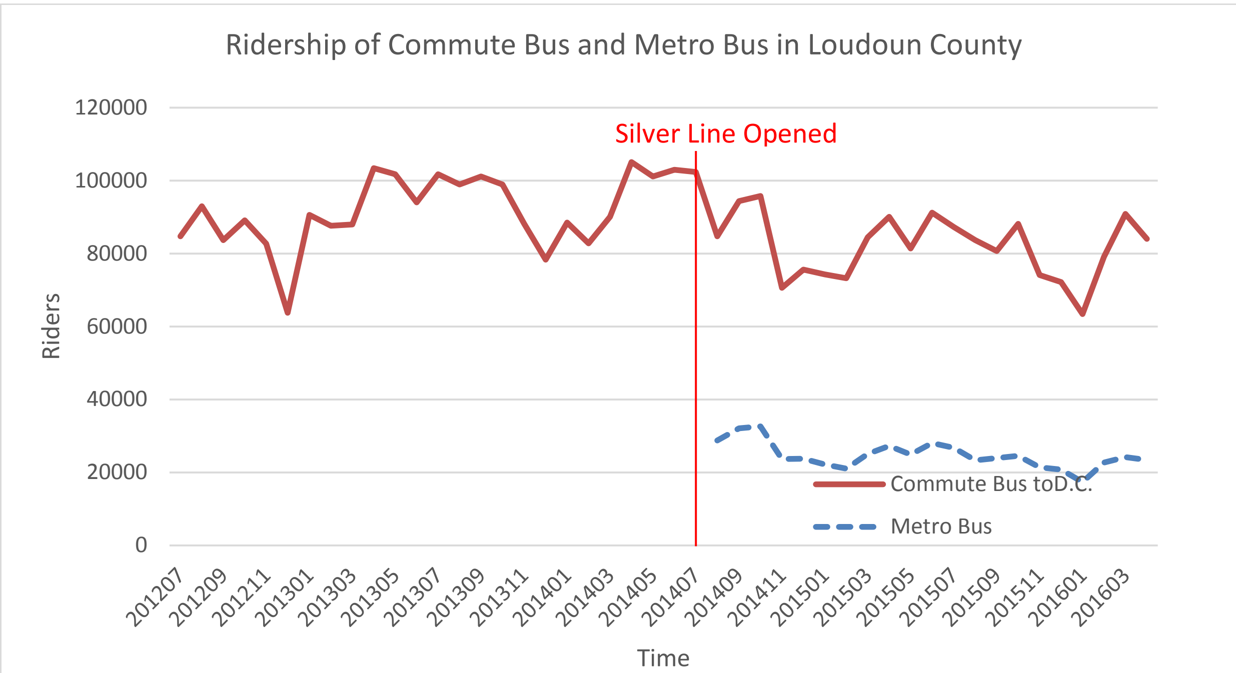


**Figure 10. Monthly Ridership of Commute Bus to Downtown D.C. and Metro Lines Serving Silver Line Stations**

## Surface Transportation System Analysis Results

Most of the analyses suggested some level of general travel growth. Examples supporting trends identified in the Reston area, Tysons Corner area, and for mode shifting are discussed here. Trends for the Reston area appeared to be largely constrained to Reston. Roads farther west (e.g., Centreville Road, Fairfax County Parkway, and Route 28) did not have similar changes to Reston Parkway.

### Reston Area

In the Reston area, two trends were identified. First, as expected, traffic, particularly toward the Wiehle-Reston East Metro Station in the AM peak and away from the station in the PM peak increased. Examples of intersections illustrating the first trend included Reston Parkway-Sunset Hills Road, Fairfax County Parkway (SR-286)-Wiehle Avenue, Wiehle Avenue-Sunset Hills Road, and Wiehle Avenue-Sunrise Valley Drive (see Figure 11). New development likely also contributed to general traffic growth. The second trend was a shifting of some commuters between the Orange and Silver Lines. Examples of intersections illustrating this trend included Wiehle Avenue-Sunrise Valley Drive, Sunrise Valley Drive-Hunter Mill Road, and Hunter Mill Road-Lawyers Road. Table 6 summarizes the largest changes observed at these intersections.

**Table 6. Intersections Illustrating Trends in the Reston Area**

| Intersection | Largest Relative Change for the Intersection | Approach with the Largest Relative Change |
|---|---|---|
| SR-286 – Wiehle Ave | >100% increase | Wiehle Avenue westbound, right turns |
| Wiehle Ave- Sunset Hills Rd | >100% increase | Sunset Hills Rd eastbound, through; Wiehle Ave southbound, left turns |
| Reston Parkway - Sunset Hills Rd | >100% increase | Reston Parkway northbound, through; Reston Parkway southbound, left turn |
| Wiehle Ave-Sunrise Valley Dr | >90% decrease | Sunrise Valley Dr eastbound, through |
| Sunrise Valley Dr – Hunter Mill Rd | >40% decrease | Sunrise Valley Dr eastbound, through |
| Lawyers Rd – Hunter Mill Rd | >40% decrease | Hunter Mill Rd, southbound, left turns Lawyers Rd, eastbound, right turns |

Intersections along SR-602 (Reston Parkway) and south of Sunrise Valley Drive potentially supported both trends (data tables are available from the authors upon request). These intersections had increased through movements along Reston Parkway Northbound in the AM peak (e.g., Reston Parkway-South Lakes Road, Reston Parkway-Fox Mill Road, Reston Parkway-Lawyers Road, and SR-608-Waples Mill Road). The intersections at Fox Mill Road, Lawyers Road, and Waples Mill Road also had increases in through movements for the southbound approach during the early evening peak, corresponding to returning commuters. These intersections possibly suggested a preference to access the Metro system at the Wiehle-Reston East Metro Station instead of the Vienna Metro Station, or a possible avoidance of US-50 and/or I-66.

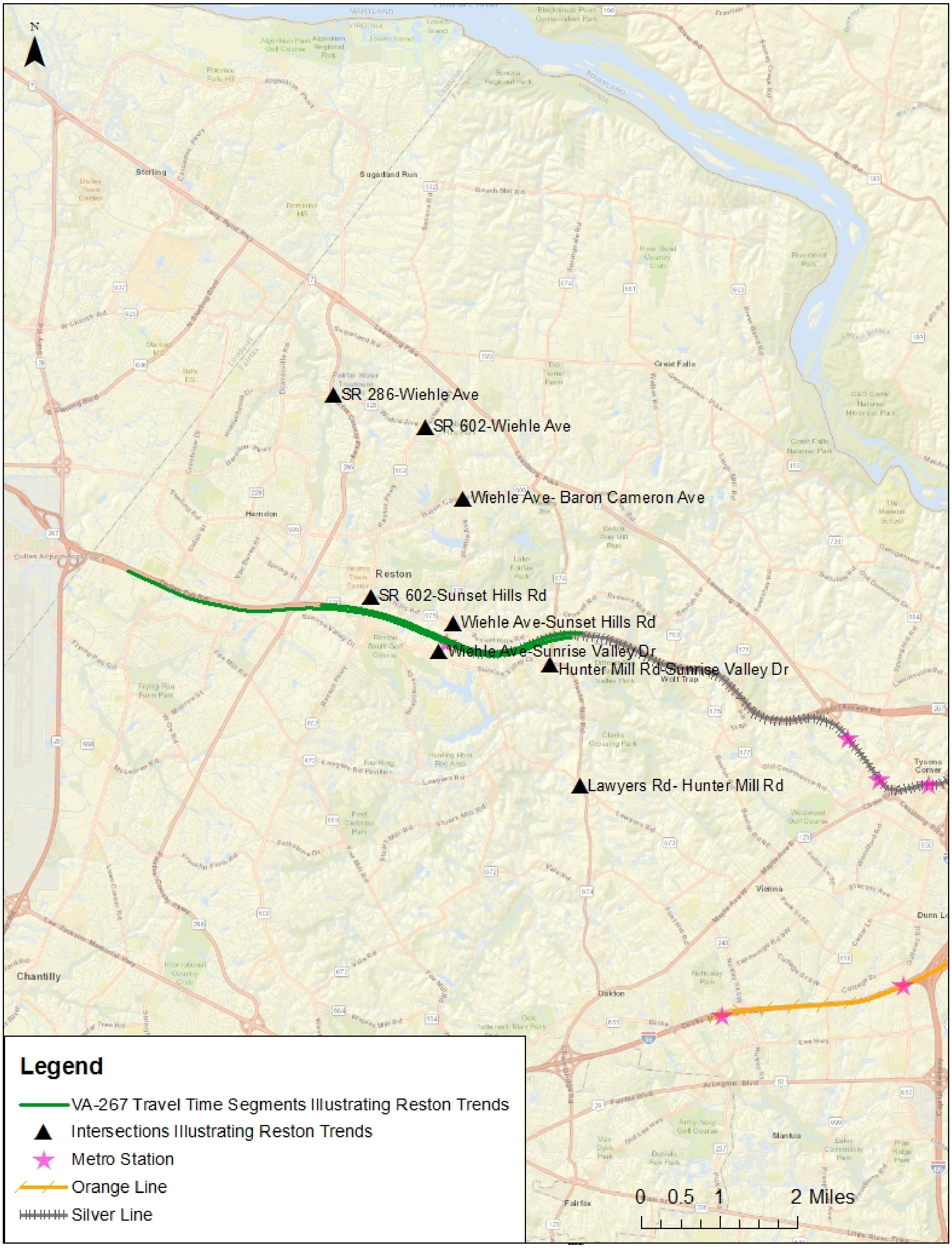


**Figure 11. Locations Illustrating Reston Trends**

*Reston Area Trend 1: Additional Traffic for New Metro Station*

As expected, additional traffic heading to the Wiehle-Reston East Metro Station was observed from both the north and south sides of the station.

From the north side, vehicles appeared to access Wiehle Avenue early in the trip. The Fairfax County Parkway (SR-286)-Wiehle Avenue intersection had an increase (up to 67%) in left turns from SR-286 Southbound onto Wiehle Avenue Eastbound (toward the Metro station) during the AM peak, as shown in Table 7. There was a corresponding increase in right turn movements from Wiehle Avenue Westbound during the PM peak. Increases in vehicle counts continued at the Wiehle Avenue intersections with Reston Parkway, Baron Cameron Avenue, and Sunset Hills Road (see Table 8).

**Table 7. Significant Volume Changes at the SR-286 - Wiehle Avenue Intersection**

| **Observation Characteristics** | **Sept/Oct 2013-14** | **Sept/Oct 2013-15** | **Apr/May 2014-15** | **Apr 2014-16** |
|---|---|---|---|---|
| **Approach** | **SR-286 SB** | | | |
| *Movement* | *L* | *L* | *L* | *L* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:00-9:00, 9:15-13:45 | 6:15-9:00, 15:15-18:15, 18:45-19:45 | 6:00-8:45, 9:30-15:15 | 7:45-8:30, 9:00-12:30, 13:30-14:45 |
| Base year count (veh in 15 min) | 44-100, 26-50 | 46-100, 21-26, 8-13 | 35-94, 27-39 | 82-86, 28-53, 20-30 |
| Direction of change | increase, decrease | increase | increase, decrease | decrease |
| Magnitude of change (veh) | 10-35, 4-25 | 11-39, 5-12, 7-9 | 11-31, 4-10 | 10-19, 7-14, 3-10 |
| Relative change (%) | 13-64, 13-51 | 11-67, 16-46, 54-100 | 14-60, 13-33 | 11-22, 19-44, 15-32 |
| **Approach** | **Wiehle Avenue WB** | | | |
| *Movement* | *R* | *R* | *R* | *R* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 15:15-19:45 | 8:00-19:45 | 16:00-19:45 | 10:15-11:00, 12:00-13:30 |
| Base year count (veh in 15 min) | 16-96 | 12-96 | 19-99 | 24-27, 28-35 |
| Direction of change | increase | increase | increase | decrease |
| Magnitude of change (veh) | 5-33 | 4-44 | 8-19 | 6-8, 4-12 |
| Relative change (%) | 12-93 | 9-121 | 9-63 | 23-28, 15-34 |

The volume comparisons for the Wiehle Avenue-Sunset Hills Road intersection are shown in Table 8. From the Sunset Hills Road Eastbound approach, the through/right turn lane had an up to 100% increase in the AM peak, or more later in the day. A decrease in right turning vehicles from the turn lane (up to 78%) suggested that drivers may have selected alternate entrances to the Metro station and/or VA-267. The intersection west of Wiehle Avenue (Metro Center Drive), provided an alternate approach to the Wiehle park-and-ride and kiss-and-ride. As shown in Table 9, the parking usage at Wiehle-Reston Station increased over the years.

As shown in Table 8, vehicle counts increased up to 38% for through movements from the Wiehle Avenue Northbound approach during the PM peak; this was expected as commuters left the Metro station.

On the west side of Wiehle Avenue is Reston Parkway. The intersection of Reston Parkway with Sunset Hills Road was expected to have increases in vehicle counts to and from the Metro station along Sunset Hills Road. Table 10 illustrates the changes relative to the Metro station. As anticipated, the overall through movement from Sunset Hills Road Eastbound increased (up to approximately 50% for a single lane) during the early part of the AM peak after the Silver Line opened. From the Sunset Hills Road Westbound approach, through movements increased during much of the day (up to approximately 50% for a single lane) (see Table 10). This movement indicated traffic movement away from the Wiehle-Reston East Metro Station (park-and-ride and kiss-and-ride), but part of the increase may be attributed to general growth and development in Reston. From the Reston Parkway Northbound approach, the right turn movements increased up to approximately 50% in the AM peak. This movement led toward the Wiehle-Reston East Metro Station. Similarly, from the Reston Parkway Southbound approach, left turn movements increased toward the Metro station early in the AM peak. Some decreases were present mid-day, as shown in Table 10.

On the south side of the Dulles Toll Road (VA-267), Wiehle Avenue intersects Sunrise Valley Drive. Table 11 presents the vehicle count changes for this intersection. The left turn movements increased up to approximately 70% during the AM peak from Sunrise Valley Drive Eastbound onto Wiehle Avenue toward the Metro station and VA-267. As shown in Table 11, the increase in vehicle counts heading toward the Silver Line station in the AM peak corresponded to an increase in vehicle counts away from the station during the PM peak.

*Reston Area Trend 2: Transfer of Modes or Orange Line Users to the Silver Line*

Several intersections in Reston and portions of VA-267 (Dulles Toll Road) suggested a transfer of Orange Line users to the Silver Line. The VA-267 findings were also consistent with some drivers switching to the Metro system.

At the intersection of Wiehle Avenue and Sunrise Valley Drive (see Table 11), the Sunrise Valley Drive Eastbound through movements decreased throughout the day. This decrease suggested that either fewer local vehicles used this intersection to avoid Metro related traffic or some commuters who used local roads to access the Vienna Metro Station changed to access the Metro system through the Wiehle-Reston East station. Some of the vehicle count decreases continued to the intersection with Hunter Mill Road. The decrease shown in Table 12 from the Sunrise Valley Drive Eastbound approach at the intersection with Hunter Mill Road suggested some transfer of travelers to the Silver Line at more western roads. It also further supported the possibility that some commuters who previously used the Vienna station switched to the Wiehle-Reston East station. Vehicle counts also decreased for the Westbound through movement.

**Table 8. Significant Volume Changes at the Wiehle Avenue – Sunset Hills Road Intersection**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 |
|---|---|---|
| **Approach** | **Sunset Hills EB** | |
| *Movement* | *R and T*[a] | *R and T* |
| Lane | R/T | R/T |
| Time of statistically significant difference | | 6:00-10:00, 14:15-18:45 |
| Base year count (veh in 15 min) | | 14-51, 23-51 |
| Direction of change | | increase |
| Magnitude of change (veh) | | 10-30, 5-44 |
| Relative change (%) | | 30-100, 13-128 |
| *Movement*[b] | *R* | *R* |
| Lane | R[a] | R |
| Time of statistically significant difference | | 6:00-20:00 |
| Base year count (veh in 15 min) | | 14-178 |
| Direction of change | | decrease |
| Magnitude of change (veh) | | 3-138 |
| Relative change (%) | | 14-78 |
| **Approach** | **Sunset Hills WB** | |
| *Movement*[b] | *L*[c] | *L* |
| Lane | L[a]; R | R |
| Time of statistically significant difference | 6:30-20:00 (R) | 6:30-20:00 |
| Base year count (veh in 15 min) | 19-131 | 19-131 |
| Direction of change | decrease | decrease |
| Magnitude of change (veh) | 8-73 | 8-61 |
| Relative change (%) | 29-63 | 14-78 |
| **Approach** | **Wiehle Ave NB** | |
| *Movement*[d] | *T* | *T* |
| Lane | L | L |
| Time of statistically significant difference | 6:30-9:00, 14:30-19:00 | 17:45-19:00 |
| Base year count (veh in 15 min) | 26-91, 51-119 | 60-104 |
| Direction of change | increase | increase |
| Magnitude of change (veh) | 6-18, 6-27 | 16-27 |
| Relative change (%) | 8-27, 5-36 | 15-38 |

[a] Invalid or missing data.
[b] Left lane data were missing or invalid.
[c] Data for September 2014 deviated significantly from the other months and showed no distinct peak volumes, so they were not used.
[d] The right through lane had invalid or missing data before the Silver Line opened.

**Table 9. Parking Facility Usage**

| Station | March | | | | | | September | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** |
| Wiehle-Reston | | | | | 76% | 88% | | | | | 69% | 90% |
| Vienna | 97% | 99% | 98% | 95% | 88% | 84% | 93% | 97% | 99% | 102% | 94% | 82% |
| Dunn Loring | 103% | 99% | 93% | 88% | 85% | 82% | 105% | 99% | 92% | 95% | 89% | 77% |
| West Falls Church | 96% | 98% | 100% | 92% | 66% | 58% | 94% | 96% | 111% | 100% | 75% | 56% |
| East Falls Church | 107% | 103% | 108% | 105% | 107% | 122% | 102% | 94% | 109% | 112% | 121% | 123% |

*Data source:* WMATA (2012a,b, 2014a,b, 2015, 2016a,b)

**Table 10. Significant Volume Changes at the Reston Parkway - Sunset Hills Intersection**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| **Approach** | **Sunset Hills Rd WB** | | | |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | L; R[a] | L; R[a] | L; R[a] | L; R[a] |
| Time of statistically significant difference | 6:30-7:45, 9:00-12:00, 16:00-19:30 | 6:30-8:15, 9:15-19:30 | 6:15-11:45, 13:30-14:45, 17:00-20:00 | 6:45-7:45, 13:15-14:45, 15:30-16:45, 17:30-19:30 |
| Base year count (veh in 15 min) | 23-54, 47-88, 51-134 | 23-61, 47-136 | 20-85, 67-79, 42-147 | 28-53, 64-70, 71-120, 52-116 |
| Direction of change | increase | increase | increase | increase |
| Magnitude of change (veh) | 8-15, 4-18, 13-38 | 4-13, 7-39[b] | 6-13, 5-16, 7-38[c] | 5-11, 8-16, 13-34, 11-43 |
| Relative change (%) | 19-50, 6-30, 11-51 | 6-46, 5-53 | 8-38, 9-21, 6-50 | 13-38, 10-22, 11-38, 17-52 |
| **Approach** | **Reston Parkway NB** | | | |
| *Movement* | *R* | *R* | *R* | *R* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:00-7:30 | 6:00-7:30 | 6:00-7:30 | 6:00-7:00 |
| Base year count (veh in 15 min) | 57-167 | 57-167 | 61-184 | 59-121 |
| Direction of change | increase | increase | increase | increase |
| Magnitude of change (veh) | 17-34 | 16-42 | 18-36 | 24-36 |
| Relative change (%) | 13-48 | 12-59 | 12-59 | 21-51 |
| **Approach** | **Sunset Hills EB** | | | |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | L; C; R | L; C; R | L; C; R | L; C; R |
| Time of statistically significant difference | 6:30-7:45(L); 6:00- 7:45, 15:45-16:30, 17:45-18:30(C); None(R) | 8:00-17:45(L); 6:00- 7:30, 15:45-16:30, 17:45-18:30(C); 7:30-8:15, 12:30-14:15, 14:30-15:15(R) | 6:00-18:00(L); 6:00-7:30, 8:00-9:00(C); 7:15-9:00, 9:45-10:30(R) | 6:00-17:45(L); 6:00- 7:00(C); None(R) |
| Base year count (veh in 15 min) | 22-43(L); 69-255, 133-147, 132-170(C) | 49-139(L); 69-203, 133-147, 132-170 (C); 233-263; 148-194; 152-160 (R) | 20-133(L); 72-213, 309-325(C); 216-260, 151-169 (R) | 15-165(L); 45-141(C) |
| Direction of change | increase(L); increase (C) | decrease(L); increase (C); decrease(R); | decrease(L); increase(C), decrease(C); decrease(R), increase(R) | decrease(L); increase(C) |
| Magnitude of change (veh) | 8-11(L); 8-31, 10-18, 25-35(C) | 7-46[d](L); 17-32, 14-20, 12-28(C); 12-33, 10-25, 9-17 (R) | 3-35[d](L); 14-33, 11-26(C); 8-14, 7-13(R) | 5-70[d](L); 17-27(C) |
| Relative change (%) | 16-50(L); 3-37, 7-12, 19-23(C) | 14-33(L); 10-38, 10-14, 7-19(C); 5-12, 6-16, 5-11(R) | 6-34(L); 8-39, 4-8(C); 3-6, 5-8 (R) | 14-53(L); 18-38(C) |

| **Approach** | **Reston Parkway SB** | | | |
|---|---|---|---|---|
| *Movement* | *L* | *L* | *L* | *L* |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:45-7:30, 8:45-9:30, 10:30-11:45, 14:30-15:15(L); 6:00-8:30(R) | 7:45-9:30, 10:15-11:45, 13:15-14:45, 17:30-18:30(L); 6:30-7:45(R) | 6:00-7:45(L); 6:00-8:30, 15:30-17:00, 17:30-18:45(R) | 6:00-6:45, 8:15-10:00, 10:30-11:15, 14:00-14:45(L); 6:15-8:00(R) |
| Base year volume range (count) | 18-29, 45-54, 37-49, 39-42(L); 5-40(R) | 41-54, 37-49, 42-61, 34-37(L); 10-27(R) | 13-41(L); 9-40, 24-26, 22-25(R) | 14-21, 39-52, 40-45, 40-46(L); 9-32(R) |
| Direction of change | increase, decrease, decrease, decrease(L); increase(R) | decrease(L); increase(R) | increase(L); increase(R) | increase, decrease, decrease, decrease(L); increase(R) |
| Magnitude of change (volume) | 5-12, 9-10, 1-12, 4-10(L); 5-10(R) | 3-16, 7-12, 4-12, 6-8(L); 3-10(R) | 5-7(L); 3-11, 3-4, 3-5(R) | 8-10, 6-11, 8-10, 8-9(L); 4-10(R) |
| Relative change (%) | 17-48, 17-22, 8-27, 10-26(L); 14-200(R) | 6-30, 16-26, 8-25, 16-24(L); 13-83(R) | 16-85(L); 9-111, 12-17, 13-20(R) | 41-66, 13-24, 20-24, 16-23(L); 14-50(R) |

[a] A single detector covered both lanes.
[b] Larger magnitudes were observed between 17:30 and 18:15 (26-39 vehicles).
[c] Larger magnitudes were observed between 17:30 and 18:45 (18-38 vehicles).

**Table 11. Significant Volume Changes at the Wiehle Avenue-Sunrise Valley Drive Intersection**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| **Approach** | **Sunrise Valley EB** | | | |
| *Movement* | *L* | *L* | *L* | *L* |
| Lane | L;R | L;R | L;R | L;R |
| Time of statistically significant difference | 6:00-10:00 (L); 7:45-9:15 (R) | 6:15-11:15 (L); 6:30-10:00(R) | 6:00-11:00, 13:45-14:30 (L); 6:30-7:15, 8:00-9:00(R) | 6:00-10:00, 18:45-19:45 (L); 7:45-9:00 (R) |
| Base year count (veh in 15 min) | 21-70(L); 94-111 (R) | 20-64(L); 52-111(R) | 20-68, 32-34(L); 70-91, 109-112(R) | 18-66, 20-32(L); 108-112(R) |
| Direction of change | increase(L); increase(R) | increase(L); increase(R) | increase(L); increase(R) | increase(L); increase(R) |
| Magnitude of change (veh) | 8-23(L); 7-17(R) | 5-27(L); 4-22(R) | 3-20, 4-5(L); 5-13, 5-11(R) | 7-28, 3-5(L); 9-15(R) |
| Relative change (%) | 10-73(L); 6-18(R) | 9-73(L); 6-26(R) | 10-69, 13-15(L); 7-16, 4-10(R) | 11-78, 11-18(L); 8-13(R) |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:00-20:00 | 6:00-20:00 | 6:00-20:00 | 6:00-20:00 |
| Base year count (veh in 15 min) | 23-127 | 23-127 | 29-122 | 20-120 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 15-111 | 16-111 | 22-105 | 19-105 |
| Relative change (%) | 65-91 | 70-97 | 71-93 | 75-97 |
| **Approach** | **Wiehle Ave SB** | | | |
| *Movement* | *L* | *L* | *L* | *L* |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 7:15-8:45, 9:30-10:30, 17:45-18:45(L); None(R) | 7:15-9:00, 17:00-18:45 (L); 6:00-7:00(R) | | |
| Base year count (veh in 15 min) | 97-139, 55-82, 56-74 (L) | 97-129, 56-93 (L); 24-66 (R) | | |
| Direction of change | decrease, decrease, increase(L) | decrease, increase(L); decrease(R) | | |
| Magnitude of change (veh) | 11-17, 4-11, 9-21(L) | 8-18, 6-29 (L); 9-20(R) | | |
| Relative change (%) | 9-16, 7-14, 13-28(L) | 6-14, 6-40 (L); 30-41 (R) | | |
| *Movement* | *R* | *R* | *R* | *R* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:00-9:15, 14:45-18:45 | 6:00-8:00, 15:30-19:30 | | |
| Base year count (veh in 15 min) | 30-149, 115-241 | 30-127, 97-241 | | |
| Direction of change | increase | increase | | |
| Magnitude of change (veh) | 12-26, 14-62 | 7-31, 12-77 | | |
| Relative change (%) | 11-40, 7-36 | 6-67, 8-43 | | |

**Table 12. Interesting Vehicle Count Changes at the Intersection of Sunrise Valley Dr and Hunter Mill Rd**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| **Approach** | **Sunrise Valley Dr EB** | | | |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:30-9:00 | 6:00-9:00, 14:45-19:00 | 6:00-8:30 | 6:00-6:45, 13:30-14:45 |
| Base year count (veh in 15 min) | 32-59 | 23-59, 54-119 | 15-58 | 16-28, 34-46 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 5-12 | 7-22, 6-19 | 3-20 | 5-6, 7-11 |
| Relative change (%) | 10-26 | 14-47, 10-32 | 12-35 | 20-39, 15-23 |
| **Approach** | **Sunrise Valley Dr WB** | | | |
| *Movement* | *T*[a] | *T* | *T* | *T* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 15:30-16:30, 17:45-18:30 | 15:30-18:00 | 17:45-19:15 | 6:00-6:45 |
| Base year count (veh in 15 min) | 39-50, 39-48 | 39-56 | 31-45 | 25-46 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 6-13, 4-8 | 6-20 | 3-8 | 3-9 |
| Relative change (%) | 14-28, 10-17 | 14-36 | 8-25 | 10-20 |

The possibility of some switching between the Vienna Metro station and the Wiehle-Reston East Metro station was further supported by Table 13 for the AM peak. The Hunter Mill Road Southbound approach at the intersection with Lawyers Road had an up to 46% decrease in left turns during the AM peak, the through and right lane also had an up to 43% decrease in the second year. The Lawyers Road Eastbound approach had an up to approximately 15% decrease in left/through movements during the AM peak and an up to 54% decrease in right turns during the AM peak after the first fall. The return commute was less consistent, perhaps due to other route diversions or latent demand (tables are available from the authors upon request).

During the AM peak in the first September after the Silver Line opened, VA-267 Eastbound from Route 28 to Hunter Mill Road had travel time decreases in the AM peak, suggesting some switching of commuters from driving along VA-267 to using the Metro system or to alternate routes. After that initial period, travel time effects varied by road segment, suggesting some rebalancing of traffic as drivers learned about traffic conditions after the Silver Line opened, effects of development in Reston and to the west, and potential construction impacts for Phase 2 of the Silver Line. Further supporting the traffic rebalancing and additional traffic due to development, travel time reliabilities in the VA-267 Eastbound direction generally improved in the first year after the Silver Line opened but worsened in the second year (supporting tables are available from the authors upon request).

**Table 13. Vehicle Count Changes at the Intersection of Hunter Mill Rd and Lawyers Rd**

| **Observation Characteristics** | **Sept/Oct 2013-14** | **Sept/Oct 2013-15** | **Apr/May 2014-15** | **Apr 2014-16** |
|---|---|---|---|---|
| **Approach** | **Hunter Mill Rd SB** | | | |
| *Movement* | *L* | *L* | *L* | *L* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:30-7:15, 17:00-17:45 | 6:15-18:30 | 6:00-9:15, 16:45-17:45 | 7:30-8:30 |
| Base year count (veh in 15 min) | 55-64, 94-101 | 29-101 | 23-67, 78-93 | 51-67 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 13-14, 9-10 | 4-26 | 5-25, 8-17 | 4-17 |
| Relative change (%) | 21-25, 9-10 | 10-46 | 15-37, 9-19 | 7-25 |
| *Movement* | *R/T* | *R/T* | *R/T* | *R/T* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | None | 6:00-7:00, 7:45-8:45 | None | 6:00-6:45 |
| Base year count (veh in 15 min) | | 43-92, 107-118 | | 33-91 |
| Direction of change | | decrease | | decrease |
| Magnitude of change (veh) | | 8-39, 6-20 | | 3-37 |
| Relative change (%) | | 9-43, 5-17 | | 9-41 |
| **Approach** | **Lawyers Rd EB** | | | |
| *Movement* | *L/T* | *L/T* | *L/T* | *L/T* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 7:30-8:15 | 6:30-8:30, 10:30-14:45 | 6:00-7:15, 11:30-12:30, 18:15-19:15 | 11:30-15:00, 15:30-16:15 |
| Base year count (veh in 15 min) | 103-125 | 85-125, 39-52 | 48-109, 43-49, 48-67 | 42-52, 56-65 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 14-16 | 7-18, 2-11 | 3-16, 4-7, 6-9 | 7-17, 7-14 |
| Relative change (%) | 11-15 | 9-18, 5-21 | 10-15, 9-15, 12-13 | 15-34, 11-21 |
| *Movement* | *R* | *R* | *R* | *R* |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 16:45-18:15 | 6:00-7:00, 16:30-18:15 | 6:00-6:30, 17:00-18:15 | 6:00-6:45 |
| Base year count (veh in 15 min) | 50-61 | 32-74, 50-61 | 33-48, 52-65 | 32-68 |
| Direction of change | increase | decrease, increase | decrease, increase | decrease |
| Magnitude of change (veh) | 4-17 | 6-40, 7-25 | 5-8, 5-13 | 12-35 |
| Relative change (%) | 7-30 | 10-54, 13-44 | 10-24, 8-20 | 36-52 |

Closer to the Wiehle-Reston East Metro station, travel times on VA-267 Eastbound between Reston Parkway and Hunter Mill Road had either no significant change or an improvement across the study period. These findings suggested benefits from the Silver Line either due to shifting of drivers to the Metro system or a shift of riders from the Orange Line (e.g., accessing the Metro system at West Falls Church) to the Silver Line. The benefits were more pronounced in the September comparisons.

During the PM peak, some Metro riders using the Wiehle-Reston East park-and-ride likely used VA-267 to return home. In the westbound direction, travel time variability increased on the segment between Wiehle Avenue and Reston Parkway, compared to pre-Silver Line conditions. This variability was potentially a reflection of the surges associated with train arrivals. These variability increases propagated into the downstream segment between Reston Parkway and Fairfax County Parkway and spilled back into the upstream segment between Hunter Mill Road and Wiehle Avenue (figures are available from the authors upon request).

**Tysons Corner and McLean Area**

In the Tysons Corner and McLean area, two trends were identified. Locations illustrating these trends are shown in Figure 12. First, traffic generally increased despite road expansion along Route 7, likely due to additional development and re-development. Intersections supporting this trend included those along Route 7 between VA-267 and SR-123 and those along SR-123 between International Drive and Georgetown Pike (see Table 14). The Metro stations in the Tysons Corner area do not have park-and-ride facilities except for private parking at the McLean station. As shown in Table 2, the ridership for the different stations are relatively low, compared to the Wiehle-Reston East station, suggesting that increased traffic in this area is not solely attributable to accessing the Silver Line. Second, some travel patterns in this area changed, including avoiding the interchange of Route 7 and SR-123 and mode and route shifts. Support for this trend was provided by the intersection of SR-123 and Gosnell Road/Old Courthouse Road, the intersection of SR-123 and International Drive, and the I-495 segment between I-66 and Route 7.

*Tysons Corner and McLean Area Trend 1: Traffic Growth*

Route 7 was heavily traveled and contained two of the new Silver Line stations in Tysons Corner. Route 7 was expanded within this area as part of the Silver Line construction project. The area has also seen development and re-development. Not surprisingly, some of the intersections along Route 7 had some of the largest volume changes, as illustrated by Table 14. However, the direction of the changes (increases or decreases) often varied by season, which may have reflected construction activities in the base year.

Another main road in the Tysons Corner area was SR-123 (Chain Bridge Road). In the section on the eastern side of Tysons Corner and continuing toward the Chain Bridge, accessing Washington, D.C., vehicle counts increased, particularly toward Washington, D.C., in the AM peak. This trend was fairly consistent at the SR-123 intersections with International Drive, Lewinsville Road/Great Falls Street, Old Dominion Drive, and Georgetown Pike (tables are available from the authors upon request). The results for the SR-123 Northbound approach to the intersection with Lewinsville Road/ Great Falls Street are also shown in Table 15 as an example. As shown in the table, both left turns and through movements increased during the morning.

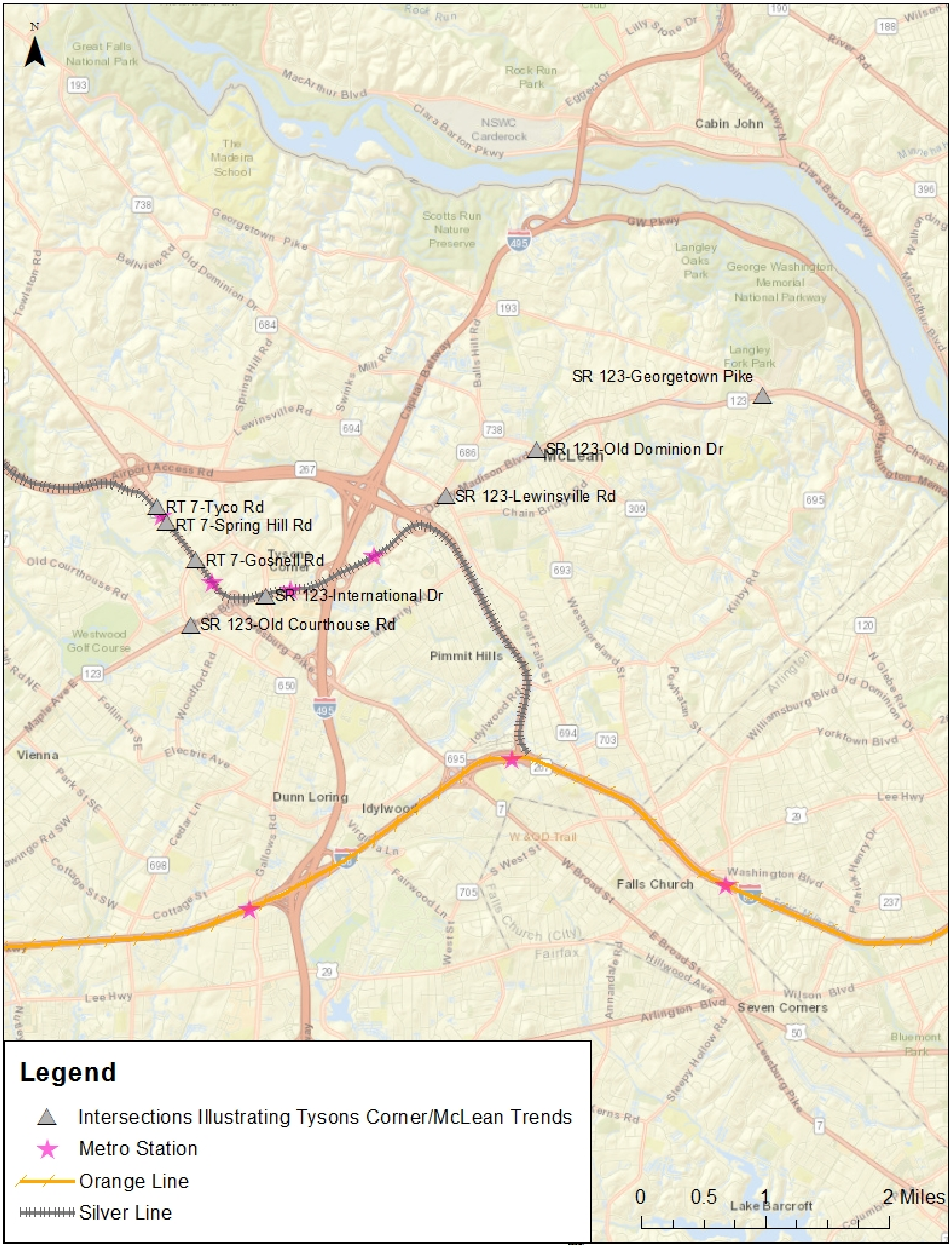


**Figure 12. Locations Illustrating Tysons Corner/McLean Trends**

**Table 14. Intersections Illustrating Tysons Corner and McLean Trends**

| Intersection | Largest Relative Change for the Intersection | Approach with the Largest Relative Change |
|---|---|---|
| Rt-7 - Gosnell Road | > 100% increase | Rt-7 westbound through |
| Rt-7 - Tyco Road | > 100% increase | Rt-7 eastbound R/T; Rt-7 westbound, left turns; Tyco Rd, right turns |
| Rt-7 - Spring Hill Road | > 100% increase | Rt-7 westbound through; Spring Hill Rd northbound, right turns; Rt-7 eastbound through |
| SR-123 - Gosnell Road/Old Courthouse Road | > 100% increase | Gosnell Rd through |
| SR-123 - International Drive | 89% increase | International Dr westbound, right turns |
| SR-123 – Lewinsville Road | 74% increase | SR-123 northbound, left turns |
| SR-123 – Old Dominion Drive | 40% increase | SR-123 northbound, through |
| SR-123 – Georgetown Pike | > 100% increase | SR-123 northbound, left turns |

**Table 15. Significant Volume Changes at the SR-123-Lewinsville Road Intersection: SR-123 NB Approach**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-14 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| Movement | L | L | L | L |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 8:00-9:45(L); 6:30-9:30(R) | 6:30-10:00(L); 6:30-9:30(R) | 7:30-11:00(L); 6:45-11:00(R) | 7:45-9:00(L); 6:45-8:45(R) |
| Base year count (veh in 15 min) | 38-56(L); 26-49(R) | 36-69(L); 26-62(R) | 30-79(L); 21-66(R) | 63-78(L); 40-62(R) |
| Direction of change | increase(L); increase(R) | increase(L); increase(R) | increase(L); increase(R) | increase(L); increase(R) |
| Magnitude of change (veh) | 9-25(L); 8-20(R) | 8-34(L); 8-17(R) | 3-10(L); 7-17(R) | 8-18(L); 9-21(R) |
| Relative change (%) | 22-56(L); 17-64(R) | 20-74(L); 19-52(R) | 6-27(L); 6-56(R) | 10-27(L); 15-48(R) |
| Movement | T | T | T | T |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:30-10:00, 13:45-15:00 (L); 8:15-10:45(R) | 6:30-10:00, 15:30-16:30 (L); 15:15-16:30(R) | 9:15-10:45(L); None(R) | 6:45-11:00(L); None(R) |
| Base year count (veh in 15 min) | 122-222, 112-126(L); 144-205(R) | 122-222, 136-174(L); 142-180(R) | 129-174(L) | 127-231(L) |
| Direction of change | increase(L); increase(R) | increase(L); increase(R) | increase(L) | increase(L) |
| Magnitude of change (veh) | 15-53, 13-28(L); 12-24(R) | 16-46, 25-49(L); 26-30(R) | 14-39(L) | 8-52(L) |
| Relative change (%) | 7-34, 10-22(L); 6-16(R) | 7-35, 17-29(L); 15-18(R) | 9-26(L) | 4-25(L) |

*Tysons Corner Area Trend 2: Changing Travel Patterns*

Two potential travel pattern changes emerged for the Tysons Corner Area. The first was avoidance of the intersection of SR-123 and Route 7; these roads together contain four of the five new Silver Line stations. This change was illustrated by the vehicle counts at the intersection of SR-123 and Old Courthouse Road/Gosnell Road. The second was a change in methods to access Tysons Corner, which was illustrated by the Silver Line ridership shown in Table 2, vehicle counts at the intersection of SR-123 and International Drive, and the travel times on I-495 between I-66 and Route 7.

At the intersection of SR-123 and Old Courthouse Road/Gosnell Road, the through traffic from Old Courthouse Road to Gosnell Road and vice versa increased, as shown in Table 16. The increase from Gosnell Road was substantial both in number of vehicles and relative change (greater than 100%) and occurred over most of the day. This increased through traffic suggested the possibility that either Metro commuters used this route to access the Greensboro or Spring Hill Metro Stations or some drivers avoided Route 7 intersections near these stations. Some of the increase from Gosnell Road in the PM peak likely came from Route 7 Eastbound, which had increases in right turns up to 35% and from Westpark Drive through traffic, which increased over 100%, as shown in Table 17. Left turns from Route 7 Westbound decreased. Most of the additional traffic coming from Old Courthouse Road to Gosnell Road and proceeding to Route 7 likely turned right after the AM peak period as shown in Table 18.

**Table 16. Significant Volume Changes at the SR 123-Old Courthouse Road Intersection**

| **Observation Characteristics** | **Sept/Oct 2013-14** | **Sept/Oct 2013-15** | **Apr/May 2014-15** | **Apr 2014-16** |
|---|---|---|---|---|
| **Approach** | **Old Courthouse Rd NB** | | | |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | L; R/T | L; R/T | L; R/T | L; R/T |
| Time of statistically significant difference | 7:00-10:00, 12:00-13:30, 16:30-19:00 (L); 8:45-10:00(R/T) | 8:15-19:00 (L); 15:30-18:45(R/T) | 16:30-19:15 (L); 6:00-8:30, 16:30-19:15(R/T) | None(L); 15:15-16:30, 17:15-19:00(R/T) |
| Base year count (veh in 15 min) | 52-83, 63-70, 46-78(L); 45-82(R/T) | 46-78(L); 50-84(R/T) | 61-80(L); 16-93, 38-88(R/T) | 51-72, 35-88(R/T) |
| Direction of change | increase(L); increase(R/T) | increase(L); increase (R/T) | increase(L); increase, decrease (R/T) | increase (R/T) |
| Magnitude of change (veh) | 5-14, 5-9, 4-18(L); 5-13(R/T) | 3-14(L); 7-16(R/T) | 3-16(L); 3-15, 6-13(R/T) | 8-12, 7-18 (R/T) |
| Relative change (%) | 6-25, 7-14, 7-37(L); 8-25(RT) | 4-29(L); 11-30(RT) | 4-22(L); 11-29, 9-23(R/T) | 12-22, 8-29(R/T) |
| **Approach** | **Gosnell Rd SB** | | | |
| *Movement* | *T* | *T* | *T* | *T* |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:00-20:00(L;R) | 6:00-20:00(L;R) | 6:30-19:45(R) | 6:00-20:00(R) |
| Base year count (veh in 15 min) | 10-83(L); 10-65(R) | 10-83(L); 10-65(R) | 28-90(R) | 19-89(R) |
| Direction of change | increase(L); increase(R) | increase(L); increase(R) | increase(R) | increase(R) |
| Magnitude of change (veh) | 19-80(L); 34-171(R) | 18-51(L); 37-247(R) | 33-252(R) | 34-351(R) |
| Relative change (%) | 28-500(L); 74-1610(R) | 36-430(L); 122-1310 (R) | 31-451(R) | 46-1473(R) |

**Table 17. Significant Volume Changes at the Route 7- Gosnell Road Intersection: Route 7 and Westpark Drive Approaches**

| Observation Characteristics | Apr/May 2014-15 [a] | Apr 2014-16 |
|---|---|---|
| **Approach** | **Route 7 EB** | |
| Movement | R | R |
| Lane | Only one | Only one |
| Time of statistically significant difference | 6:00-16:45, 17:00-18:15, 18:30-20:00 | 6:00-15:45, 17:00-18:00, 18:45-20:00 |
| Base year count (veh in 15 min) | 100-172, 117-140, 106-128 | 103-171, 120-140, 102-124 |
| Direction of change | decrease, increase, decrease | decrease, increase, decrease |
| Magnitude of change (veh) | 7-96, 28-44, 11-33 | 13-99, 25-36, 14-32 |
| Relative change (%) | 6-63, 20-35, 10-31 | 10-63, 18-29, 12-31 |
| **Approach** | **Route 7 WB** | |
| Movement | L | L |
| Lane | L; R | L[b]; R |
| Time of statistically significant difference | 6:00-20:00 (L); 6:00-9:30, 16:15-18:45(R) | 6:45-8:30, 16:00-18:15(R) |
| Base year count (veh in 15 min) | 98-171(L); 121-165, 99-122(R) | 153-164, 99-122(R) |
| Direction of change | decrease | decrease(R) |
| Magnitude of change (veh) | 17-125(L); 73-147, 52-85(R) | 125-147, 40-91(R) |
| Relative change (%) | 16-75(L); 56-93, 49-70(R) | 82-93, 40-74(R) |
| **Approach** | **Westpark Dr SB** | |
| Movement | T | T |
| Lane | L/T;T | L/T;T |
| Time of statistically significant difference | 6:00-10:45, 14:45-19:45(L/T); 6:00-10:45, 14:45-19:45(T) | 6:00-10:00, 14:00-19:30(L/T); 6:00-10:00, 14:00-19:30(T) |
| Base year count (veh in 15 min) | 18-66, 18-30(L/T); 20-90, 25-34(T) | 18-65, 17-33(L/T); 20-92, 25-33(T) |
| Direction of change | decrease, increase (L/T); decrease, increase(T) | decrease, increase (L/T); decrease, increase(T) |
| Magnitude of change (veh) | 6-49, 6-51 (L/T); 6-69, 2-34(T) | 12-47, 4-60 (L/T); 17-69, 4-40(T) |
| Relative change (%) | 19-78, 22-204(L/T); 19-85, 6-126(T) | 31-78, 14-253(L/T); 42-85, 11-144(T) |

[a] Missing/invalid data for Sept/Oct 2013.
[b] Missing/invalid data.

On the east side of the interchange of Route 7 and SR-123, turns from International Drive onto SR-123 toward this interchange either decreased (see Table 19) or were insignificantly different, further supporting avoidance of the interchange. However, this change could also be consistent with changing modes and routes for accessing Tysons Corner. Mode and/or route changes were supported by the other movements' volume changes at this intersection. As shown in Table 19, from the SR-123 Northbound approach, left lane left turns into the Tysons Corner office area decreased (up to 70% for a single lane) throughout the day, as did through movement counts from International Drive both Eastbound and Westbound (up to approximately 40%). (International Drive Westbound appears Northbound on a map). This suggested that there may have been some mode or route shifts, potentially for accessing the shopping malls (Tysons I and Tysons II) as well as commuting, based on the timing of the changes shown in Table 19.

Limited travel pattern shifts were also suggested by travel time changes on the I-495 segment between I-66 and Route 7. In the clockwise direction, some AM peak travel times decreased or showed no significant change. Later portions of the AM peak had increases. Decreases were observed throughout the day after the AM peak. Similar to the opposing direction, the counterclockwise segment between Route 7 and I-66 had moderate improvements in travel time over much of the day. However, the second year had some increases during the PM peak. The I-495 effects appeared constrained to this segment as the segment between Route 7 and SR-123 had travel time increases. In the clockwise direction, the SR-123 exit is further east than much of Tysons Corner. Travel times increased during the AM peak in the first and second fall and first spring, but not in the second spring. Similarly, the counterclockwise segment between SR-123 and Route 7 had increased travel times throughout much of the day in the fall and in the PM peak in the spring (tables are available from the authors upon request).

**Table 18. Significant Volume Changes at the Intersection of Gosnell Rd and Route 7: Gosnell Rd Approach**

| Observation Characteristics | Apr/May 2014-15 [a] | Apr 2014-16 |
|---|---|---|
| **Approach** | **Gosnell Rd NB** | |
| Movement | L | L |
| Lane | Only one | Only one |
| Time of statistically significant difference | 10:00-12:00, 16:00-18:30 | 16:45-19:00 |
| Base year count (veh in 15 min) | 55-67; 55-85 | 53-83 |
| Direction of change | decrease | decrease |
| Magnitude of change (veh) | 7-21; 7-45 | 6-36 |
| Relative change (%) | 12-31; 12-40 | 9-43 |
| Movement | T | T |
| Lane | L/T; T[b] | L/T; T[b] |
| Time of statistically significant difference | 6:00-10:15, 11:00-20:00(L/T) | None(L/T) |
| Base year count (veh in 15 min) | 11-45, 47-111(L/T) | |
| Direction of change | increase, decrease(L/T) | |
| Magnitude of change (veh) | 3-35, 3-57(L/T) | |
| Relative change (%) | 7-100, 4-51(L/T) | |
| Movement | R | R |
| Lane | Only one | Only one |
| Time of statistically significant difference | 7:30-9:45, 10:15-20:00 | 6:30-9:30, 10:30-20:00 |
| Base year count (veh in 15 min) | 41-63, 17-32 | 33-63, 17-32 |
| Direction of change | decrease, increase | decrease, increase |
| Magnitude of change (veh) | 11-43, 8-84 | 17-47, 22-129 |
| Relative change (%) | 27-79, 27-332 | 38-79, 52-489 |

[a] Missing/invalid data for Sept/Oct 2013.
[b] Missing/invalid data.

**Table 19. Significant Volume Changes at the SR-123-International Drive Intersection**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| **Approach** | **SR 123 NB** | | | |
| Movement | L | L | L | L |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:00-20:00 (L); 6:00-12:30(R) | 6:00-20:00 (L); 6:15-7:15, 8:00-10:00, 11:15-12:30(R) | None(L; R) | 7:30-8:45, 12:00-17:30 (L); 6:45-9:00, 11:00-16:30(R) |
| Base year count (veh in 15 min) | 8-68(L); 6-42(R) | 8-68(L); 8-18, 17-42, 15-27(R) | | 27-41, 14-29(L); 47-64, 22-37(R) |
| Direction of change | decrease(L); increase(R) | decrease(L); increase(R) | | decrease(L); decrease(R) |
| Magnitude of change (veh) | 2-37[b](L); 2-19(R) | 4-40[b](L); 3-8, 4-10, 2-10(R) | | 6-8, 3-10(L); 3-14, 4-9(R) |
| Relative change (%) | 12-70(L); 9-100(R) | 21-66(L); 17-100, 19-36, 9-67(R) | | 19-24, 18-54(L); 5-41, 14-30(R) |
| **Approach** | **International Dr. EB** | | | |
| Movement | T | T[a] | T | T[a] |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:00-18:45 (L); 7:00-18:45(R) | | 6:00-14:00 (L); 6:00-14:00 (R) | |
| Base year count (veh in 15 min) | 19-102(L); 29-127(R) | | 9-82(L); 10-82(R) | |
| Direction of change | decrease(L); decrease(R) | | decrease(L); decrease(R) | |
| Magnitude of change (veh) | 3-20(L); 2-38(R) | | 2-18(L); 2-16(R) | |
| Relative change (%) | 9-42(L); 7-40(R) | | 7-36(L); 11-39(R) | |
| Movement | R | R | R | R |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 10:45-12:15, 16:15-18:45 | | 16:45-19:15 | |
| Base year count (veh in 15 min) | 32-75, 73-110 | | 53-111 | |
| Direction of change | decrease | | decrease | |
| Magnitude of change (veh) | 5-21, 10-36 | | 7-18 | |
| Relative change (%) | 14-28, 12-31 | | 7-26 | |
| **Approach** | **International Dr. WB** | | | |
| Movement | T | T | T | T |
| Lane | L; R | L; R | L; R | L; R |
| Time of statistically significant difference | 6:15-18:30 (L); 6:00-20:00(R) | 6:00-20:00 (L); 6:00-20:00(R) | 11:15-15:00, 15:45-19:00(L); 15:45-19:30(R) | 10:30-19:30 (L); 15:15-19:30(R) |
| Base year count (veh in 15 min) | 21-84(L); 23-84(R) | 21-84(L); 23-84(R) | 41-68, 42-63(L); 47-66(R) | 37-69(L); 50-68(R) |
| Direction of change | decrease(L); decrease(R) | decrease(L); decrease(R) | decrease(L); decrease(R) | decrease(L); decrease(R) |
| Magnitude of change (veh) | 5-26(L); 6-29(R) | 4-33(L); 5-28(R) | 4-11, 5-17(L); 3-17(R) | 6-20(L); 7-16(R) |
| Relative change (%) | 8-40(L); 8-35(R) | 12-49(L); 12-37(R) | 10-17, 10-29(L); 6-25(R) | 12-37(L); 10-29(R) |

[a] Missing/invalid data.
[b] Larger magnitudes of change were observed during the AM peak.

## Orange Line and HOV Effects

Some of the Silver Line ridership came from the Orange Line. Decreased use of the Orange Line west of the Rosslyn station was particularly evident at the West Falls Church Metro station (see Table 9 and Figures 4 and 5).

Corresponding to the decreased parking usage at the West Falls Church station, the vehicle counts toward this station decreased in the AM peak and vehicle counts away from this station decreased in the PM peak, particularly at the intersection of Route 7 and Haycock Road. As shown in Table 20, the left turns from Route 7 Eastbound onto Haycock Road decreased during the AM peak by up to 57%. During the PM peak, both the left and right turns from Haycock Road onto Route 7 decreased by up to 37%. Most of the change in the parking facility usage likely came from the Route 7 and Haycock Road direction or special access from the I-66 ramp rather than from the east. The results of the vehicle count comparisons at the intersection of Haycock Road and Great Falls Street showed either insignificant changes or mixed effects.

Parking usage also decreased at the Vienna Metro station (see Table 9) after the first fall and increased at the Wiehle-Reston East Metro station. The Orange Line parallels I-66 west of the Ballston station. The I-66 eastbound segment between US-50 and Nutley Street (leading to the Vienna Metro station) had no significant change in the AM peak travel time in the first year, which, given growth and development in the region, could indicate a benefit from the Silver Line and switching between the two lines. Similarly, the westbound direction did not have a significant change during the PM peak in the first year. This segment was anticipated to most benefit from the Silver Line. Indeed, on downstream links, the travel times and their variability between Nutley Street and I-495 increased over much of the day (tables and figures are available from the authors upon request).

The Silver Line may have drawn some of its ridership from carpools. Inside the Beltway (I-495), I-66 is restricted to HOVs in the peak period in the peak direction. The I-66 Eastbound segment between I-495 and Route 7 had lower travel times throughout the day after the Silver Line opened (tables and figures are available from the authors upon request). Variability on this segment also generally decreased after the Silver Line opened. Considering this segment with its upstream neighbor, it is possible that the increase in travel times on the upstream segment was due to congestion on I-495 and/or a shift from carpools to single drivers during a portion of the AM peak. The shift away from HOV use was further supported by a travel time increase along the downstream segments between Route 7 and Westmoreland Street and between Westmoreland Street and US-29. From 8:45 AM to 10:00 AM, across the study months, there was a travel time increase, which suggested some drivers entered the road near the end of or after the HOV restrictions were lifted at 9:00. This potential shift from HOVs was less clear in the westbound direction east of Route 7, but other activities may take place during the evening (e.g., shopping, recreation), which can diversify routing and departure times. However, there was a clear decrease in travel times over much of the day between Route 7 and I-495, particularly between 15:30 (3:30 PM) and 19:00 (7:00 PM).

**Table 20. Significant Volume Changes at the Route 7- Haycock Road Intersection**

| Observation Characteristics | Sept/Oct 2013-14 | Sept/Oct 2013-15 | Apr/May 2014-15 | Apr 2014-16 |
|---|---|---|---|---|
| **Approach** | **Haycock Rd SB** | | | |
| Movement | L | L | L | L |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 6:45-7:30, 16:45-18:30 | 6:45-7:30, 14:00-15:00, 16:45-18:30 | 6:30-7:30, 14:15-15:00, 15:45-17:00 | 6:00-7:30, 15:45-17:45 |
| Base year count (veh in 15 min) | 24-46, 30-35 | 24-46, 18-38, 30-35 | 14-45, 23-40, 24-30 | 8-44, 25-31 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 5-25, 3-9 | 5-26, 3-9, 5-12 | 3-26, 5-10, 4-5 | 3-25, 4-9 |
| Relative change (%) | 13-55, 10-25 | 21-57, 17-38, 15-35 | 21-58, 22-37, 13-18 | 30-56, 16-31 |
| Movement | R | R | R | R |
| Lane | Only one | Only one | Only one | Only one |
| Time of statistically significant difference | 16:00-19:00 | 14:30-19:00 | 6:00-7:45, 16:15-19:30 | 15:15-16:30, 17:00-19:30 |
| Base year count (veh in 15 min) | 46-71 | 38-71 | 19-58, 40-64 | 38-49, 40-65 |
| Direction of change | decrease | decrease | decrease | decrease |
| Magnitude of change (veh) | 6-22 | 5-23 | 4-11, 5-16 | 3-10, 5-15 |
| Relative change (%) | 12-34 | 12-36 | 10-32, 12-27 | 8-21, 9-25 |
| **Approach** | **Route 7 EB** | | | |
| Movement[a] | L | L | L | L |
| Lane | L;R | L;R | L;R | L;R |
| Time of statistically significant difference | 6:00-9:15, 12:15-15:15(L); 7:00-8:45(R) | 6:15-9:00, 12:15-15:30, 16:45-18:00(L); 9:00-10:15, 16:45-18:15(R) | 6:00-9:00, 12:00-14:15(L); 6:00-7:15, 8:00-9:00(R) | 6:00-9:00, 16:00-17:15(L); 7:45-8:30, 16:30-18:00(R) |
| Base year count (veh in 15 min) | 14-35, 20-27(L); 19-24(R) | 17-35, 20-28, 34-41(L); 15-19, 32-41(R) | 16-34, 21-23(L); 10-21, 17-26(R) | 16-35, 28-40(L); 23-26, 32-45(R) |
| Direction of change | decrease(L); decrease(R) | decrease, decrease, increase(L); increase(R) | decrease(L); decrease(R) | decrease, increase(L); decrease, increase(R) |
| Magnitude of change (veh) | 2-11,3-7(L); 3-4(R) | 5-12, 3-9, 7-15(L); 7-10, 4-15(R) | 4-13, 2-5(L); 2-7, 2-5(R) | 4-13, 6-10(L); 5-7, 5-12(R) |
| Relative change (%) | 6-48, 15-27(L); 14-21(R) | 21-57, 14-26, 19-37 (L); 34-53, 9-35(R) | 17-42, 7-24(L); 17-33, 11-22(R) | 14-56, 16-29(L); 19-27, 14-38(R) |

[a] The detector data for eastbound through and right turn movement were unavailable.

## CONCLUSIONS

- The regression analysis showed that everything else being equal, the Silver Line attracted approximately 20,000 new one-way rider trips on a typical weekday (entrances and exits combined). This increase in ridership should have helped with general road congestion.

Consistent with the rest of the Metro rail network, ridership declined from 2015 to 2016. This trend is likely to continue in 2017 with the ongoing SafeTrack project and other external factors such as low gas prices. Therefore, more people are likely to drive and traffic is likely to increase on the surface network in the future.

- Ridership at the terminal station of Phase 1 of the Silver Line, Wiehle-Reston East, showed a strong pattern of commuting traffic, with a detectable morning and afternoon peak for entries and exits, respectively. Changes in the intersection counts in Reston were consistent with this pattern. Intersections to both the north and south of the station had increases in vehicle counts toward the Metro station during the AM peak and away from the station during the PM peak, defining the first trend in vehicle traffic for the Reston area. Flow toward the Wiehle-Reston east station in the AM peak also corresponded to the second trend in the Reston area, which was a shift from the Orange Line to the Silver Line.

- Further evidence was present for the shift from the Orange Line to the Silver Line. Orange Line ridership and parking facility usage decreased after the Silver Line opened. Decreased intersection counts in the AM peak suggested fewer (possibly former) Orange Line users from Reston using the path east on Sunrise Valley Drive to Hunter Mill Road to Lawyers Road to Vienna, where the Vienna Metro Station is located. Some improvements in travel time along VA-267, particularly between Wiehle Avenue and Hunter Mill Road, may have also been due to shifting between the two lines, as well as some mode shifts from driving to rail. Lower usage of the Orange Line's West Falls Church station was consistent with the intersection counts at Haycock Road and Route 7.

- The number of entries and exits during the peaks for the other four stations in the Tysons Corner and McLean area were more balanced compared to the Wiehle-Reston East station. The ridership pattern at the Tysons Corner station exhibited more characteristics of shopping and recreational traffic. The availability of transfer modes, parking lots, and land use patterns helped explain these differences in ridership patterns.

- Some mode or route shifts in the Tysons Corner area were suggested at the intersection of SR-123 and International Drive. Left turns into the Tysons Corner office area from the SR-123 Northbound approach decreased throughout the day for the left lane. Through movement counts from both International Drive approaches also decreased. The I-495 segment between I-66 and Route 7 also showed improvement, perhaps due to some mode or route shifts in the Tysons Corner area.

- Another change in the Tysons Corner area was a possible avoidance of the Route 7 – SR-123 interchange. Through traffic from the minor approaches at the SR-123 and Gosnell Road/Old Courthouse Road intersection increased significantly.

- The Silver Line could have attracted residents in Arlington and Washington, D.C., to commute westward and work in the Tysons Corner area. When the same periods of 2014 were compared to 2015, the number of riders traveling westward and visiting the five Silver Line stations increased in 2015. An analysis of origin and destination stations for riders visiting the five new Silver Line stations showed a significant number of people going from Arlington to the Tysons Corner area with the Silver Line.

- An analysis of bus ridership data of major bus operators in the region, including the Metro Bus, Fairfax County Connector, and Loudoun County Bus services showed mixed results. Most transit operators only collected ridership data by routes instead of stops, which made it difficult to relate any ridership changes to the opening of the Silver Line. Moreover, no transfer data were available. The research team could only regroup bus routes based on whether they intersected with the Silver Line or not. An analysis of both Metro Bus and Fairfax County Connector data showed that ridership of bus routes that intersected with the Silver Line dropped after the Silver Line opened. This may be because some riders switched to the Metro system after it became available in their area. In contrast, related bus routes in the Loudoun County Commuter Bus system did not serve the area before the Silver Line opened and after it opened, they stopped at the terminal station, Wiehle-Reston East. The ridership for buses in the Loudoun County Commuter Bus system has been stable over time.

- Metro Bus and Fairfax County Connector lines that served the areas around the Silver Line stations were more likely to be competing with the Silver Line instead of complementing it. In contrast, the Loudoun County Commuter Bus system served more as a connection mode for passengers who wanted to transfer to the Silver Line. As they will serve the same area, these dynamics may change when Phase 2 of the Silver Line opens.

- The region appeared to experience a general growth in traffic, likely due to development. While some Silver Line ridership was drawn from other lines, up to approximately 10,000 new round trips were made using the system. If they had all been from single occupant vehicles (SOVs) rather than a mixture of SOVs, buses, and carpools, the traffic impact would have been a visible benefit in the absence of general growth and development. Some benefits of removing vehicles from the system were hidden by the traffic growth as well as traffic rebalancing. Given the growth, the general road system performance could have worsened in the absence of the Silver Line. It is highly likely that continued development will have similar effects when trying to assess the impact for Phase 2 of the Silver Line.

## RECOMMENDATIONS

1. *VDOT's Northern Region Operations should conduct detailed studies of the intersections and road segments identified in this study, particularly the intersection of SR-123 and Gosnell Road/Old Courthouse Road; SR-123 between International Drive and the Chain Bridge; and the intersection of Sunset Hills Road and Metro Center Drive.* The increase of through traffic between Gosnell Road and Old Courthouse Road was fairly large, and traffic mitigation strategies may be needed. The vehicle counts at the intersections on SR-123 between International Drive and the Chain Bridge increased during the AM peak, which may necessitate signal timing adjustments or other strategies in the future. Data were not available for the intersection of Sunset Hills Road and Metro Center Drive, but results from

the adjacent intersection suggested that Metro Center Drive was heavily used to access the park-and-ride at the Wiehle-Reston East Metro station.

2. *In preparation for Phase 2 of the Silver Line, VDOT's Northern Region Operations should collaborate with local transit providers to collect information on service changes, parking space provisions, and ridership to help predict impacts to the road system.* The analysis in this study showed that the connecting modes, including park-and-ride lots and bus routes, had an impact on the number of riders attracted by different Silver Line stations. This, in turn, affects the surface traffic on roads near those stations. Phase 2 stations with park-and-ride lots anticipated to serve commuters and adjacent arterials might benefit from signal timing adjustments. Bus transfer data would help in achieving a better understanding of overall mobility choices. Changes in bus routes will affect Metro access locations. To help predict overall Metrorail ridership and the impact on the corridor and local roads, VDOT and WMATA should track external factors such as socioeconomic factors, gas prices, and the quality of Metro services. More extensive data sets with longer histories would facilitate the use of time-series models.

## BENEFITS AND IMPLEMENTATION

### Benefits

It was beyond the scope of this study to conduct a full economic assessment of the impact of the Silver Line on the region, but this study did identify some benefits and discovered some important trends for future planning and mitigation of negative impacts. Based on the regression model, it appears that the Silver Line generated approximately 10,000 new round trips (more than 20,000 total entries and exits). Although some of these riders came from bus ridership and some may have come from carpools, other riders were from single occupancy vehicles. Removal of some vehicles from the road system allowed accommodation of traffic generated from general growth and regional development, which are expected to continue in the future.

Implementing the study recommendations will help VDOT plan for Phase 2 of the Silver Line. For example, the terminal station, particularly if it has a park-and-ride facility, will likely serve commuters. VDOT can prepare for this by developing peak period signal plans near the station. VDOT can also prepare for through traffic to avoid some of the traffic related to Metro stations.

### Implementation

1. *VDOT's Northern Region Operations will initiate follow-up studies to examine locations experiencing larger traffic growth.* The goal will be to determine if signal timings need to be adjusted or traffic management strategies need to be implemented.

2. *VDOT's Northern Region Operations will coordinate and collaborate with local transit agencies to prepare for Phase 2 of the Silver Line.* Recommendations 2 and 3 emphasize the

need for multimodal coordination. VDOT's Northern Region Operations will use their existing contacts at the transit agencies to obtain the data they need to plan for the traffic impacts of Phase 2.


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## REFERENCES


Asare, S., Fontaine, M., Murray-Tuite, P., and El-Metwally, M. Transportation Impacts of the 2013 Federal Government Shutdown in Northern Virginia. *Journal of Transportation Engineering*, Vol. 141, No. 7, 2015, pp. 04015004-1–04015004-12.

Ashe, A. Metro Admits It Has Hit a Low Point in Reliability. WTOP, 2015. http://wtop.com/sprawl-crawl/2015/10/metro-admits-hit-low-point-reliability/. Accessed December 21, 2016.

Chun, P., and Fontaine, M.D. *Evaluation of the Impact of the I-66 Active Traffic Management System.* VTRC 17-R5. Virginia Transportation Research Council, Charlottesville, 2016.

Day, C.M., T.M. Brennan, A.M. Hainen, S.M. Remias, and D.M. Bullock. *Roadway System Assessment Using Bluetooth-Based Automatic Vehicle Identification Travel Time Data.* Purdue University, West Lafayette, IN, 2012.

Devore, J.L. *Probability and Statistics for Engineering and the Sciences.* Duxbury, CA, 2000.

Fisher, R.A. *Statistical Methods for Research Workers.* Oliver and Boyd, London, 1934.

Freund, R.J., W.J. Wilson, and D.L. Mohr. Data and Statistics. In *Statistical Methods.* Academic Press, Boston, 2010, pp. 1-65.

Hu, J., M.D. Fontaine, and J. Ma. Quality of Private Sector Travel-Time Data on Arterials. *Journal of Transportation Engineering*, Vol. 142, No. 4, April 2016, pp. 04016010-1–04016010-11.

Lomax, T., and Margiotta, R. *Selecting Travel Reliability Measures*. Texas Transportation Institute, College Station, 2003. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2003-3.pdf. Accessed October 15, 2016.

Lyman, K. *Travel Time Reliability In Regional Transportation Planning*. Field Area Paper. Master of Urban and Regional Planning. Portland State University, Portland, OR, 2007.

Mann, H.B., and D.R. Whitney. On a Test of Whether One of Two Random Variables Is Stochastically Larger Than the Other. *The Annals of Mathematical Statistics*, Vol. 18, No. 1, 1947, pp. 50-60.

Nachar, N. The Mann-Whitney U: A Test For Assessing Whether Two Independent Samples Come From the Same Distribution. *Tutorials in Quantitative Methods for Psychology*, Vol. 4, No. 1, 2008, pp. 13-20.

National Capital Region Transportation Planning Board. *Financially Constrained Long Range Transportation Plan for the National Capital Region.* 2015. http://old.mwcog.org/clrp/resources/2015/2015CLRPSummaryBrochure.pdf. Accessed July 15, 2016.

Rakha, H., and Van Aerde, M. Statistical Analysis of Day-to-Day Variations in Real-Time Traffic Flow Data. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1510, 1995, pp. 26-34.

Siddiqui, F., and Powers, M. Metro Fourth-Quarter Ridership Plunges 11 Percent. *Washington Post*, 2016. https://www.washingtonpost.com/local/trafficandcommuting/metro-fourth-quarter-ridership-plunges-11-percent/2016/09/06/b94a2fa6-744c-11e6-b786-19d0cb1ed06c_story.html?utm_term=.879e0bd7c4e4. Accessed December 21, 2016.

Siegel, S. *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill, New York, 1956.

StataCorp LP. *STATA Time Series Reference Manual, Release 13.* College Station, TX, 2013. http://www.stata.com/manuals13/ts.pdf. Accessed July 1, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 3rd Quarter FY 2012*. 2012a. http://www.wmata.com/about_metro/docs/Q3%20FINANCIAL%20REPORT%20FINAL.pdf. Accessed October 15, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 1st Quarter FY 2012*. 2012b. http://www.wmata.com/about_metro/docs/1st%20QUARTER%20Financial%20Report%20FY12%20v2.pdf Accessed October 15, 2016

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 3rd Quarter FY 2014*. 2014a. http://www.wmata.com/about_metro/docs/Q3%20FA%20Report%202014-05-23%20Final.pdf. Accessed October 15, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 1st Quarter FY 2014.* 2014b. http://www.wmata.com/about_metro/docs/FY2014%20Q1%20Financial%20Report.pdf. Accessed October 15, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 3rd Quarter FY 2015*. 2015. http://www.wmata.com/about_metro/docs/FA%20Report%20Q3%20FY2015.pdf. Accessed October 15, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 3rd Quarter FY 2016.* 2016a. http://www.wmata.com/about_metro/docs/Q3%20Finance%20Committee%20Report_20160504.pdf. Accessed October 15, 2016.

Washington Metropolitan Area Transit Authority. *Quarterly Financial Report 1st Quarter FY 2016.* 2016b. http://www.wmata.com/about_metro/docs/Q1FY2016_FA_Report.pdf. Accessed October 15, 2016.