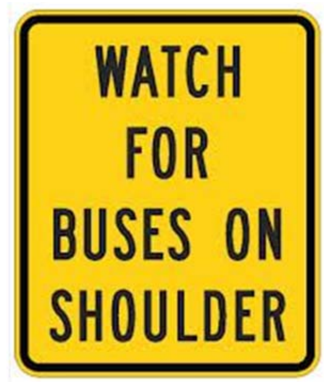
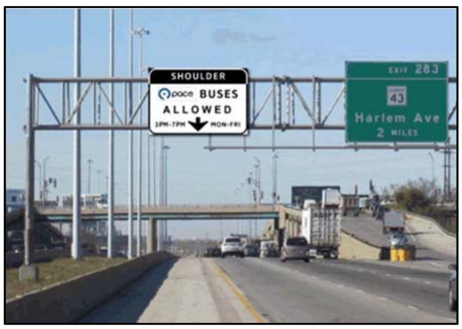
I-66 Inside the Beltway
Bus on Shoulder Pilot Study
Final Report





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Prepared by:
VDOT NoVA Transportation Planning Section
with assistance from COG/TPB Staff and
Foursquare Integrated Transportation Planning

Source for cover photos: TCRP (2012), VDOT, and http://www.dot.il.gov/busonshoulder/index.html accessed 10/4/2012

Table of Contents

Table of Figures

Table of Tables

Executive Summary

Bus on Shoulder (BOS) systems have been used in other states and localities as a congestion mitigation method. In Northern Virginia, there is one BOS application on the eastbound Dulles Airport Access Highway (VA 267) where buses are allowed to use the shoulders during the AM and PM peak period to bypass the recurring congestion. The recommendation for a pilot BOS program on Interstate 66 (I-66) inside the Capital Beltway (I-495, hereafter Beltway) resulted as part of stakeholder discussions for the recently completed I-66 Multimodal Study (Inside the Beltway). This study was conducted with the assistance of a multimodal working group comprised of staff from local and regional transit agencies staff, the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the Northern Virginia Transportation Commission (NVTC), and staff from VDOT Northern Virginia District (hereafter NoVA District) management as well as NoVA District staff from the planning, engineering, operations, and location and design sections. The working group's responsibilities were to determine the requirements for BOS application on I-66 inside the Beltway and potential locations where a pilot program can be implemented. Additional technical assistance was provided by staff from the Metropolitan Washington Council of Governments / National Capital Region Transportation Planning Board (COG/TPB) and their consultant, Foursquare Integrated Transportation Planning (FITP).

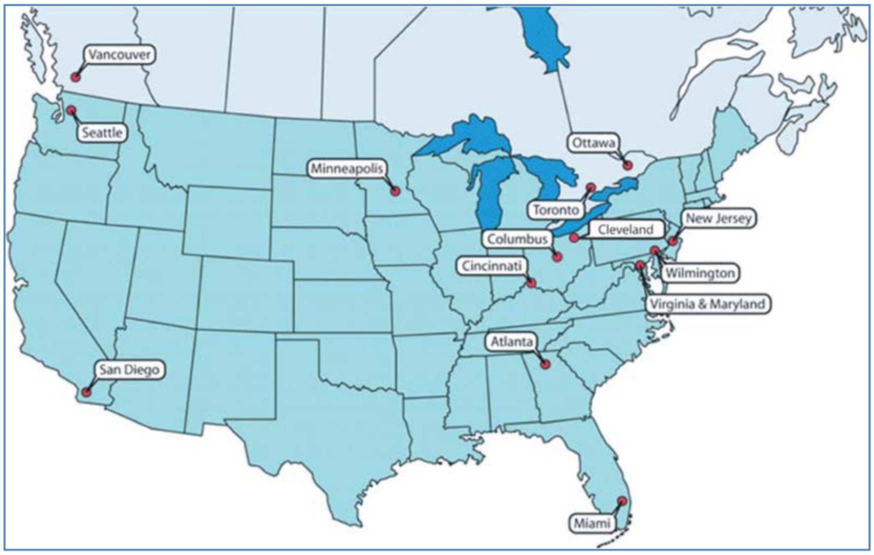
This report recommends implementing a one-year BOS pilot program on I-66 inside the Beltway. To support this recommendation, the report presents the following information:

- The findings of a literature review on BOS systems in North America
- Analysis of data to identify potential locations for BOS applications in a corridor
- Conditions for the use of shoulders for bus operation
- BOS operating protocols
- A plan for implementation
- A plan for monitoring and evaluation of the pilot to determine if continuing BOS on I-66 is warranted following the one-year program

A total of eight potential locations have been identified for BOS operations. Five locations are recommended to begin preliminary engineering, design, and implementation immediately for the pilot program, two are recommended for implementation in the near term and one location is recommended for implementation in the long term depending on the level of effort and associated cost. The near term and long term recommendations (planned for implementation two to five years after the conclusion of the pilot project) supplement the pilot program locations by extending their length and thereby further enhancing the overall BOS program on I-66.

A literature review was conducted to identify the best practices on BOS applications nationwide. The recently published *Transit Cooperative Research Program Report (TCRP) Report 151 - A Guide for Implementing Bus on Shoulder (BOS) Systems* (hereafter TCRP 151) provides considerable information on BOS operations in North America, including 11 in metropolitan regions in the United States and three in Canada, as shown in Figure ES-1.

Figure ES- 1: North American Cities with BOS Operations[1]

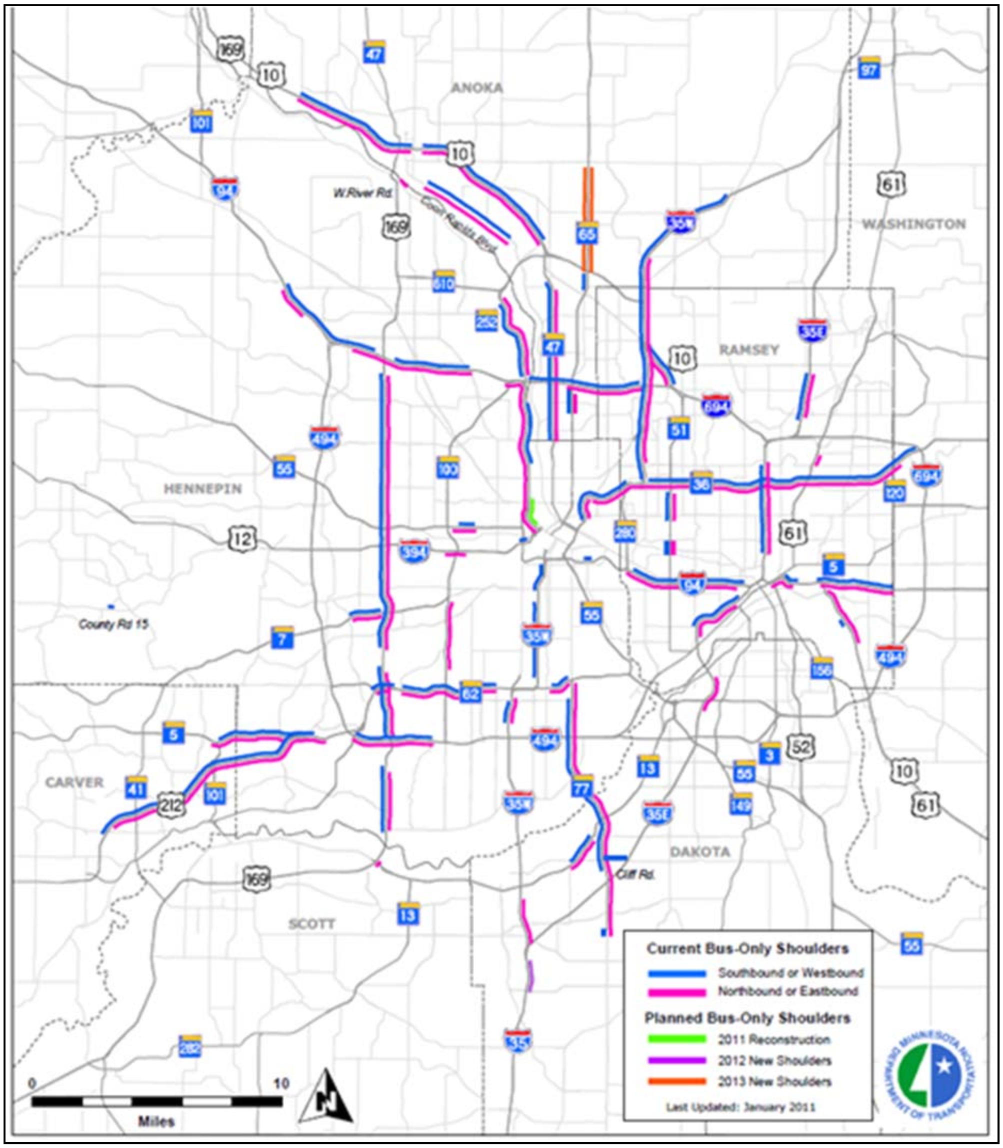


The dominant example of BOS is in the Twin Cities area of Minneapolis and St. Paul, Minnesota. Begun in 1991 in response to floods shutting down several key points on the road network, the quickly implemented measure proved successful, leading to further expansion. The Twin Cities now have a network of over 280 miles of highways with BOS, with four to eight miles added per year. As shown in Figure ES-2, the BOS Network in the Twin Cities is not a continuous network, but rather a series of distinct corridors or segments, focused on areas where there is recurring congestion that buses want to circumvent.

Besides the Twin Cities, most BOS operations are newer and typically consist of just one or two corridors. The best practices and issues highlighted in this report were used by the working group to identify conditions of use, operating protocols, a data analysis methodology to identify potential locations for a pilot program on I-66, and to develop the implementation plan. The conditions of use and operating protocols are briefly described below.

[1] Source: TCRP (2012)

Figure ES- 2: Overview of Minneapolis / St. Paul BOS Network[2]



Conditions for Use of Shoulders

Roadway shoulders provide a range of important functions such as:

- Emergency vehicle use
- Staging area for maintenance / construction
- Storage of disabled vehicles
- Snow storage and drainage

[2] Source: TCRP (2012).

Introducing BOS operations could affect these functions even if limited to occasional bus use and as such clearly defining the conditions for use of shoulders during the development of the pilot program. For the pilot program the following conditions of use are defined:

- Use of shoulders permitted only when mainline travel speeds fall below a predefined threshold and adversely impact transit service
- Authorized buses use the shoulders when it is safe to do so under the following conditions:
    - Shoulder not being used for enforcement / emergency response
    - Shoulder not being used by broken down / stalled vehicle
    - Shoulder space not required for snow removal and maintenance operations.

Operations Protocol

One of the primary issues in TCRP 151 is ensuring that the bus operators / drivers and motorists clearly understand the rules for BOS use. For the pilot program the working group identified the following operations protocol:

- Buses can use the shoulder when the mainline traffic is operating at speed below 35 miles per hour (mph)
- Buses operating on the shoulder may not exceed the speed of traffic on the general purposes lanes by more than 15 mph, with a maximum speed of 25 mph
    - The slower bus operating speed increases the ability to maneuver safely which driving on narrower shoulders and avoids the perception of being a hazard to both transit passengers and motorists in adjacent lanes
- Buses operating in the shoulder must merge back into general traffic when the shoulder is blocked by an incident or debris, or must yield the shoulder to first responders

A specific protocol for the minimum volume of buses required for BOS operation was not developed as part of this study. The case studies included in TCRP 151 show greatly varying levels of bus volumes among those locations with successful BOS operations. The BOS deployment guidelines for the Minneapolis / St. Paul area in Minnesota, which has the largest BOS network in North America, include a minimum of six buses per day. In addition, TCRP 151 concludes that usually at least four buses per hour are part of the basic requirements for successful BOS operation. Bus volumes along I-66 inside the Beltway far exceed this threshold for most of the daily bus operating hours; peak period bus volumes range from 13 to 33 buses per hour.

Design and Approvals

Although BOS is not new to Northern Virginia due to the existing BOS operation on VA 267 noted earlier in the report, design approvals will be needed for the I-66 BOS implementation. The presence of BOS on VA 267 indicates that a BOS pilot project on I-66 inside the Beltway can be implemented; however, if the enabling legislation for the VA 267 BOS is specific to that roadway it will need to be amended to include I-66 inside the Beltway. In some other states the head of the State Department of Transportation has the authority to allow BOS applications as a one or two year pilot program. Some other state transportation agencies have amended their motor vehicle codes to allow BOS operations. The design and approvals as well as other aspects of implementation of the VA 267 BOS operation may serve as a model for this pilot project.

Designs and design exceptions /waivers for BOS pilot locations will need to be reviewed and approved by both the VDOT Chief Traffic Engineer and FHWA since I-66 is part of the Interstate Highway System. This study included a field review of the corridor that identified several design elements that must be addressed as part of BOS implementation, including the following:

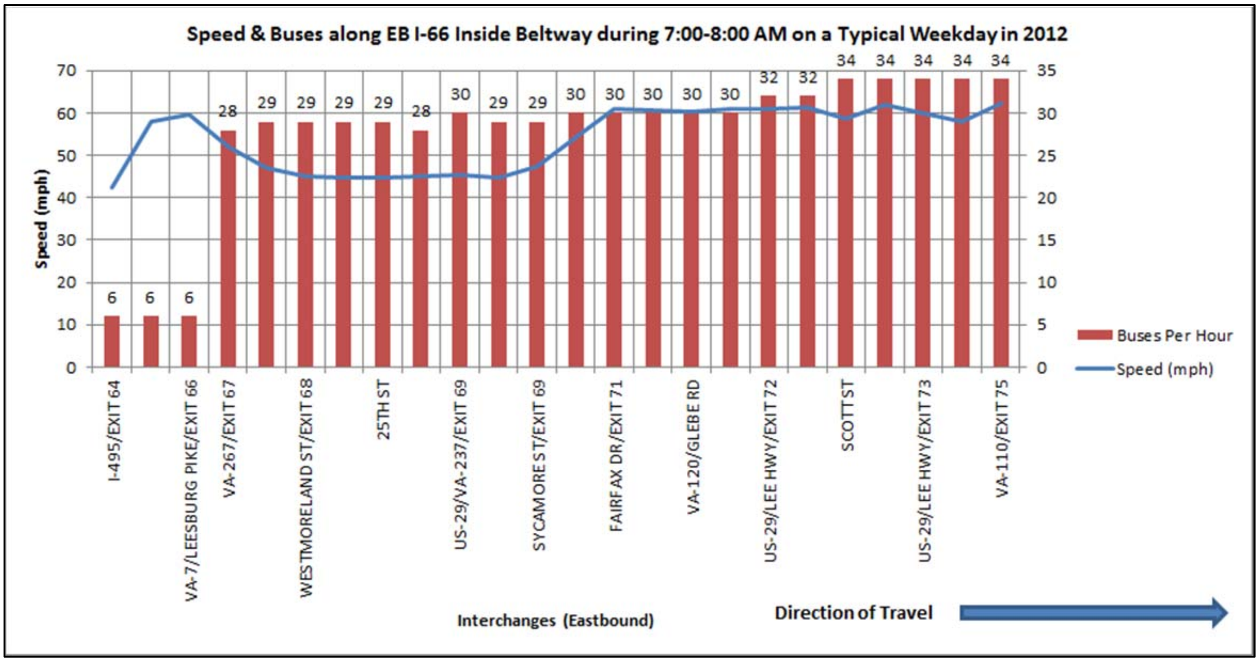
- Adequate shoulder width
- Adequate shoulder strength
- Placement of signage to identify BOS locations
- Placement of signage at merge and diverge locations to indicate the potential presence of buses operating on the shoulder
- Lateral obstructions exist in some locations and these may require additional protection or design exceptions
- Modifications to drainage inlets may be needed to accommodate BOS operation, which may compromise the inlets' effectiveness at removing water from the roadway and may require design exceptions
- In certain locations the general travel lanes may need to narrowed through restriping in order to achieve the 11 foot minimum shoulder required for BOS, and this action may require design exceptions
- Environmental evaluation and related approvals may be necessary

Shoulder width and shoulder pavement strength have been specifically addressed in this study through the development of specific parameters and materials testing. With regard to shoulder width, for the pilot the working group recommended 11 foot wide shoulders in locations without lateral obstructions and 11.5 feet where there are lateral obstructions. While other agencies have used 10 foot shoulders for BOS operation in straight sections without lateral obstruction, the 11 foot minimum is recommended along I-66 inside the Beltway to accommodate the wider buses used by the area transit agencies. With regard to shoulder strength, geotechnical analysis of shoulder conditions indicates that with sufficient shoulder width, a one-year pilot program is acceptable as long as daily bus volumes do not exceed 150 buses per day.

Data Collection and Analysis

Using the above conditions of use, operations protocols, and design parameters defined by the working group, data were collected on travel speeds, bus densities, and right-of-way (ROW). These data were analyzed to identify the potential locations with recurring congestion (indicated by low average travel speeds) and high bus density where BOS application will provide an advantage to transit. Figure ES-3 below shows a sample of bus density and travel speed data in the corridor. This information was used to determine which segments of the study corridor meet the bus density and speed thresholds for BOS operation.

Figure ES- 3: Sample Bus Density / Travel Speed Chart



The engineering survey which was done for the previously completed I-66 Spot Improvement 1 study was overlaid on recent aerial imagery for the corridor to identify potential locations for the pilot program which provided the adequate shoulder width as defined in the design parameters and could be implemented relatively easily. Additional near team and long term improvements which would require moderate to high level of design and construction effort were also identified. Figure ES-4 below provides a sample of overlaid engineering survey on the aerial imagery for the corridor.

Figure ES- 4: Sample of Right-of-Way, Shoulder Width Data, and Aerial Imagery for the Study Corridor

Pilot Program Locations

Using the methodology described, eight locations were identified for BOS application in the corridor and a preliminary planning level feasibility analysis was conducted. Five of the eight locations are recommended for the one-year pilot program as they require minimal design and construction effort. Two locations are identified for the near term and one location is identified for the long term as they will require a moderate or high level of design and construction. These locations were presented to the working group and based on the recommendations received five are being carried forward to preliminary engineering and design on the way to implementation and evaluation of the pilot program. Images showing field conditions along some of the pilot locations are shown in Figure ES- 6 through Figure ES- 9.

Cost Estimate for Pilot Locations

Since the project is anticipated to be implemented first at the pilot locations, preliminary planning level cost estimates for these locations were prepared. These estimates are summarized below in Table ES-1. Additional details on the cost estimate are provided in Appendix F.

Table ES- 1: Cost Estimates for Pilot Locations

Name	Preliminary Engineering	Construction	Total
Pilot 1	$80,000	$370,000 - $470,000	$450,000 - $550,000
Pilot 2	$50,000	$200,000 - $300,000	$250,000 - $350,000
Pilot 3	$40,000	$160,000 - $260,000	$200,000 - $300,000
Pilot 4	$40,000	$160,000 - $260,000	$200,000 - $300,000
Pilot 5	$90,000	$460,000 - $560,000	$550,000 - $650,000
Overall Cost for Pilot	$300,000	$1.35M - $1.85M	$1.65M - $2.15M

Recommended Near Term and Long Term Locations

The near term locations require a moderate level of engineering and construction effort compared to the pilot locations, and the long term location requires a high level of engineering and construction compared to the pilot locations. Out the eight potential locations two are considered as near term, and one as long term. The near term locations are adjacent extensions of the pilot locations. It is anticipated that the near term and long term BOS locations would be implemented within two to five years after successful completion of the pilot program; they are described in more detail in Table ES-3. The aerial and survey information for these locations in provided in Appendix F. As the detailed time frame for the implementation of these locations is uncertain, cost estimates for these locations are excluded.

Traffic Operations Solutions and Infrastructure Upgrades for BOS Locations

This planning study has identified places in the BOS pilot locations where traffic operations solutions and infrastructure upgrades will be needed prior to BOS implementation. The analysis done for this study does indicate that updated signage and markings will be needed at locations where BOS operation crosses a merge or diverge point along I-66 (interchange on-ramps and off-ramps). For example, a "watch for buses" sign may need to be added, as well as markings where a bus operating on the shoulder could cross the ramp and gore area. In addition, there are drainage grates and junction boxes in the pilot locations that will need to be strengthened or replaced to handle the additional weight of buses driving over them on a daily basis. Preliminary planning level cost estimates of these infrastructure changes are included in the overall costs for the pilot project. Detailed review of these issues will be undertaken as the project proceeds into preliminary engineering and design, and so it is not the place of this study to recommend specific solutions. All upgrades and signage and marking would need to be completed prior to commencing BOS operations.

Implementation Plan and Evaluation

Based on the literature review and analysis conducted for this study, the main elements of the implementation plan include the following:

- Conditions for use of shoulders
- Operations Protocol
- Funding
- Design and FHWA approvals
- Transit agency coordination, agreements and driver training
- State police and first responders coordination

The regulatory / statutory requirements to allow buses to use the shoulders, transit agency agreements, driver training, State Police coordination and evaluation plan will require special attention prior to the implementation of the pilot program. These tasks may be accomplished while the design and funding for the program is being finalized. Coordination with the Virginia State Police has already begun and they have communicated specific recommendations that VDOT will fold into the next phase of the project, as well as additional agencies that should be included in the implementation plan and outreach efforts.

Figure ES- 5: Potential BOS Pilot Locations

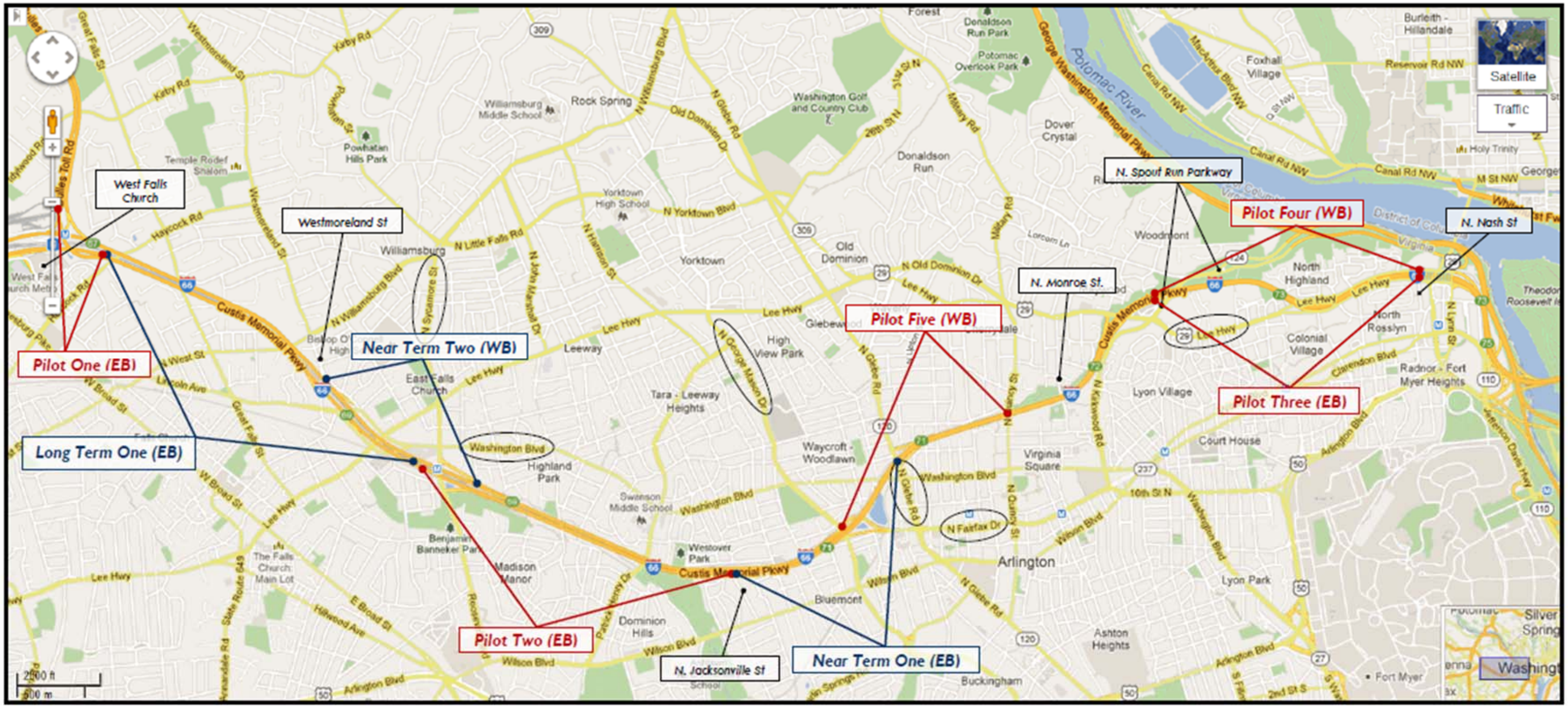


Table ES- 2: Recommended BOS Pilot Locations

Name	From	To	Length (miles)	Shoulder Width (ft)	Avg. Speed (mph) [3]	Max. Bus Density (buses / hr) [4]	Notes
Pilot 1 (EB VA 267 outside shoulder)	End of existing BOS operation of VA 267	Merge point with I-66	1.75	>=11.5	23	32	This location is an extension of the existing BOS application on VA 267 and proposes to use the shoulder on the fly over ramp (bridge) from VA 267 to I-66 eastbound.
Pilot 2 (EB I-66 outside shoulder)	100 ft west of N. Sycamore Street overpass	200 ft west of N. Jacksonville St.	1.4	>=11.5	27	32	A traffic operations solution would be needed for the merge at the on ramp from Sycamore Street. Additionally, there are drainage grates and junction boxes in this segment which will need to be upgraded to support the bus loads. The location can be readily extended to Glebe Road (see Near Term 1).
Pilot 3 (EB I-66 outside shoulder)	50 ft west of Lee Highway (US 29) overpass near North Spout Run Parkway	50 ft west of North Nash Street (Rosslyn Tunnel)	1.4	>=11.0	48	30	In this segment a traffic operations solution will be needed at the off ramp to US 29 near N. Veitch St. Majority of the shoulder width in this section is greater than 11 ft except for a short piece just east of N. Nash St. (10.6 ft) width where additional width can be gained by restriping.
Pilot 4 (WB I-66 outside shoulder)	N. Nash Street (exit from Rosslyn Tunnel)	US 29 overpass at Spout Run Pkwy	1.4	>=11.0	36	31	A traffic operations solution would be needed for merge point at on-ramp from US 29 near North Veitch Street. Shoulder width minimum of 11.5 feet for segment except for short piece at 11 feet near N. Scott Street overpass. I-66 Spot Improvement 3 will construct a westbound acceleration / deceleration lane and 12 foot full strength shoulder from US 29 to N. Glebe Road (VA 120), allowing further BOS operation.
Pilot 5 WB I-66 outside shoulder)	N. Quincy St	Fairfax Drive on-ramp merge point	1.1	Varies 10-11 ft	21	30	In this segment majority of the shoulder width is about 10 feet and additional width will be required which may be achieved by restriping or adding shoulder width as right of way is available in this section. This section along with the completed I-66 Spot Improvement 1, and the future BOS Near Term 2 and Spot Improvement 2 will result in a continuous facility for bus use from N. Quincy Street to VA 267 by utilizing the shoulder and the auxiliary lane combinations.

[3] Average speeds are based on analysis of data for I-66 inside the Beltway from the I-95 Corridor Coalition Vehicle Probe Project (typical referred to by the name of company that collects and administers the data, INRIX, Inc.) provided to COG/TPB. Average speeds are for a typical weekday in the year 2010; therefore, an average speed higher than 35 mph does not mean that BOS operations will not occur on that segment as traffic conditions vary widely from day to day. Even though average speeds are above 35 mph in some pilot locations on any given day due to variations in traffic volumes the operating speed could fall below 35 mph and trigger BOS operation. A description of the data and analysis methodology is provided in Appendix A.

[4] Bus densities are based on analysis of scheduled bus operations in the study corridor by all transit agencies combined with the INRIX data. A description of the analysis methodology is provided in Appendix A.

Table ES- 3: Recommended Near-Term and Long-Term BOS Locations

Name	From	To	Length (miles)	Shoulder Width (ft)	Avg. Speed (mph)[5]	Max. Bus Density (buses / hr)[6]	Notes
Near-Term 1 (EB I-66 outside shoulder)	N. Jacksonville St	N. Glebe Rd	1	<=10	27	32	This location begins at where Pilot 1 ends; when implemented it will provide a continuous 2.5 mile long shoulder for bus use in the eastbound direction. Visual inspection of this location reveals that adequate shoulder width is available due to the openness of the roadway section in this area and no lateral obstruction; however the survey data indicates additional width will be needed for BOS operation. The shoulder width may be gained by constructing additional shoulder in this portion or by restriping the main line lanes to narrower 11.5 feet width which will require design exceptions and Federal approval.
Near-Term 2 (WB I-66 outside shoulder)	Off-Ramp N. Sycamore St	Westmoreland St	~1	<=9.6	32	30	This location begins at the end of the recently completed Spot Improvement 1 and before the beginning of the future Spot Improvement 2. This location in conjunction with Pilot 5, Spot Improvement 1 and Spot Improvement 2 can result in a continuous facility for buses comprising of auxiliary lane and shoulder use. The additional shoulder width in this section will require construction of wider shoulders in the available right of way and may be accomplished with the Spot Improvement 2 construction. Restriping may not be an option as the left shoulder is narrow in this section.
Long-Term 1 (EB I-66 outside shoulder)	VA 267 on-ramp (Pilot 1)	Sycamore St	2.1	<=9	23	33	Most congested and physically constrained segment. The outside shoulder width is less than 9 feet, right of way is limited and the number of lanes in this section varies between two and four lanes depending on the location. Traffic operations solutions will be needed for at the VA 267 on-ramp, the Westmoreland Street off-ramp, and the Fairfax Dr. off-ramp (to the signal at US 29 – a location that experiences queuing into the regular travel lanes during peak periods).

[5] Average speeds are based on analysis of data for I-66 inside the Beltway from the I-95 Corridor Coalition Vehicle Probe Project (typical referred to by the name of company that collects and administers the data, INRIX, Inc.) provided to COG/TPB. Average speeds are for a typical weekday in the year 2010; therefore, an average speed higher than 35 mph does not mean that BOS operations will not occur on that segment as traffic conditions vary widely from day to day. A description of the data and analysis methodology is provided in Appendix A.

[6] Bus densities are based on analysis of scheduled bus operations in the study corridor by all transit agencies combined with the INRIX data. A description of the analysis methodology is provided in Appendix A.

Figure ES- 6: View of Shoulder and Roadway on EB I-66 along Pilot 2

Figure ES- 7: View of Shoulder and Roadway on WB I-66 along Pilot 4

Figure ES- 8: Example of Lateral Obstruction – WB I-66 at North Scott Street (Pilot 4)

Figure ES- 9: View of Shoulder and Roadway on WB I-66 between Pilot 5 and Near Term 2 (between Fairfax Dr. and Sycamore St. [Spot Improvement 1])

1. Introduction

Bus on Shoulder (BOS) systems have been used in other states and localities as a congestion mitigation method. In Northern Virginia, there is one BOS application on the eastbound Dulles Airport Access Highway (VA 267) where buses are allowed to use the shoulders during the AM and PM peak period to bypass the recurring congestion. The purpose of this planning study is to identify potential locations on I-66 inside the Capital Beltway (I-495) for a BOS application. More specifically, the study identifies the best practices related to BOS systems, potential locations for BOS operation, and evaluates operational elements (e.g., shoulder width, timings, signage, regulatory requirements and agreements, bus operator training, enforcement), as well as design and safety issues related to a pilot BOS implementation on I-66 inside the Beltway.

The study area includes the I-66 corridor between I-495 and the Potomac River in Fairfax and Arlington counties. This corridor has several transportation facilities and services. I-66 has two through lanes in each direction which are restricted to high occupancy vehicles (HOV-2, two or more persons per vehicle) only in the inbound (eastbound) direction during the AM peak period (6:30 AM to 9:00 AM) and in the outbound (westbound) direction during the PM peak period (4:00 PM to 6:30 PM). Trucks are prohibited from this section of I-66. Rail transit within the corridor is provided by the Metrorail Orange Line and future Silver Line (rail to Wiehle Ave is expected to open by January 2014). A number of transit operators provide express and local bus services in the corridor, including Metrobus (operated by the Washington Metropolitan Area Transit Authority [WMATA]), Fairfax Connector (a service of Fairfax County), Loudoun County Transit, and OmniRide (a service of the Potomac and Rappahannock Transportation Commission [PRTC]).

This recommendation for a pilot BOS program on this section of I-66 resulted as part of stakeholder discussions for the recently completed I-66 Multimodal Study inside the Beltway. The subsequent VDOT Northern Virginia (NoVA) District initiative calls for the development of a limited term pilot program to evaluate the impact of allowing transit buses to operate on the shoulders of I-66 inside the Capital Beltway when the mainline congestion impedes the bus' ability to maintain its schedule.

Project Goals and Objectives

The goals of the I-66 inside the Beltway BOS pilot study are as follows:

- Successfully implement a BOS pilot project on I-66 inside the Beltway
- Develop design and operational protocols for BOS that can be used in other areas of the Commonwealth
- Evaluate and document VDOT experiences with BOS design, operation, safety, maintenance, and cost

The objectives of the pilot study include:

- Reduce the impact of congestion on bus travel times
- Increase bus ridership in the I-66 corridor inside the Beltway
- Quantify and identify benefits, costs, and issues associated with implementing BOS

Study Scope and Coordination

The study scope of work was broken into seven (7) tasks which are briefly described below:

Task 1 – Baseline Data Analyses and Literature Review

This task included a review of the recently published TCRP Report 151: A Guide for Implementing Bus on Shoulder (BOS) Systems. The study team collected information on the recently implemented BOS operations in the I-55 corridor in the Chicagoland area, and the I-40 corridor in the Triangle area of North Carolina. The purpose of this review was to identify the best practices related to operational, design, safety and implementation elements of BOS.

1. Identification of operational elements (hours of operation, bus speed for operation on shoulders, and ITS / technology such as AVL, VMS, and ramp meter bypasses, to address operations, design and safety elements)
2. Identification of design elements (shoulder width requirements, drainage requirements, structural strength of shoulders)
3. Identification of safety elements (treatment of buses on shoulders at interchanges / ramps, signage, emergency operations and snow removal, merging of buses with mainline roadway)
4. Identification of stakeholders (transit agencies, emergency first responders, VDOT location and design engineers, traffic engineers, and transportation planners, Federal Highway Administration [FHWA], Federal Transit Administration [FTA], Metropolitan Planning Organization [MPO] and other regional planning agencies (e.g., NVTC / NVTA) , local jurisdictions, and others)
5. Identification of Implementation requirements (agreements with transit agencies, bus driver training, Virginia Code requirements for use of shoulders, Federal / State design exceptions, trial runs prior to pilot implementation)

This task also involved collection of data related to the evaluation of the key elements identified above. Where possible, data were obtained from the I-66 Multimodal Study inside the Beltway and prior efforts along the study corridor. Some of the data items proposed for collection are identified below:

- AM and PM peak and off-peak period vehicle volumes on I-66 and interchange ramps
- AM and PM peak and off-peak period bus volumes on I-66 and interchange ramps
- I-66 engineering survey
- I-66 aerial imagery
- AVL data if available from transit operators
- Transit operator experiences related to recurring congestion in corridor
- Speed and travel time data
- Other data as identified (e.g., information on ramp meters, ramp queuing, merge / diverge distances)

Task 2 – Pilot Program Objectives

In this task the objectives of the pilot program were defined. Objectives such as reduction in travel time for the existing routes, potential for starting new service and others identified in this task were used in subsequent tasks to guide the development of the pilot program.

Task 3 –Definition of Problem and/or Opportunities

This task involved definition of the problem in terms of location and magnitude of congestion and using the results of Tasks 1 and 2 to identify candidate locations for BOS operations in the I-66 corridor inside the Beltway. One suggested methodology to develop a list of candidate locations was to overlay the speed data, the number of buses, and available engineering survey data on an aerial photograph to identify the locations with recurring congestion and heavy bus volumes for evaluation in the next task.

Task 4 – Identify Range of Solutions

In this task a set of criteria were developed to evaluate the planning level feasibility of implementing BOS in the problem locations identified in Task 3. Some of the basic criteria that were considered for additional screening are shoulder width, type of shoulder, pavement thickness, length of roadway segment, duration of and severity of congestion, available right of way, sight distance, and number of buses. Using the criteria developed the locations identified in Task 3 were screened further using a multidisciplinary team to evaluate a range of solutions and their feasibility to implement BOS. The locations were grouped by the complexity involved in the implementation of BOS and cost (i.e., no improvements needed to shoulders, minor improvements needed and major improvements needed to the shoulder). Using the results of this task, a set of locations for BOS pilot implementation was identified.

Task 5 -- Develop Operations and Design Criteria for the Program

In this task, based on the results of tasks 3 and 4 above a set of operations and design criteria were developed to assist in the future application of this strategy. Operations criteria include determination of operating speeds, and when shoulders will be open for use. Design criteria include shoulder widths, signage, merge and diverge maneuvers, and markings.

Task 6 – Implementation Plan and Final Report

In this task a detailed plan for implementation of a pilot project was developed. The plan will address the agreements needed, any improvements needed to shoulders, bus driver training, outreach, signing plan, post-implementation evaluation of the benefits of the project (i.e., “before and after”), Federal and State approvals needed, and a cost estimate for the pilot BOS. The implementation plan will serve as a blueprint to request funding, identify any agreements needed, plan for effective outreach and communication regarding the pilot, perform evaluation, and identify signage needs.

Task 7 – Presentations

This task involves presentations to NVTA / NVTC and others about the findings of the study and pilot program. Study team staff briefed the NVTC Management Advisory Committee on April 16, 2013 and other presentations are anticipated as the planning study is completed.

Starting with study initiation, the project team has closely coordinated with regional and local transportation staff, in particular the agencies that operate transit service in the pilot program corridor. A project working group was established early on during the study. The list of agencies represented on the working group includes Loudoun County Transit, PRTC, Arlington County, Fairfax County, WMATA, NVTC, the Metropolitan Washington Council of Governments (MWCOG), the Federal Transit

Administration (FTA) and Federal Highway Administration (FHWA), as well as other VDOT NoVA sections outside of the Planning section.

While this study has been proceeding, a BOS task force convened by the National Capital Region Transportation Planning Board (TPB) has been conducting a high-level consideration of BOS as a regional transportation improvement. The TPB BOS task force was established based on a request at the July 18, 2012 meeting of the TPB, and its purpose is "to identify promising locations in the region to operate buses on the shoulders of highways."[7] In addition,

> …this task force will bring together the stakeholder agencies, including transit operators, departments of transportation, and local jurisdictions, to coordinate an assessment of the experience and potential for BOS operations on the region's freeways and major arterials. The task force will oversee a scoping of potential locations for BOS, including a high-level benefit-cost analysis of implementing BOS along select corridors and bus routes.[8]

The TPB task force is expected to complete its work soon after the completion of this study of I-66, and provide a full briefing to the TPB Technical Committee and the Board in early summer. In general, the regional task force is taking a broader, high-level look at the issues involved with BOS and will be not performing some of the more detailed analysis undertaken for the I-66 pilot study, as their scope and resources are limited. The pilot study team has provided updates on the study to the TPB BOS task force at its meetings in October 2012, January 2013, and April 2013, and coordination between the two groups will continue through the conclusion of both studies. Follow-up work at the regional level is anticipated and TPB staff will continue to receive updates on the progress of the I-66 BOS pilot implementation.

Organization of the Report

The remainder of the report is organized in a manner to best demonstrate the potential efficacy of BOS operation on I-66 inside the Beltway:

- **Section 2** summarizes the literature review and provides examples of successful BOS operations in North America and their operating and policy characteristics. The results from the literature are synthesized into findings applicable to a BOS pilot in Northern Virginia.
- **Section 3** describes the data collected and analyzed in the study corridor and summarizes the results of the analysis and what the data mean for the feasibility of BOS in the study corridor.
- **Section 4** provides the methodology used in the review of the study corridor and describes the recommended locations for BOS operation along I-66 inside the Beltway, both those for the pilot project, and for near-term and long-term sections following successful completion of the pilot.
- **Section 5** lays out the steps necessary for implementing the BOS pilot and operating buses on shoulders in the locations along I-66 inside the Beltway, including any regulatory approvals (if needed), operating agreements with the transit agencies, bus driver training, coordination with Virginia State Police and other first-responders, and ways of funding the pilot program.

[7] National Capital Region Transportation Planning Board (2013).
[8] *Ibid.*

- **Section 6** contains a methodology for evaluating the BOS pilot project, including data collection and analysis, and how to assess the performance of the implementation and determine the viability and time frame for the near-term and long-term BOS locations in the corridor.
- **Section 7** provides a brief summary of the study and describes the next steps toward implementation.

2. Literature Review[9]

BOS is an arrangement by which buses providing public transportation service operate on designated highway shoulders, when safe and practical to do so, in order to circumvent peak traffic congestion. As described in the recently published *Transit Cooperative Research Program (TCRP) Report 151: A Guide for Implementing Bus On Shoulder (BOS) Systems*: "Typically, the BOS projects limit buses using the shoulder to times when traffic on the highway is congested and moving very slowly, and they cap the speed buses are allowed to operate on the shoulder."[10]

Current regional BOS experience includes, in Northern Virginia, a short section (1.3 miles) of the Dulles Airport Access Highway (VA 267) in Fairfax County for bus access to the West Falls Church Metrorail Station, and, in Maryland, along the shoulders of Columbia Pike (US 29) near Burtonsville, Montgomery County. Previously, bus service operated between Bethesda and Tysons Corner along the Capital Beltway (I-495) over the American Legion Bridge was permitted to operate on the shoulders in the Maryland portion of the Beltway; however, this service was discontinued in 2003 due to low ridership.

In addition, as described in the TCRP report, several other cities across the United States and Canada also have BOS service; of these, Minneapolis / St. Paul has the most-developed network with over 280 miles of BOS corridors.

Local Experience with BOS

As introduced above, there are two current examples of BOS in the region, on VA 267 and on US 29 near Burtonsville in Montgomery County, MD. In addition, there was BOS operation along the Maryland portion of the Capital Beltway from 1999 to 2003.

Northern Virginia: VA 267

BOS operation for 1.3 miles along the eastbound outside shoulder of VA 267 inside the Beltway (from just east of the interchange with Chain Bridge Road [VA 123]) began operation in the year 2000.[11] The BOS operation leads directly to and ends at a bus-only access ramp to the West Falls Church Metrorail Station on the Orange Line, just before the overpass and ramp to merge with eastbound I-66. The implementation of this BOS corridor is described in detail as the second case study in *TCRP Synthesis 64: Bus Use of Shoulders*.[12] Key findings from the TCRP case study include:

- Primary reason for implementation was to bypass congestion backing up on VA 267 from the merge with I-66 eastbound.
- Joint implementation by Fairfax County, Virginia State Police, the Metropolitan Washington Airports Authority, and VDOT.
- Use of BOS is restricted to the PM peak period (3:00 - 8:00 PM) and the maximum permitted bus speed is 25 MPH.
- Operators call in if any breakdowns or obstacles are encountered on the shoulder, at which point transit dispatchers instruct all bus drivers not to make use of the shoulder.

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[9] Portions of this section excerpted from National Capital Region Transportation Planning Board (2013).
[10] Transit Cooperative Research Program [TCRP] (2012).
[11] See Virginia Department of Transportation ([VDOT] 2009).
[12] See Transit Cooperative Research Program (2006), pp. 26-28.

Following the TCRP Synthesis 64 case study, VDOT expanded the BOS operating hours in 2009 to also include a morning peak period of 6:00 AM to 10:00 AM.[13] The outside shoulder on which buses operate is 14 feet wide.

Maryland: US 29

This corridor provides for BOS operation along approximately 4 miles, between MD 198 at the north end and Randolph Road / Cherry Hill Road at the south. However, BOS operation is now very infrequent due to significant reconstruction of this highway. Grade-separated interchanges were completed in recent years (MD 198 in 2004, Randolph Road/Cherry Hill Road in 2005, and Briggs Chaney Road in 2007) that have largely eliminated the congestion experienced previously at the then-signalized intersections. In addition, a new interchange with the Inter-County Connector (MD 200) has sizable entry and exit ramps that impact shoulder availability in the vicinity of the interchange. Portions of the corridor remain posted for BOS, and buses will occasionally make use of the shoulders. However, the relative infrequency of BOS operation limits useful information from this corridor.

Maryland: I-495

In 1998, Metrobus Route 14 service between points along the I-270 corridor in Maryland and Tysons Corner in Virginia was introduced, operating along the Beltway and crossing the American Legion Bridge. Metrobus was given permission to operate along the shoulders on the Maryland portion of the Beltway to circumvent congestion, with appropriate signage installed. However, in practice the benefits were modest. VDOT did not allow shoulder operation on its portion of the Beltway for safety reasons. In addition, a major primary cause of congestion for traffic headed to Tysons Corner during this time frame was the poor I-495 (outer loop) access in Virginia to the Dulles Toll Road (VA 267), which the bus could not avoid (this ramp was subsequently widened from one lane to two lanes in August 2005 and the bottleneck was eliminated). Ridership on the Metrobus Route 14 did not meet expectations, and by May 2002 was averaging only six persons per trip. The service was discontinued on December 26, 2003.

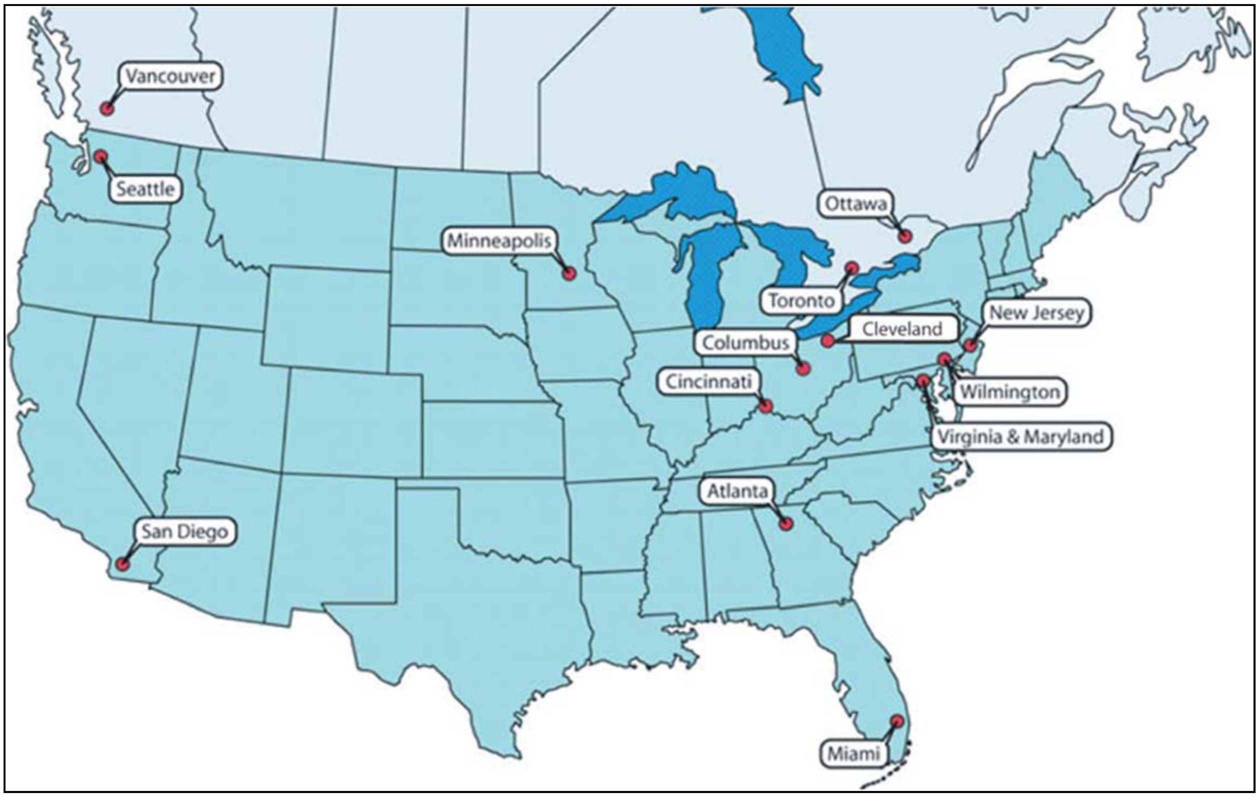
The one key finding from this BOS implementation was that without end-to-end coverage of the corridor/route, and in particular not at the most congested location, BOS did not offer improved travel time or reliability. In addition, there were reports that “jealous motorists”, whether in automobiles or trucks, occasionally attempted to block the buses.

Identification of Best Practices: National and Other Experience with BOS

There have been a number of studies of BOS operation by the Federal Highway Administration (FHWA) and by the TCRP. TCRP Report 151 provides considerable information on BOS operations in North America, including 11 case studies in metropolitan regions in the United States and three in Canada, as shown in Figure 1.

[13] See VDOT (2009).

Figure 1: North American Cities with BOS Experience[14]



The dominant example of BOS is in the Twin Cities area of Minneapolis and St. Paul, Minnesota. Begun in 1991 in response to floods shutting down several key points on the road network, the quickly implemented measure proved successful, leading to further expansion. The Twin Cities now have a network of over 280 miles of highways with BOS, with four to eight miles added per year. Some 1,700 bus trips a day (400 buses) make use of at least part of the BOS network. Key characteristics of the Twin Cities' network include:

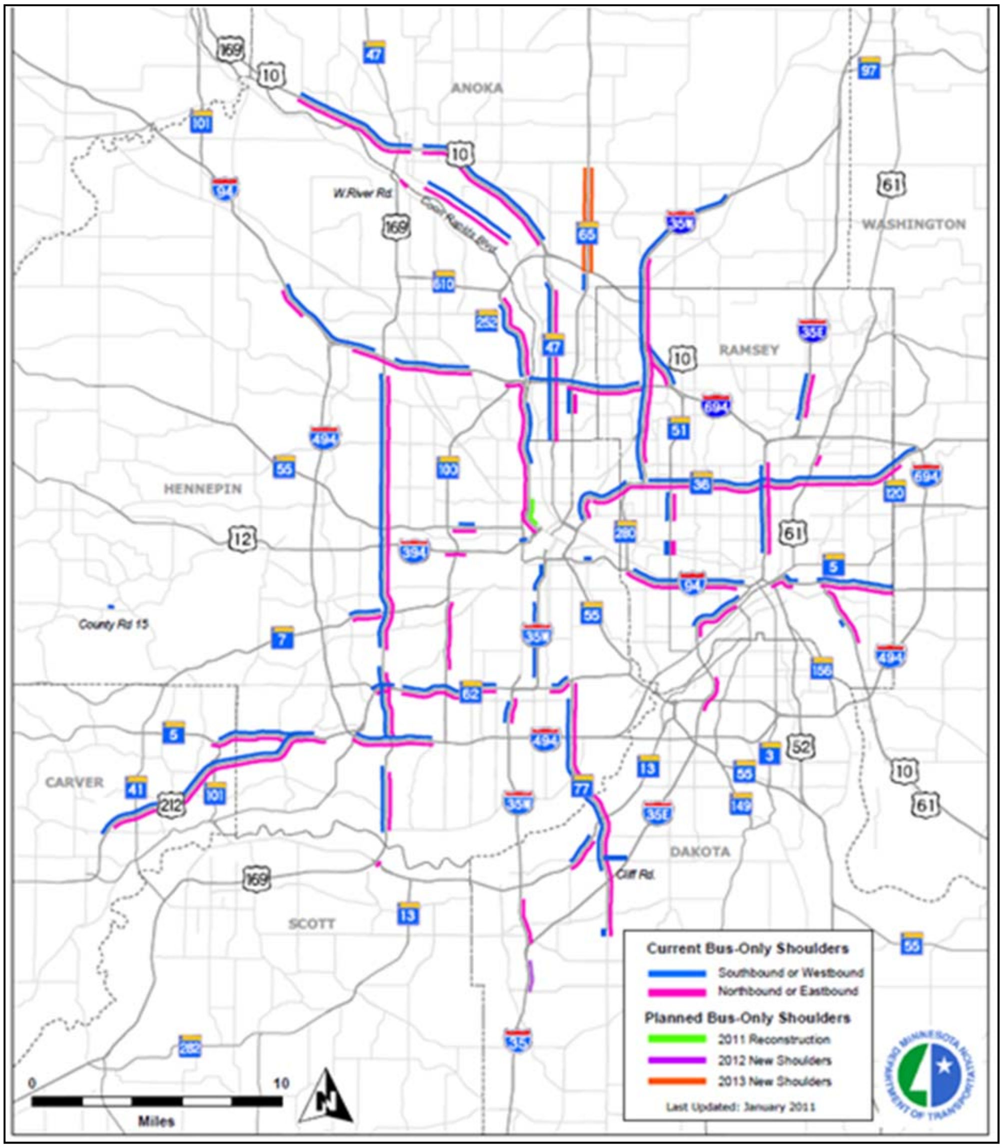
- Dedicated funding line item in the Minnesota DOT (MnDOT) budget, which funds the road upgrades necessary for BOS at a cost of $150,000 to $250,000 per mile
  - Originally $2 million a year, funding approximately 20 miles of improvements
  - Now $1 million per year for improvements (funding 4 to 8 miles) and $1 million a year for maintenance of the shoulders
- Rider perception of time savings is two times greater than actual time savings measured
- Safety reviews have found no statistically significant differences between BOS and routine operations

The policies for BOS implementation, operating requirements, and other elements of the Twin Cities' BOS program are described further in this section.

[14] Source TCRP (2012).

As shown in Figure 2, the BOS Network in the Twin Cities is not a continuous network, but rather a series of distinct corridors or segments, focused on areas where there is recurring congestion that buses want to circumvent.

Figure 2: Overview of Minneapolis / St. Paul BOS Network[15]

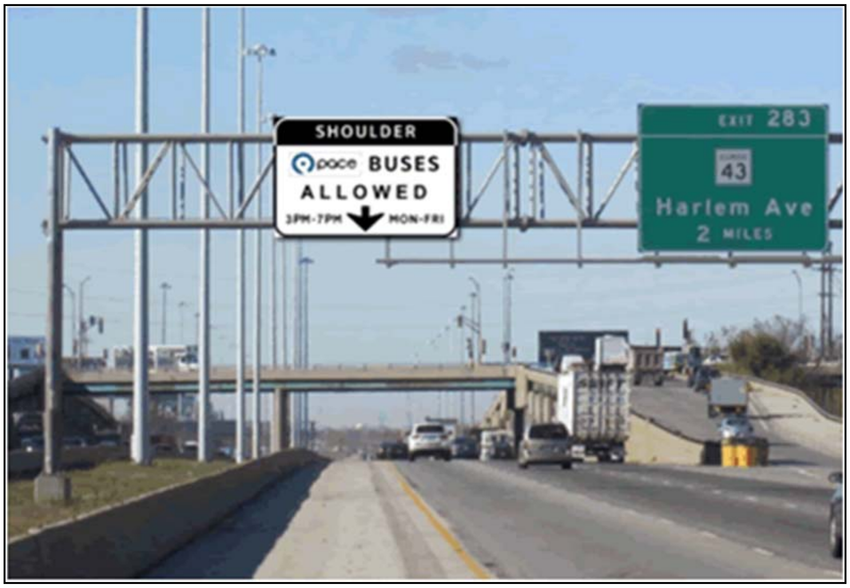


Besides the Twin Cities, most BOS operations are newer and typically consist of just one or two corridors. One recently implemented BOS operation is along the Stevenson Expressway (I-55) corridor in the Chicagoland area. I-55 connects southwestern Chicago and its suburbs with the Chicago Loop (downtown area). Two express routes operated by regional bus agency PACE Transit began a two-year demonstration project on November 14, 2011 that permit BOS operation on the inside (left) shoulder. To date, the Chicago experience has proven very successful, with PACE Transit now having to add bus trips on the two express routes that utilize BOS operation. From when the BOS pilot project began on

[15] Source: TCRP (2012).

November 14, 2011 to April 2012, travel times and on-time performance on the two routes using BOS improved from 68 percent of trips arriving on-time to 92 percent. Six months after implementation, the two routes carry a total of about 500 passengers per day, up almost 75% from before BOS was implemented.

Figure 3: I-55 BOS Implementation near Chicago[16]



Another recent BOS pilot implementation has taken place in the Triangle area (Raleigh / Durham / Chapel Hill) of North Carolina along I-40.[17] This pilot project covers four Triangle Transit bus routes operating along on a little over 10 miles of roadway (most both directions, a small section one direction only) on the outside shoulder. Operation is 24/7 and cost is approximately $2,000 per mile for signage.

The most recent BOS implementation in North America (as of time of writing) is the Jo Xpress express buses operating on I-35 in Johnson County, KS, in the Kansas City Metropolitan Area.[18] BOS operation began in January 2012. The project is a joint effort between Johnson County Transit and the Kansas Department of Transportation (KDOT), along with the Kansas Highway Patrol. BOS operation is permitted during peak periods and both signage and markings have been installed to allow buses to operate on the outside (right) shoulder. Buses are not permitted to use the shoulders at system to system interchanges with multiple ramps. Buses operating on the shoulders may not exceed the speed in the general traffic lanes by more than 10 mph and the maximum operating speed for BOS is 35 mph. The approximate cost of the shoulder improvements was $9,250 per mile.

Findings

There are numerous issues and topics that must be addressed in implementing a BOS project. The TCRP reports and the reports, presentations, and other documentation prepared by federal and state agencies review the lessons learned and challenges of BOS implementation in considerable detail. As a

[16] Source: http://www.dot.il.gov/busonshoulder/index.html accessed 10/4/2012
[17] See Triangle Transit Authority (2012).
[18] See Johnson County Transit (2012) and HNTB Corporation (2012)

supplement to these comprehensive studies, this section of the report notes some of the highlights from these studies and provides some comparisons among BOS projects.

Operational Speeds, Hours, Limits

Most BOS projects have specified speeds for traffic in the general purpose travel lanes that indicate when shoulders may be used and the operating speeds of buses using them. In addition, there may be restricted hours of operation and other limits set upon bus use of shoulders. The operational speeds standard developed in the Twin Cities are the following:

1. Buses must not use the shoulder when traffic is moving faster than 35 mph
2. Buses cannot exceed the speed of general traffic by more than 15 mph
3. Maximum bus speed on the shoulders is 35 mph.

Most other BOS projects in the United States have used these same rules, as shown in Table 1; however, the VA 267 BOS operation in Northern Virginia uses 25 mph for criteria (1) and (3) above.

Table 1: BOS Operational Speeds and Limits[19]

Area / Characteristic	**Twin Cities, Columbus, New Jersey, North Carolina**	**Atlanta, Miami**	**Cincinnati**	**San Diego**	**Ottawa**
General Traffic Speeds	35 mph or less	25 mph or less	30 mph or less	35 mph or less	None
Maximum Bus on Shoulder speed	Up to 15 mph faster than general traffic, not to exceed 35 mph	Up to 15 mph faster than general traffic, not to exceed 35 mph	Up to 15 mph faster than general traffic. (i.e., up to 45 mph).	Up to 10 mph faster than general traffic, not to exceed 35 mph	Up to posted highway speed of 100 kph (62 mph)

In establishing protocols, operational speeds and permitted speed differentials should be matched with the corresponding shoulder width and the frequency of intersections or merge points. Another limit occasionally discussed is the impact of foul weather and whether operational limits should be imposed on shoulder use. Due to increased congestion, shoulder use by buses during foul weather typically offers greater than usual travel time and reliability savings. However, the driving conditions are also more challenging in foul weather and bus drivers are therefore cautious in their use of shoulders, thus limiting the potential benefit in travel time and schedule adherence.

Bus Volumes

The case studies included in TCRP 151 show greatly varying levels of bus volumes among those locations with successful BOS operations. The BOS deployment guidelines for the Twin Cities include a minimum of six buses per day. Furthermore, the report notes that "…non-transit stakeholders often believe that a minimum volume of buses are required to warrant priority measures like BOS. As such, education of other stakeholders is sometimes required on the subject of priority measures for low-volume bus

[19] Source: TCRP (2012).

services (less than 20 buses an hour)."[20] Finally, the report concludes that usually at least four buses per hour are part of the basic requirements for successful BOS operation.[21]

Bus Travel Time Savings / Reliability

The primary goal of implementing BOS is to reduce travel time and improve travel reliability for buses and their passengers. Accordingly, policy criteria for implementing BOS are typically established. In the Twin Cities, for BOS to be considered a corridor must be used by at least six buses a day, and use of the shoulders must save a bus eight or more minutes per mile per week in travel time. In Miami, congestion measured at level of service (LOS) E or F in the peak hour was identified as one threshold for screening corridors for BOS implementation. Note that while criteria are typically established for recurring (i.e., regular) congestion, bus operating agencies also note the value of being able to use shoulders during non-recurring congestion, such as when lanes are by blocked by a breakdown or during congestion due to a special event. This is why bus agencies typically recommend allowing use of the shoulders unrestricted by time of day. Regions in which BOS has been implemented have collected data on the travel time savings and increased schedule reliability of bus operations when using the shoulders. Some of those results are shown below in

Table 2: Observed Travel Time and Reliability Data[22]

Area / Measure	**Twin Cities**	**San Diego**	**New Jersey**	**Miami**
Segment Length	(multiple corridors)	8 miles	4 miles	9 miles
Travel Time Savings	5-20 min. (10-60 min. worst case)	Up to 5 min.	3-4 minutes	n/a
Reliability Improvement	n/a	99% on time	n/a	50% reduction in late buses

Shoulder Width, Structural Strength, and Slope

The width of corridor shoulders is one of the primary factors affecting BOS, given that a public transit bus with mirrors typically requires at least ten feet of width. Generally, shoulder widths range from a minimum of 10 feet to the standard lane width of 12 feet. Some BOS is operated along lanes as narrow as 9.5 feet; however this narrow width appears to be feasible only for short segments and infrequent use. On the Twin Cities network, some 90% of the approximately 280 miles of designated shoulders are the minimum 10 feet wide, though the standard is 12 feet for all new construction. To provide sufficient shoulder width, MnDOT has reduced some adjoining general lane widths by up to six inches. Miami requires at least a twelve-foot shoulder when truck volumes exceeded 250 trucks per hour. In Cincinnati and Chicago where shoulders are in use along the median (i.e., left shoulder bus operation), a twelve foot minimum for these shoulders is required due to the restricted sight lines of the bus drivers towards the right, as well as to allow for the tendency of congested motorists to pull left towards the median in order to see further ahead. An exception in shoulder width is Ottawa, which has widened shoulders beyond general lane width to allow BOS operation at full speed of 100 kph (62 mph). Shoulder width is 5 meters (16.4 ft) on one corridor, Regional Road 174, and 7 meters (23 ft) on Regional Road 417 (peak bus densities on these corridors is 100 buses per hour and 60 buses per hour, respectively). Seattle also has extra-wide shoulders for BOS operations.

[20] *Ibid.* page 6-5.
[21] *Ibid.*, page 7-1.
[22] Source: TCRP (2012).

After width, the second most important physical factor is the strength of the shoulder, which is largely determined by the pavement thickness. Typical pavement thickness on general travel lanes is a minimum of seven inches; however, shoulders are typically thinner, sometimes being only three inches thick. While thinner pavement can support infrequent use, this is not acceptable for frequent use, especially by heavier vehicles like buses. In the Twin Cities, all shoulders are now built to a seven inch thickness.

Shoulders typically have increased slope for drainage purposes. Reconstruction to build up the shoulders to a flatter slope is recommended; MnDOT has moved to a two degree slope standard from the four percent slope of older shoulders. New Jersey required 2/5 degree slopes from the previous four degrees. The areas around drains should also be a focus for structural improvements; New Jersey added 78 new drain inlets for its four-mile long Old Bridge BOS project, which was along an arterial roadway.

Roadway Geometry and Sight Distances

Roadway geometry affects both the operation of a vehicle itself and also the sight distances of the driver. Buses may off-track around curves (i.e., rear wheels swing wider) and require a larger shoulder width, while curves may also restrict sight lines to an obstacle in the shoulder and require the bus speed to be reduced. MnDOT requires that shoulders be upgraded to the same grades and slopes as the general purpose lanes, along with a 250 foot minimum sight distance (see Table 4-1 in TCRP 151). For arterial highways with unrestricted access (i.e., access roads or driveways along the road), wider shoulder widths are recommended due to motorists pulling forward into the shoulder to set up for merging.

Merging at Intersections and Ramps

Typically buses on shoulders must yield to any vehicle entering the shoulder, including at freeway ramps or intersections. In complex or very busy intersections, shoulder use by buses is generally not permitted. Generally, more than 1,000 vehicles per hour entering or exiting at an intersection indicate that buses should re-merge with general traffic beforehand, though another option is to implement ramp metering. For dual exit lanes, re-merging with the general lanes is standard practice; for dual entry lanes, bus drivers are usually permitted to weave through the traffic.

In Atlanta, a more restrictive protocol specifies that all buses must re-merge with general traffic before interchange off-ramps and not access the shoulder again until after the on-ramp merge. It should be noted that motorists are more likely to illegally make use of shoulders at intersections, especially to exit during congestion, which can further impact safety at intersections.

To assist with merging, Minnesota DOT uses ramp metering, which is regarded as being effective in ensuring vehicle spacing for safer merging. In San Diego all intersections along the BOS corridor have auxiliary lanes between the off-ramps and on-ramps, enabling safer merges.

The above discussion applies to most BOS operation, which is along the right-hand (outside) shoulders of highways. However Cincinnati and Chicago are examples of median (left-hand or inside) shoulder BOS operation for which intersections are typically less of a concern, unless there are left exits and merges present along the roadway). However, buses have to merge with general traffic and gradually cross to the other side of the highway when transitioning between median shoulders and right-hand entry and exit ramps. This can be challenging when crossing right due to restricted bus driver visibility towards the right rear of the bus.

Clearance at Barriers and Overpasses

For BOS application the minimum shoulder width is governed by the width of the bus including the mirrors and allowance for lateral clearance on both sides as well as the presence of truck traffic on the facility. As indicated in the TCRP Report 151, most agencies have used 10 feet as a minimum width on straight road segments with no lateral obstruction, but with a 11.5 feet minimum width on bridges or adjacent to barriers and curbs. In the Twin Cities and most other cities, a 10 foot shoulder width is the minimum acceptable for BOS operation, and is also acceptable for short distances on an overpass. For longer bridges, a minimum of 11.5 feet is required due to the challenge of driving a bus next to a bridge railing.

Posted Signage, Markings, and Warning Devices

In general, BOS implementation has used minimal signing and markings. In addition to relevant signage recommended in the Manual for Uniform Control Devices (MUTCD), regions implementing BOS projects have used a number of different signs as appropriate to their state codes, though there does appear to be a gradual convergence. Signs will indicate authorized bus use of shoulders, both along the shoulders and at intersections and merges. For roads within the National Highway System, the precise signage is subject to approval from the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA).

Figure 4: Examples of BOS Signage

In the Twin Cities, small yellow advisory “pinch-point” signs are posted when the shoulder narrows to less than 10 feet and the bus must re-merge into the general lanes. While in Maryland and New Jersey the authorized time period for BOS operation has been included on signage, there is a growing opinion that this is unnecessary, as bus operations already take into account any time period limitations, while more flexibility might be needed in special circumstances. The exception would be if there are time period rules in effect for general traffic as well (e.g., high occupancy vehicle operation in peak periods, such as on I-66 inside the Beltway, or no turns on arterial highways in peak periods).

In addition to signage, pavement markings may be used, such as a double white line or a double-wide line, or a there may be a warning device such as rumble strips. Rumble strips between shoulders and the general travel lanes may not be possible if shoulder width is narrow, and existing strips may need to be removed if restricting the useable portion of the shoulder by buses.

Dynamic Signage and Lane Control

The use of Intelligent Transportation Systems (ITS) technology offers some potential applications for BOS. VDOT currently employs ITS along I-66 between the Beltway and US 50 to allow use of the shoulder lane by all traffic, when enabled by overhead signals. Ottawa, which has bus stops along the highways, has customer actuated call buttons so that buses can exit the shoulders and access the stops to pick up waiting passengers. BOS operations can benefit from variable message signs with specific information on shoulder use or conditions, or from coordinated traffic operations information on blocked shoulders being pushed to the drivers. Looking to the future, the University of Minnesota has designed a lane guidance concept, which would use GPS location and other sensors to assist in steering and provide warnings, including a collision avoidance system, for implementation onboard buses. Further developments may lead to deployment of this technology in buses intended for BOS operation.

BOS Safety and Emergency Incidents and First Responder Access

The reported safety record for all BOS systems evaluated in the TCRP reports has been exceptional. Periodic accident review has not produced any statistically significant findings concerning BOS operation. In general only minor property accidents have taken place, mostly involving mirrors. Proper education, enforcement, training, and signage have all been important in achieving this record in all the BOS projects evaluated. Except in unusual circumstances, with completely blocked traffic, there have been few reported instances of buses not being able to re-merge into the general lanes to clear the way for emergency vehicles. In Atlanta, additional bulb-outs outside the shoulders were added, for both enforcement use and for disabled vehicles.

Enforcement and Encroachment / "Jealous Motorist" Issues

Enforcement's primary role for BOS operation is to ensure only authorized buses use the shoulders. In addition to motorists using the shoulders, motorists can also encroach upon the shoulders, blocking safe bus use. According to interviews and surveys, bus drivers using BOS often experience motorists blocking the shoulder so that the bus could not pass or pass only with difficulty; in Miami up to 44% of bus drivers reported experiencing this daily. This encroachment on the shoulder is particularly problematic when the other vehicle is a truck. Most of these incidents are ascribed to poor or inattentive driving, but there are also cases of other drivers deliberately blocking the bus: the "jealous motorist" issue. Education and enforcement are the common strategies to combat encroachment of any type. In Miami, the fine for failure to yield to buses as they enter and exit shoulders, or for following a bus on the shoulders, is $133.50 plus license points. Dedicated additional police enforcement is often provided during the early stages of BOS operation on a corridor; six to eight hours during the first couple of weeks and two hours per week for another four weeks. Some projects have also used escort vehicles the first day of operation, to accompany the buses.

Public Outreach and Education

In advance of the Miami BOS project on SR-874/878, a three-element outreach plan was conducted. First, a service campaign with details on the bus service to be provided: routes, travel time, fares, and park-and-ride lots. Second, a media and elected officials event, including a comparative trip by two buses, one using the shoulders and one not. Third, a public service announcement was made for the project, emphasizing enforcement. For implementation in North Carolina, NCDOT drafted a one-page fact sheet and developed a list of Frequently Asked Questions (FAQs) and responses, for stakeholders to use in public outreach efforts.

Shoulder Cleaning / Snow Removal

Ensuring the shoulders are clear of debris or snow is essential for safe BOS operation. The Twin Cities includes shoulder clearance in their snow clearance plans. In Columbus, OH, the frequency of debris clearance for shoulders was increased from once every three weeks to once a week for the BOS segment.

Federal and State Exceptions to Design Code

FHWA must approve design code exceptions to allow BOS along the National Highway System. The Federal Transit Administration may also be involved if any FTA funds are used for implementation. Most states also have vehicle codes that require amendment when first authorizing BOS; the amendments typically carefully define the shoulders as limited-access or special transit use to get around general roadway standards. Exceptions are often used for pilot periods of two or three years, before legislation for permanent programs is required. It is important to note for liability issues that any nonstandard exceptions to design code could be targeted in court in the event of a crash or accident. Several states, such as California, incorporate permission into code for transit-only use of shoulders provided comprehensive safety and engineering studies are completed and approved. The exact designation of the BOS segments, whether as transit lanes or shoulder lanes, will in turn be reflected in the necessary traffic signage.

Eligible Vehicles

In most cases, BOS operation is typically limited to public transit buses. North Carolina further limits BOS operations to transit buses of standard size, though other projects offer wider latitude. Operationally, large transit buses can be seen by other motorists and the drivers sit high enough to see potential hazards. The drivers are also trained and supervised, as detailed below. Policy wise, this restriction limits shoulder use to a small number of vehicles and those vehicles are transit buses that directly help to reduce congestion. In addition, roughly half of BOS projects allow deadheading (i.e., empty) buses to make use of the shoulders; others only allow use when carrying passengers. However, there are exceptions. The Twin Cities allow paratransit vehicles to use the shoulders. Private charter buses that have gained permits are also allowed to use the shoulders, though reports are that few private operators have invested in the necessary driving training in order to obtain permits. Additionally, when Atlanta first implemented BOS, school buses also made use of the shoulders, even though they were not permitted; this violation was quickly corrected.

Bus Driver Training Requirements and Supervision

Public transit bus drivers are allowed to use the shoulders because they are professional drivers. They are accountable to operating rules and trained to handle complex driving decisions while driving on the shoulder. Driver training typically includes class room lessons on the purpose and policy for BOS use, knowledge of signs and markings, operating speed limits for the bus and for general traffic, merging at interchanges, accessing and exiting the shoulders, and procedures when the shoulders are blocked or need to be used by first responders. In addition driver training videos are also prepared to familiarize drivers with operating buses on shoulders. For instance, in the Twin Cities the BOS drivers are instructed to merge with the general lanes once within 1,000 feet of an obstruction. In addition, to protocols, there may be special instructions when operating in the shoulder; for instance, in the Twin Cities, Miami, Columbus, and North Carolina, buses activate their four-way flashing lights. In San Diego buses don’t use flashing lights but put on low-beam headlights.

Funding for Construction and Implementation

Costs range considerably for BOS implementation, depending upon the initial condition of the roadway and the desired conditions. The Twin Cities, with a specific fund of $1 million a year, is able to add four to eight miles of shoulder segments a year, at a cost of roughly $150,000 to $250,000 per mile. Other areas have had lesser costs per mile for less frequently used shoulders, typically only four to six buses per hour. At the higher end, the Old Bridge BOS project in New Jersey was $8.5 million for nine miles of arterial highway, but this involved substantial shoulder improvements, as well as bus shelters, sidewalks, and pedestrian islands. Capital funding for BOS implementation typically comes from state and local sources. In the long run, fixed guideway miles become eligible for federal transportation funds, and shoulders may qualify under certain criteria. In the Twin Cities, with twenty years of operation, the transit agency collects FTA Section 5307 capital guideway funds of roughly $30,000 per shoulder lane mile.

3. Data Collection and Analysis

In order to determine the feasibility and suitability of BOS operation on I-66 inside the Beltway, the project team obtained and analyzed data from various sources on the operating characteristics and physical characteristics of the study corridor. This section describes the data, their sources, and the results of the analysis.

Speed Data

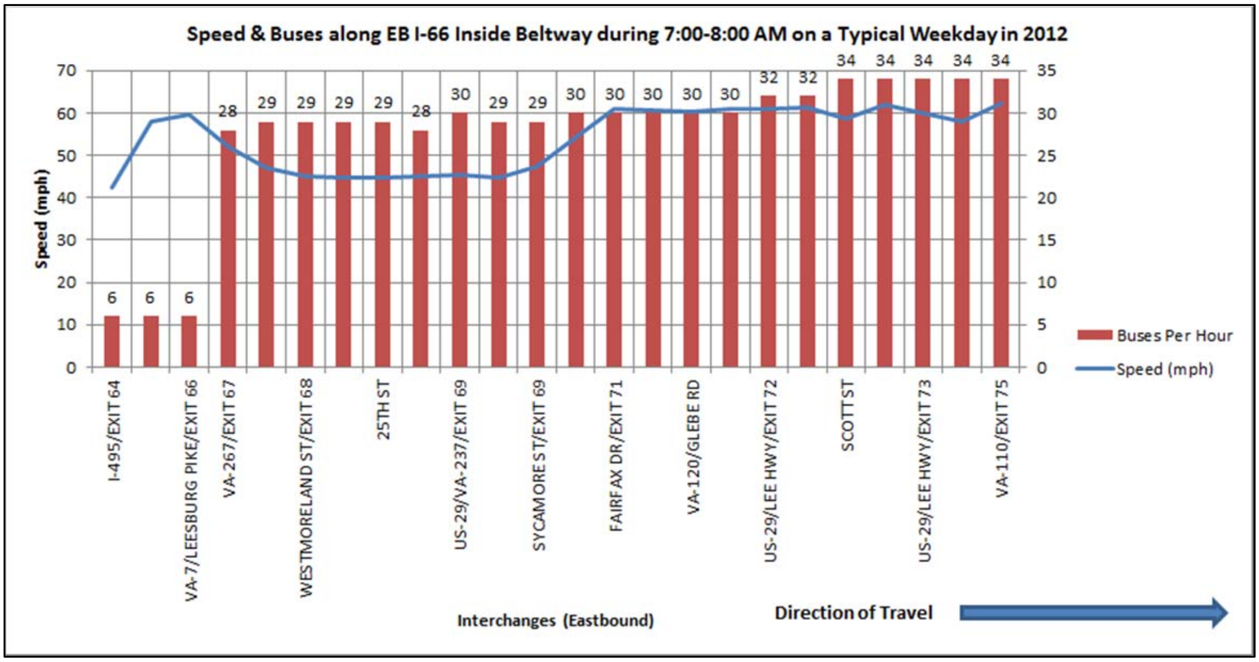
Travel speeds on the corridor were taken from the I-95 Corridor Coalition Vehicle Probe Project database for the National Capital Region maintained by COG/TPB staff. Colloquially referred to as INRIX data after the company that collects and processes the raw data for the Coalition, the probe vehicle data offer continuous, highly granular data on travel speeds (and by extension, travel time and reliability) over most of the regional freeway network and a growing proportion of the regional major arterial network. Data are collected 24 / 7 / 365 at one-minute intervals from probe vehicles including fleet vehicles and private automobiles, and via the INRIX smart phone application, which grants the company the right to sample user mobile devices as part of the software agreement.

For the pilot study, data were initially obtained for the study corridor for an average weekday in 2010, for both directions (eastbound to Washington, D.C. and westbound to the Beltway) for a morning analysis period of 5:00 am to 11:00 am, and an afternoon / evening analysis period from 1:00pm to 8:00pm. The temporal boundaries of the analysis periods were deliberately chosen to cover not only the traditional peak periods but also the shoulder hours to the HOV restrictions on I-66, as congestion is significant during those times as single-occupant vehicles flood the roadway, particularly after the HOV restrictions end. Data were initially obtained in 15-minute time segments and then aggregated to consecutive hourly segments (e.g., 8:00 am – 9:00 am, 9:00 am – 10:00 am, etc.). The data were segmented based on INRIX geography, which locates data using Traffic Message Channel (TMC) location codes that typically go from freeway interchange to freeway interchange.

Bus Volume Data

Bus information was collected from the regional transit providers operating along I-66 inside the Beltway: WMATA, Fairfax Connector, PRTC, and Loudoun County Transit. Both the number of trips and their specific schedule timepoints for each trip (in both directions for revenue service) were obtained. By combining the bus volume data with the speed data, the team was able to produce 15-minute time slices of average travel speeds and bus densities along the entire study corridor. The data were then aggregated to consecutive hourly time slices for ease of analysis; consecutive 30-minute time slices were used immediately before and after the HOV restricted periods due to the more dynamic traffic conditions. The resulting data was used to produce a series of charts illustrating the conditions along the study corridor during the analysis periods, with the travel speed as a line and the bus densities as vertical bars. An example chart is shown below in Figure 5. The full set of charts for the study corridor and the detailed methodology for combining the datasets and producing the results charts is contained in Appendix A.

Figure 5: Sample Bus Density / Travel Speed Chart



The resulting analysis of travel speeds and bus densities show that conditions vary widely throughout the analysis time period (both HOV and non-HOV operations), and there are conditions where bus performance is significantly hampered by congested conditions in the regular travel lanes, suggesting that bus performance could be improved by allowing BOS operation in the corridor. Furthermore, bus densities are within the range supportive of BOS operation, based on the other BOS implementations reviewed in TCRP Report 151. Most buses using I-66 inside the Beltway reach the facility via VA 267, so densities on the segment of I-66 between the Beltway and VA 267 tend to remain fairly low. Bus densities on the rest of I-66 from between VA 267 and the Theodore Roosevelt Bridge (TR Bridge) range from a minimum of 1-2 buses per hour to a maximum of 30-33 buses per hour. Average travel speeds range from a free-flow speed of about 60 mph to as low as 10 mph. Specific problem areas will be discussed as part of the recommendations in Section 5.

Shoulder Strength Data

The VDOT Northern Virginia District Materials section conducted a pavement evaluation for the pilot program; specifically, they evaluated the existing shoulders along I-66 for use by buses only. The geotechnical analysis found that the existing shoulders along I-66 could be safely used as a travel lane for buses for up to two years before significant structural failure, assuming a maximum volume of 150 buses per day in each direction of travel. The analysis memorandum from the Materials section is included as Appendix B.

Safety Data

Data were obtained from the VDOT Safety Service Patrol (SSP), a program to "assist stranded motorists and provide traffic control during traffic incidents including traffic accidents and road work."[23] The data cover all of I-66 within the Northern Virginia District – from the TR Bridge to the western border of Prince William County near the Gainesville interchange with Lee Highway (US 29), mile marker 43, for a

[23]See http://www.virginiadot.org/travel/safetypatrol.asp

12 month period (November 2011 to November 2012). Based on analysis of these data, it is estimated that approximately nine incidents per mile per year occur on the pilot program corridor. This level is not expected to significantly impact BOS operation, nor is BOS operation expected to significantly increase the number of incidents along the corridor – based on the literature review and assuming proper signage, markings, and bus operator training. The detailed information from the SSP is included as Appendix C.

Right of way (ROW) data

VDOT's Northern Virginia District Location and Design section had performed a detailed engineering survey of I-66 inside the Beltway as part of the previously completed I-66 Spot Improvements Study. This work involved both review of right-of-way plats and field data collection for items such as shoulder width. The collected data were digitized and mapped using CAD and GIS and were available for this pilot study for use in evaluating potential locations for BOS operation. A sample of the data is shown in Figure 6 below. A complete set of ROW and shoulder width maps for the entire pilot corridor is included as Appendix D.

Figure 6: Sample of ROW and Shoulder Width Data for Pilot Program Corridor

4. Methodology and Recommendations

In consultation with the project working group, the study team reviewed the information presented in the two previous sections of the report. Combined with VDOT descriptions of the current operations of I-66, the study team developed initial criteria for BOS operation and segment locations. These criteria were presented to the working group at their October meeting and received general concurrence from the group; however, the study team was asked to provide some refinements.

At the October meeting, the study team requested that working group members representing transit agencies provide additional information on deadhead (non-revenue) bus trips using I-66 in either direction, and information on bus vehicle dimensions (capacity, length, width, curb weight, loaded weight) to assist with the decision making process on the minimum shoulder width appropriate for BOS operations and the impact on the structural integrity of the shoulders. This information, which is contained in detail in Appendix E, was used to refine the operating parameters and initial BOS locations, both of which were presented to the working group at their December meeting.

Operating Parameters

Below are the recommended operating parameters for BOS operation on I-66 inside the Beltway:

- Bus on shoulder operation will be in effect 24 hours per day, seven days per week in both directions
- Traffic in the general purpose lanes must be traveling below 35 mph to allow bus on shoulder operation
- When operating on the shoulder, maximum bus speed is 25 mph
- Buses operating on the shoulder may not exceed the speed of traffic on the general purpose lanes by more than 15 mph
- Buses operating in the shoulder must merge back into general traffic when the shoulder is blocked by an incident or debris, or to yield the shoulder to first responders
- There must be a minimum shoulder width of 11 feet in straight sections with no lateral obstruction and 11.5 feet where there is a lateral obstruction to use the shoulders
- Geotechnical analysis of shoulder conditions indicates that with sufficient shoulder width, a one-year pilot program is acceptable as long as daily bus volumes do not exceed 150 buses per day
- Analysis of Safety Service Patrol data indicates that incident rates are likely to be around nine incidents per mile per year, which will not interfere with bus on shoulder operation as long as buses return to the general traffic lanes in the case of an incident

The maximum BOS bus speed (when operating on the shoulder) of 25 mph makes the proposed BOS pilot program on I-66 compatible with the existing BOS implementation on VA 267, where the maximum BOS bus speed is 25 mph. Currently, the VA 267 BOS operation terminates at the exit ramp to the bus loop of the West Falls Church Metrorail station; field observation indicates that there is sufficient shoulder width on the bridge over I-66 to potentially continue BOS operation beyond the Metrorail station exit ramp.

The study team also acknowledges that a minimum 11 foot shoulder width may be insufficient to accommodate Metrobus vehicles. WMATA currently operates Metrobus route 5A along I-66, connecting the District of Columbia and intermediate stops in Arlington and Fairfax counties with Washington Dulles International Airport (IAD). WMATA staff has expressed a preference for a minimum 12 foot shoulder for BOS operations based on driver experience and comfort.

BOS location options

Eight potential locations for BOS were identified using the analysis of the speed data, bus volume data, and the shoulder width information, as well as the operating parameters. A preliminary planning level feasibility review was conducted for each location and the eight locations were screened into three groups based on the level of effort needed to implement BOS:

- **Pilot locations** –Minimal level of engineering and construction effort
- **Near term locations** – Moderate level of Engineering and Construction effort
- **Long term locations** – High level of Engineering and Construction effort

Figure 7 shows a map of the corridor depicting these locations. Additional details on the length of the location, shoulder width, average speed, and bus density is provided in the sections below. The aerial maps and right of way information sheets for these locations are provided in Appendix E.

Recommended Pilot Locations

As described above the pilot locations are those which require a minimal level of engineering and construction effort. Three locations identified are in the eastbound direction and two are in the westbound direction. More details on each of these locations are provided in Table 4. Photos of some of the locations are shown in Figure 8 through Figure 11.

Cost Estimate for Pilot locations

Since the pilot locations are anticipated to be implemented first, preliminary planning level cost estimates for these locations were prepared. These estimates are summarized below. Additional details on the cost estimate are provided in Appendix F.

Table 3: Cost Estimates for Pilot Locations

Name	Preliminary Engineering	Construction	Total
Pilot 1	$80,000	$370,000 - $470,000	$450,000 - $550,000
Pilot 2	$50,000	$200,000 - $300,000	$250,000 - $350,000
Pilot 3	$40,000	$160,000 - $260,000	$200,000 - $300,000
Pilot 4	$40,000	$160,000 - $260,000	$200,000 - $300,000
Pilot 5	$90,000	$460,000 - $560,000	$550,000 - $650,000
Overall Cost for Pilot	$300,000	$1.35M - $1.85M	$1.65M - $2.15M

Recommended Near Term and Long Term Locations

The near term locations require a moderate level and the long term a high level of engineering and construction effort compared to the pilot locations. Out of the eight potential locations two are considered as near term and one as long term. The near term locations are adjacent extensions of the pilot project. The near term and long term locations (which would be implemented between two and five years after successful completion of the pilot project) are described in more detail in Table 5. The aerial and survey information for these locations in provided in Appendix F. As the actual time frame for the implementation of these locations is uncertain, cost estimates have not been prepared.

Figure 7: Overview of Recommended BOS Locations

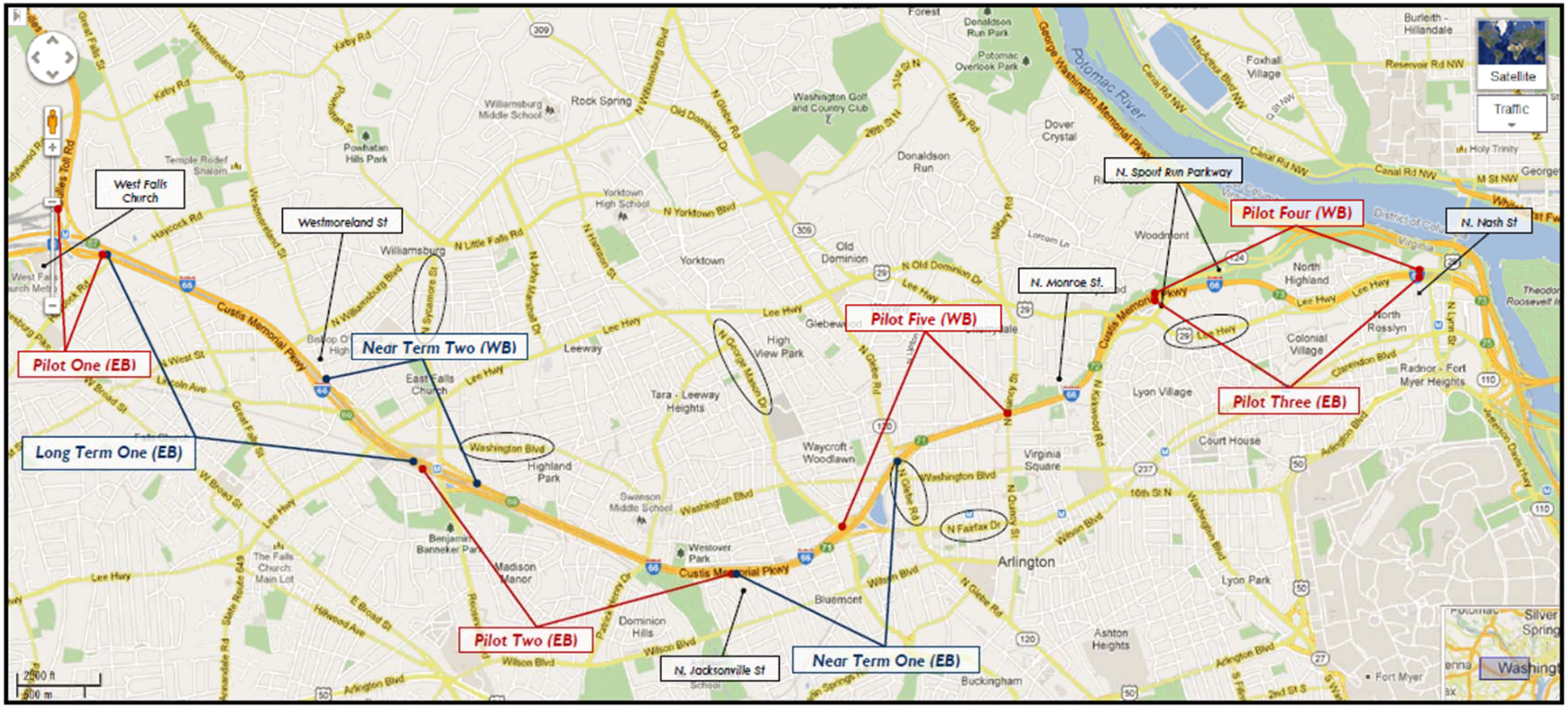


Table 4: Recommended BOS Pilot Locations

Name	From	To	Length (miles)	Shoulder Width (ft)	Avg. Speed (mph) [24]	Max. Bus Density (buses / hr) [25]	Notes
Pilot 1 (EB VA 267 outside shoulder)	End of existing BOS operation of VA 267	Merge point with I-66	1.75	>=11.5	23	32	This location is an extension of the existing BOS application on VA 267 and proposes to use the shoulder on the fly over ramp (bridge) from VA 267 to I-66 east bound.
Pilot 2 (EB I-66 outside shoulder)	100 ft west of N. Sycamore Street overpass	200 ft west of N. Jacksonville St.	1.4	>=11.5	27	32	A traffic operations solution would be needed for the merge at the on ramp from Sycamore Street. Additionally, there are drainage grates and junction boxes in this segment which will need to be upgraded to support the bus loads. The location can be readily extended to Glebe Road and the extension from Jacksonville St to Glebe Road is recommended as a near term project.
Pilot 3 (EB I-66 outside shoulder)	50 ft west of Lee Highway overpass near N. Spout Run Parkway	50 ft west of North Nash Street (Rosslyn Tunnel)	1.4	>=11.0	48	30	A traffic operations solution will be needed at the off ramp to US 29 near N. Veitch St. A majority of the shoulder width in this section is greater than 11 ft except for a short piece just east of N. Nash street (10.6 ft) width where additional width can be gained by restriping.
Pilot 4 (WB I-66 outside shoulder)	N. Nash Street (exit from Rosslyn Tunnel)	US 29 overpass at Spout Run Pkwy	1.4	>=11.0	36	31	A traffic operations solution needed for merge point at on-ramp from US 29 near North Veitch Street. Shoulder width minimum of 11.5 feet for segment except for short piece at 11 feet near North Scott Street overpass. I-66 Spot Improvement 3 will construct a westbound acceleration / deceleration lane and 12 foot full strength shoulder from US 29 to North Glebe Road (VA 120), allowing further BOS operation.
Pilot 5 WB I-66 outside shoulder)	N. Quincy St	Fairfax Drive on-ramp merge point	1.1	Varies 10-11 ft	21	30	A majority of the shoulder width is about 10 feet and additional width will be required which may be achieved by restriping or adding shoulder width as right of way is available in this section. This section along with the completed I-66 Spot improvement 1, near term improvement 2 and spot improvement 2 (to be advertised soon) will result in a continuous facility for bus use from N. Quincy Street to VA 267 by utilizing the shoulder and the auxiliary lane combinations

[24] Average speeds are based on analysis of data for I-66 inside the Beltway from the I-95 Corridor Coalition Vehicle Probe Project (typical referred to by the name of company that collects and administers the data, INRIX, Inc.) provided to COG/TPB. A description of the data and analysis methodology is provided in Appendix A.

[25] Bus densities are based on analysis of scheduled bus operations in the study corridor by all transit agencies combined with the INRIX data. A description of the analysis methodology is provided in Appendix A.

Table 5: Recommended Near-Term and Long-Term BOS Locations

Name	From	To	Length (miles)	Shoulder Width (ft)	Avg. Speed (mph)[26]	Max. Bus Density (buses / hr)[27]	Notes
Near-Term 1 (EB I-66 outside shoulder)	N. Jacksonville St	N. Glebe Rd	1	<=10	27	32	This location begins at where Pilot 1 ends and therefore when implemented it will provide a continuous 2.5 mile long shoulder for bus use in the eastbound direction. On visual inspection of this location it may appear that adequate shoulder width is available due to the openness of the roadway section in this area and no lateral obstruction but as indicated from the survey additional width will be needed for BOS application. The shoulder width may be gained by constructing additional shoulder in this portion or by restriping the main line lanes to narrower 11.5 feet width which will require design exceptions and Federal approval.
Near-Term 2 (WB I-66 outside shoulder)	Off-Ramp N. Sycamore St	Westmoreland St	~1	<=9.6	32	30	This location begins at the end of the recently completed Spot 1 improvements before the beginning of the soon to be advertised Spot 2 improvements. As such this location in conjunction with Pilot 5, Spot improvement 1 and spot improvement 2 can result in a continuous facility for buses comprising of auxiliary lane and shoulder use. The additional shoulder width in this section will require construction of wider shoulders in the available right of way and may be accomplished with the Spot 2 improvements which will be advertised for construction soon. Restriping may not be an option as the left shoulder is narrow in this section.
Long-Term 1 (EB I-66 outside shoulder)	VA 267 on-ramp (Pilot 1)	Sycamore St	2.1	<=9	23	33	While this segment is the most congested it also has the most constraints. The right shoulder width is less than 9 feet, right of way is limited and the number of lanes in this section varies from two lanes to four lanes to back to two lanes depending on the location. Traffic operations solutions will be needed for merge location at VA 267 on-ramp, merge / diverge location at Westmoreland Street off-ramp, and Fairfax Dr off-ramp (to signal at US 29 – location experiences queuing into regular travel lanes during peak periods).

[26] Average speeds are based on analysis of data for I-66 inside the Beltway from the I-95 Corridor Coalition Vehicle Probe Project (typical referred to by the name of company that collects and administers the data, INRIX, Inc.) provided to COG/TPB. A description of the data and analysis methodology is provided in Appendix A.

[27] Bus densities are based on analysis of scheduled bus operations in the study corridor by all transit agencies combined with the INRIX data. A description of the analysis methodology is provided in Appendix A.

Figure 8: View of Shoulder and Roadway on EB I-66 along Pilot 2

Figure 9: View of Shoulder and Roadway on WB I-66 along Pilot 4

Figure 10: Example of Lateral Obstruction – WB I-66 at North Scott Street (Pilot 4)

Figure 11: View of Shoulder and Roadway on WB I-66 between Pilot 5 and Near Term 2 (between Fairfax Dr. and Sycamore St. [Spot Improvement 1]))

5. Implementation Plan

The previous sections of this report have provided background information on BOS and the benefits of BOS operation, as well as recommended locations for a pilot project and near and long term BOS operations within the study corridor. This section describes the steps necessary for implementing the BOS pilot project in the locations identified in Section 4. More specifically, this section addresses the following items which were identified from the literature review as being key to a successful implementation of BOS:

- Conditions for use of shoulders
- Operations Protocol
- Funding
- Design and FHWA approvals
- Transit agency coordination and agreements
- State police and first responders coordination

Conditions for Use of Shoulders

Roadway shoulders provide a range of important functions such as:

- Emergency vehicle use
- Staging area for maintenance / construction
- Storage of disabled vehicles
- Snow storage and drainage

The use of shoulders by buses could affect these functions even if limited to bus use and as such it is important to clearly define the conditions for use of shoulders during BOS implementation. For the pilot program the following conditions of use are defined:

- Use of shoulders permitted only when mainline operations exceed predefined threshold impacting transit service
- Authorized buses use the shoulders when it is safe to do so under the following conditions:
  - Shoulder is not being used for enforcement / emergency response
  - Shoulder is not being used by broken down / stalled vehicle
  - Shoulder space is not required for snow removal and maintenance operations

Operations Protocol

One of the primary issues with BOS identified in TCRP 151 is ensuring that the bus operators / drivers and motorists clearly understand the rules for BOS use. For the pilot program the working group identified the following operations protocol:

- Buses can use the shoulder when the mainline traffic is operating at speeds below 35 mph
- When operating on the shoulder, maximum bus speed is 25 mph
  - The slower bus operating speed increases the ability to maneuver safely while driving on narrower shoulders and avoids the perception of being a hazard to both transit passengers and motorists in adjacent lanes

- Buses operating on the shoulder may not exceed the speed of traffic on the general purpose lanes by more than 15 mph with maximum speed of 25 mph
- Buses operating in the shoulder must merge back into general traffic when shoulder is blocked by an incident or debris, or to yield shoulder to first responders

Funding

The purpose of the pilot program is to initially implement BOS in a short time frame as a low cost strategy for improving the transit travel times and reliability in the corridor. To achieve this purpose the study team identified the following funding sources:

- Preliminary Engineering / Design funding - it is possible that some of the pilot locations will require minimal design and may be completed under an existing on-call consultant contract. If that route is not possible, a separate project in the Six Year Improvement Program (SYIP) will be needed to enable design of all the locations under the same project and maintain time and cost efficiency.
- Construction – Depending on the level of construction effort determined from the design of the pilot locations, construction may be completed along with some of the regular operations or maintenance work scheduled in the corridor. Alternatively, a separate project in the SYIP may be used to complete the work at all the pilot locations identified.

As the pilot project moves from planning into preliminary engineering and design, special consideration should also be given identifying funds for the continuing operations and maintenance of the BOS infrastructure, assuming continued BOS operation following completion of the one-year pilot. Increased funding for the operations and maintenance of I-66 will be needed to cover the signage and markings, as well as maintenance of the roadway surface itself – the shoulders on which buses are operating and related infrastructure such as drainage grates and junction boxes. The frequency of shoulder cleaning may increase following a BOS implementation, and funding for that additional cost should also be identified.

Finally, funding must also be identified for an education and marketing outreach campaign for the general population so that when BOS operation begins along I-66 the traveling public is well aware of the pilot project. This effort will include outreach to local media and interest groups through VDOT's Office of Public Relations. NVTC staff has also offered their assistance with this process.

Design and approvals

Although BOS is not new to Northern Virginia due to the existing BOS operation on VA 267 described earlier in the report, various design approvals will be needed for the I-66 BOS implementation. The presence of BOS on VA 267 indicates that the BOS can be implemented; however, if the legislative resolution used for the VA 267 BOS is specific to that facility it will need to be amended to include I-66 inside the Beltway. In some of the other states noted in the TCRP 151 case studies the head of the State Department of Transportation has the authority to allow BOS applications as a one or two year pilot program. Some other transportation agencies have amended their state vehicle codes to allow BOS operations. The design and approvals as well as other aspects of implementation of the VA 267 BOS operation may serve as a model for this pilot project.

VDOT NoVA District management will begin coordination with the Chief of Policy and Environment in the VDOT Central Office and the Office of the Attorney General to determine if VDOT has the authority to allow the use of shoulders by buses during non-emergency situations.

Designs and design exceptions /waivers for the BOS pilot locations will need to be reviewed and approved by both the VDOT Chief Traffic Engineer and FHWA since I-66 is part of the Interstate Highway System. This study included a field review of the corridor that identified several design elements that must be addressed as part of BOS implementation, including the following:

- Adequate shoulder width
- Adequate shoulder strength
- Placement of signage to identify BOS locations
- Placement of signage at merge and diverge locations to indicate the potential presence of buses operating on the shoulder
- Lateral obstructions exist in some locations and these may require additional protection or design exceptions
- Modifications to drainage inlets may be needed to accommodate BOS operation, which may compromise the inlets' effectiveness at removing water from the roadway and may require design exceptions
- In certain locations the general travel lanes may need to be narrowed through restriping in order to achieve the 11 foot minimum shoulder required for BOS, and this action may require design exceptions
- Environmental evaluation and related approvals may be necessary

Transit Agency Agreements and Driver Training

The execution of a separate agreement with each regional transit agency will be necessary. The agreement will define the terms of BOS pilot program as well as the roles and responsibilities related to driver training requirements and evaluation of the program.

Driver training for BOS operations is mandatory for any implementation plan. In order to utilize the BOS pilot locations, each regional transit operator must develop a driver training program in collaboration with VDOT and VDRPT. The program must educate the drivers on terms of use, operating protocols, safe merging in and out of the shoulder, and negotiating interchange ramp junctions, as well as meet any other requirements of the transit agency. Each transit agency must provide for the training of its drivers and document completion of the required instruction. Individual transit operators will then approve their drivers for BOS operation on the pilot locations. Key elements of driver training identified from the literature review are provided below to assist the transit agencies in the development of the driver training program.

Table 6: Sample Elements of BOS Driver Training

Purpose of BOS program • Conditions of use • Operating protocol • Speed and speed differential • Yielding right-of-way • Interchange areas • Staying on paved shoulder • Judging operating speeds of mainline traffic • Signs, pavement markings • Motoring public • Specific information for bus drivers **Additional Elements** • Agency-specific policies and applicable statutes	**Communications** • Intra-agency • Inter-agency • Driver to motorist/driver courtesy • Emergency communication **Pilot Location Elements** • Start and end points • Interchange and/or intersection locations • Shoulder widths • Special attention locations • Restricted locations **Safe Operation near Interchanges** • Ramps and gore areas

Prior to the pilot implementation, trial runs to familiarize the bus drivers with the pilot locations may be necessary. VDOT is looking into the feasibility of creating a video that shows what driving along the pilot locations looks like from the bus driver's point of view. This video would supplement actual trial runs and not serve as a substitute.

State Police Coordination

While the SSP data reviewed indicates a fairly low rate of incidents along the pilot project corridor, coordination with the Virginia State Police (VSP) and other area first responders is essential for efficient operation of buses on shoulders and to insure that BOS operation does not negatively impact incident response along I-66. Members of the project team, or District senior management, should meet with VSP to begin the conversation about the pilot implementation and provide an update on the BOS application. VSP should be made aware of all the operational requirements and protocols for the BOS pilot (e.g., when and where to expect buses on the shoulder) and their assistance requested for enforcing the regulations for safe BOS operation, including responding to "jealous motorist" issues if they occur.

In turn, the project team must be prepared to address any concerns expressed by VSP or other first responders (area fire and rescue, local police departments, WMATA police) about how BOS may impact their ability to execute their mission. VSP will also be a crucial partner in the pilot program evaluation plan, as they will be a source of data on incidents and enforcement issues during BOS operation in the corridor. Finally, having VSP input into bus driver training and making sure there are clear lines of communication between the transit operators and VSP will improve the success of BOS operations. Both sets of stakeholders need to serve as "eyes and ears" on the corridor and report incidents to each other.

VDOT held an initial meeting with VSP as part of this study to begin the formal coordination process. Generally, VSP was supportive of the proposed BOS operation, but identified several issues with the pilot project that will need to be worked out well prior to implementation, including:

- Begin direct coordination with the VSP Sergeant who is in charge of the Arlington section of I-66

- Establish communications protocol between transit operators, VSP, and the Northern Virginia Traffic Operations Center (TOC)
    - VDOT's Regional Operations Director suggested that the TOC may need dedicated staff to communicate information to the different transit operators
- Increased enforcement in the initial stages of the pilot program to deter the auto drivers from using the shoulder by following a bus on the shoulder
- Placement of speed limit signs for enforcement of speed at which buses are operating on the shoulder
- Placement of regulatory signs to clearly identify the beginning and end of the BOS locations
- In addition to those entities already identified by VDOT, outreach efforts should also include the following:
    - The Chief Judge of Arlington County General District Court (for traffic court)
    - The Chief Judge of Fairfax County General District Court (for traffic court)
    - Arlington County Fire Department
    - Fairfax County Fire and Rescue Department

VDOT's project managers will incorporate VSP's guidance into the preliminary engineering and design phases of the pilot.

6. Monitoring and Evaluation Plan

A formal monitoring program and evaluation of the BOS pilot locations must be undertaken to determine if continued BOS operations are warranted following the 12 month pilot, and to assist with the feasibility, planning, and design of the near-term and long-term BOS locations identified in Section 4 of this report. The key elements on which data will need to be collected to conduct the evaluation are shoulder usage by buses, safety (incidents), and shoulder conditions.

Shoulder Usage Data

Data on the usage of shoulder by the transit buses will be needed to evaluate the effectiveness of the pilot program. The users of the pilot program, in this case the transit operators, will be responsible for reporting this data. Some of the data elements which will need collection include:

- Frequency or number of times shoulder was used for each pilot location
- Deadhead or revenue operation
- Number of passengers before and after the pilot implementation

The reporting process should be as simple as possible; complex reporting mechanisms will interfere with safe vehicle operation and will in turn result in lack of reporting / underreporting of shoulder usage. At a minimum, the use of the shoulder at any point during a bus trip (either revenue or deadhead operation) should be reported. Background information such as the traffic conditions, presence of an incident, number of passengers on the bus, and bus schedule adherence / performance can be obtained from complementary sources and will be useful for assessing the efficacy of the pilot program (e.g., how much person-time savings occurred from BOS operation can be computed if the bus passenger count is known at the time of BOS usage). It is hoped that much of this data can be collected from electronic sources: bus ridership from automatic passenger counters (APCs), speed data from INRIX, and others. Unfortunately, AVL data resolution is insufficient to determine shoulder presence.

Safety Data

Incidents that require a bus operating on the shoulder to merge back into the general purpose travel lanes should be monitored, reported, and tracked, regardless of whether or not the bus is involved; however, incidents involving a bus operating on the shoulder should be separately categorized. There will be three sources of reported safety data: the VDOT SSP, VSP and other first responders, and the transit operators themselves. The data to be gathered for each of the three sources to assess the Data assess the safety of BOS operations include the following:

- **VDOT SSP**
    - Number of assists at Pilot locations

- **VSP data**
    - Number of crashes related to BOS
    - Track illegal use of shoulder by autos ("jealous motorists")
    - Impedance to emergency operations due to BOS

- **Transit Agencies**
    - Incidents that require buses operating in shoulder to merge back into traffic (incident nature, location, time)

- **VDOT Maintenance**
  - Incidents of clearing shoulder debris *(impacts BOS operation)*
  - Snow removal operations
  - Use of shoulders for staging during maintenance operations

Each reported incident should contain detailed location information and additional information that can be used to evaluate any safety issues associated with the introduction of BOS operation on I-66 inside the Beltway, particularly at merge / diverge points where buses may need to cross ramp traffic flows and gore areas to maintain BOS operation. Data should be scrubbed for confidentiality purposes prior to the safety analysis, but must be done so in a way that retains sufficient information for evaluation of conditions. Items that need to be retained include but are not limited to: type of crash (e.g., sideswipe, rear-end, etc.), number of vehicles involved, citations issued, and speed estimates of vehicles involved.

Issuance of citations without a crash occurring should be treated as a reportable incident for purposes of the safety evaluation of the BOS pilot projects. This includes illegal uses of the shoulder by automobiles and other actions that impede or otherwise render BOS operation unsafe: vehicles following a bus operating on the shoulder (i.e., "jealous motorists"), or vehicles bypassing traffic by using the shoulder. There are situations where maintaining safe operation of the overall roadway (e.g., police enforcement of speed limits or HOV restrictions) may require buses operating on the shoulder to merge into general traffic; while these incidents are inevitable, they do have the potential to impact effective BOS operation and should be monitored, analyzed, and reported where possible. Debris on the shoulder that causes buses operating on the shoulder to need to merge back into general traffic as well as snow removal operations and use of shoulder as a staging area for maintenance work that restrict the use of shoulders should also be reported .

Shoulder Conditions

VDOT's Northern Virginia District Materials section should conduct a pavement assessment similar to the one conducted for this report following six months of BOS operation on the pilot locations, and then again at the conclusion of the pilot project (12 months). The assessment should include core samples specific to the pilot locations. Both reviews should cross-reference with the collected data on BOS usage since the shoulder deterioration rate increases directly with increased BOS operations. The shoulder condition data will also be used to assess the need to strengthen or reconstruct the shoulders if the pilot program is to be continued.

Assessment of Pilot Program / Recommendations

Since the pilot program duration is 12 month, a formal assessment will be completed prior to the end of the program. Therefore, data collection should be continuous and reviewed each month, rather than waiting until all data are compiled to write-up the assessment. The assessment will review all of the data and analysis described above and include a recommendation whether or not to continue the pilot program and seek funding for the near-term and long-term BOS improvements on I-66 inside the Beltway. It is strongly recommended that bus ridership data be collected immediately prior to the pilot implementation so that the assessment can also determine if the anticipated time savings from the BOS operation has attracted any new bus riders. The assessment will also include lessons learned from the pilot implementation, both to improve future BOS operations on this corridor as well as any ideas applicable to studies of other BOS corridors in the Commonwealth. Finally, it is recommended that the specific data collection requirements described above be incorporated into the agreements that the transit operators must enter into with VDOT in order to drive buses on the BOS pilot locations.

7. Conclusions

Bus on Shoulder (BOS) systems have been used in other states and localities as a congestion mitigation method. In Northern Virginia, there is one BOS application on the eastbound Dulles Airport Access Highway (VA 267) where buses are allowed to use the shoulders during the AM and PM peak period to bypass the recurring congestion. The recommendation for a pilot BOS program on I-66 resulted from stakeholder discussions for the recently completed I-66 Multimodal Study inside the Beltway. The results of this planning study are anticipated to be used to implement the BOS pilot on selected segments of I-66.

This report presents the findings of the literature review on BOS systems, data needed and analysis of data to identify potential locations for BOS applications in the I-66 corridor, conditions for use of shoulders and operating protocols as well as a plan for implementation and evaluation of the I-66 pilot program. A total of eight potential BOS locations have been identified in the I-66 corridor; five locations are recommended to be implemented for the pilot program, two are recommended for implementation in the near term and one location is recommended for implementation in the long term depending on the level of effort and associated cost. Implementation of the near term and long term recommendations depend on the success of the pilot and will supplement the pilot program locations by extending their length and thereby further enhancing the BOS program.

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Appendix A: Average Speed (INRIX) and Bus Density Data

Bus Density Analysis Updated Methodology and Speed Data

In the summer of 2012 MWCOG asked their consultant to produce one-hour bus density graphs using the 2010 INRIX speed data. This was accomplished by combining the number of buses in each freeway segment and by averaging the 15-minute INRIX speed data for each segment. This was done for each 15-minute time window analyzed. In short, the speed and bus density information for each freeway segment, from four 15-minute time windows, was combined to generate the average speed by freeway segment, and the buses per hour density on each segment. This is illustrated in the simple table below which shows how the average speed and buses per hour is calculated for a given segment.

Time	Freeway Segment (TMC)	Speed (mph)	Bus Density
8:00	110+04163	45	10
8:15	110+04163	40	6
8:30	110+04163	35	9
8:45	110+04163	30	7
8:00 – 9:00	110+04163	37.5 (average)	32 (total)

In the winter of 2013 MWCOG requested an additional update to the analysis, this time using INRIX speed data from 2012. The analysis of bus density on freeway segments on I-66 inside the Beltway was updated using the 2012 INRIX speed data, with all other analysis input factors remaining static. The analysis produced new 15-minute window bus density graphs as well as new one-hour bus density graphs (buses per hour).

A comparison of the 2010 graphs and 2012 graphs showed significant increases in averages speeds during most of the AM and PM peak periods analyzed (5am – 11am and 1pm – 8pm). This is due to a number of factors but the primary reason is both a national and regional reduction in traffic volume.[28] This reduction in traffic volume has directly positively influenced speeds on regional freeways. Furthermore, two additional factors played a role in increasing speeds on I-66. The first was the completion of construction on the I-66 related to a repaving project and construction related to the pending WMATA Silver Line. The second was the completion of improvements in the westbound direction from Fairfax Drive to Sycamore Street.[29] This improvement provides a continuous auxiliary lane between the two interchanges and a new 12-foot-wide shoulder. This type of improvement reduces merge-diverge conflicts by providing drivers more time to accelerate and find gaps in the traffic stream into which they can merge thus reducing turbulence in the traffic stream due to slow merging and/or late merging. In addition to improving safety this improves speed in the segment and potentially upstream of the segment as well.

There is one important detail to note when comparing the speeds between 2010 and 2012. The speeds at or close to the transition between no-HOV and HOV restrictions (eastbound at 6:30 and 9:00 am and westbound at 4:30 and 6:30 pm) were virtually unchanged between 2010 and 2012. This indicates that although the freeway speeds outside these transition times is highly variable due to a number of aforementioned factors, the speeds at these transition times is not. This indicates that the 2012 INRIX speed data is viable for use in analysis and is not reflecting speeds that are unrealistic.

[28] Federal Highway Administration Travel Monitoring, Traffic Volume Trends - http://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm
[29] http://www.virginiadot.org/projects/northernvirginia/i-66_spot_improvements_-_spot_1.asp

Background

In early 2012 the Virginia Department of Transportation (VDOT) requested that TPB/COG conduct a study of bus operations along I-66 to inform a study about bus priority along that roadway. The study area includes I-66 between I-495 and the Theodore Roosevelt Bridge in both directions. To support this effort, TPB/COG hired Foursquare Integrated Transportation Planning (FITP) to conduct data collection and analysis of bus trips and speed by highway segment to identify congested areas where buses experience delay.

In order to provide a broader understanding of the number of bus trips at any given time along the corridor, FITP supplemented previous work performed for COG as part of the Multimodal Coordination for Bus Priority Hot Spots study, with additional data collection and analysis, particularly for bus trips from Prince William and Loudoun Counties. The data collected includes bus volumes for Fairfax Connector, WMATA, Potomac and Rappahannock Transportation Commission (PRTC) and Loudoun County Commuter Bus (LC) bus service along I-66 inside the Beltway, by time of day (AM and PM Peaks). The routes that were already a part of the bus service and travel time database created for the Hot Spots study were Routes 595 and 597 (Fairfax Connector) and Route 5A (WMATA). Those that were added to the database as part of this task are: Manassas Metro Direct (PRTC); Linton Hall Metro Direct (PRTC); Manassas Omni-Ride to Pentagon and Downtown Washington (PRTC); Purcellville & Harmony to Rosslyn & DC (LC); Leesburg to Rosslyn (LC); Dulles North Transit Center to Rosslyn & DC (LC); Dulles South to Rosslyn and DC (LC); and Ashburn North to DC (LC). Both services do not currently have AVL so INRIX speed data was used to calculate the bus location along I-66. FITP obtained bus trip data from each agency's scheduling system.

Methodology

The methodology for this project involves several distinct steps to lay the foundation for the technical analysis. The first step was to collect all of the bus departure times and bus departure locations from the four agencies whose buses utilize I-66 for a portion of their trip. These were tabulated so that each run or trip could be uniquely identified. The second step was to calculate the distance from the departure point to the where the bus would enter I-66. The third step was to calculate the time it would take each bus to travel from its departure point to I-66. As a result we determined the time each bus trip would enter I-66 (inside the Beltway) by adding its estimated travel time to I-66 to its scheduled departure time from its origin. This provided the data necessary to track each unique bus trip through the I-66 corridor.

The process by which each bus was tracked through the I-66 corridor based on arrival time and speed is described in Section 3 of this report. The purpose of this analysis was to produce the number of bus trips on each segment on I-66 in the AM and PM analysis periods. For example, for the AM analysis period, defined as 5:00 am to 11:00 am, the analysis results in the number of bus trips per highway segment for 24 15-minute time windows. As the data on the number of bus trips is overlaid with INRIX speed data for the corresponding highway segments, the observer can ascertain how many buses are experiencing various highway conditions at any given time.

For example, in the 5:00-5:15 AM time window, only one bus may be observed traveling through the I-66 highway segments at approximately 60 mph. Later in the peak period during the 7:00-7:15 AM time window, as many as 10 buses may be observed traveling through the I-66 highway segments, experiencing speeds as low as 22 mph. As a result one can conclude where the highest number of bus trips is experiencing the lowest speeds and longest travel times in the corridor. The 15 minute time slices were ultimately aggregated to successive hourly time periods, which VDOT deemed to be more appropriate for a planning level analysis. It should be noted that while the aggregation process for the bus volumes simply adds together the buses from each 15-minute segment and results in an hourly bus density, aggregation requires the INRIX speeds to be averaged, which masks the variability in conditions along I-66 inside the Beltway, particularly during the HOV-restricted time periods and the shoulder hours to HOV restrictions. Because bus densities are currently fairly low in the off-peak direction (westbound in the morning, eastbound in the afternoon and evening), the off-peak speed data and charts were not aggregated to hourly levels and remain at the 15-minute time segment. These charts show speeds only and not bus densities.

Transit Service in the Study Corridor

The transit agencies that provide bus service utilizing the I-66 corridor are described in the table below. WMATA, Fairfax Connector, Loudoun County and PRTC all provide long-haul commuter express bus on I-66.

Transit Agency Descriptions

Transit Agency Name	Parent Agency / Jurisdiction	Coverage Area	Routes Operating on I-66 Inside the Beltway
WMATA	WMATA	Region	5A
Fairfax Connector	Fairfax County	Fairfax County and Arlington County	595, 597
OmniRide / Metro Direct	PRTC	Prince William County to NoVA and District of Columbia	Manassas Metro Direct Linton Hall Metro Direct Omni-Ride Manassas to DC
LC Transit	Loudoun County	Loudoun County to NoVA and District of Columbia	Purcellville/Harmony to DC Dulles North to DC Dulles South to DC Ashburn to DC

Utilizing the latest published schedules at the time of analysis, the bus trips utilizing I-66 were tabulated for each agency. Their departure location and time was also documented. Ridership data procured through previous projects is listed as well when available. The two following tables summarize the data collected for each agency.

AM Bus Data Summary

Transit Agency Name	Number of Unique AM Departures	Departure Location	Approach to I-66	Average AM Weekday Ridership
WMATA	7	Herndon P&R	VA 267	Not Available
Fairfax Connector	11	Reston P&R	VA 267	258[30]
OmniRide / Metro Direct	25	Gainesville	I-66 outside the Beltway	787[31]
LC Transit	52	Dulles South P&R Dulles North TC Ashburn Leesburg P&R Harmony P&R (Hamilton)	VA 267	2,080[32]
Total	**83**	**Eight locations**		**3,125**

PM Bus Data Summary

Transit Agency Name	Number of Unique PM Departures	Departure Location	Departure from I-66 inside the Beltway	Average AM Weekday Ridership
WMATA	13	Rosslyn Metrorail Station	VA 267	NA
Fairfax Connector	12	Downtown DC	VA 267	258[33]
OmniRide / Metro Direct	27	OmniRide: Downtown DC Metro Direct: West Falls Church Metrorail Station	I-66 outside the Beltway	787[34]
LC Transit	53	Downtown DC / Arlington County except for 955, 956, 957 that leave from West Falls Church Metrorail Station	VA 267 and I-66 outside the Beltway	1,961[35]
Total	**105**			**3,006**

INRIX Highway Speeds

INRIX highway segment speed data representing an average weekday from 2010 was provided by COG/TPB for I-66 in 15-minute segments. Table 3 provides an example of the data, and Figure 1 depicts the data graphically. The speed data is broken down into two types of segments, general highway segments and highway segments within interchanges. As a result segment names are often used twice, once to depict the highway segment before the interchange and once to depict the segment within the interchange itself. The INRIX data provides the location, speed, time in seconds to traverse each segment, and the length of each segment.

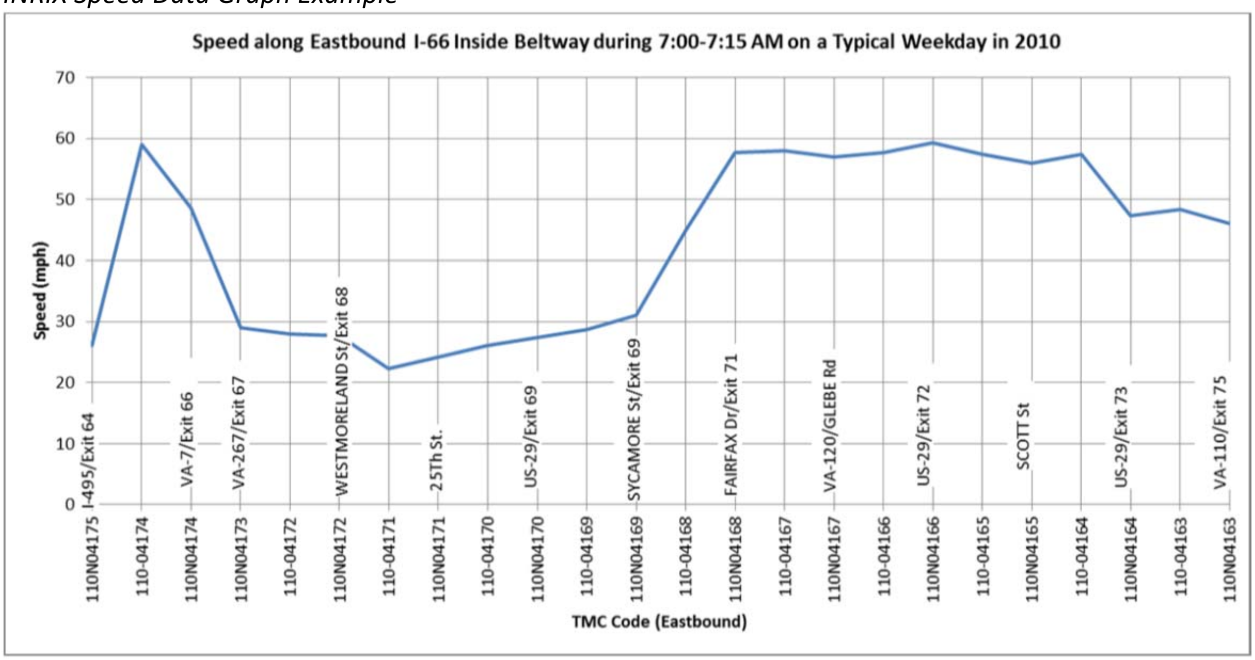
[30] May 2011 total average weekday ridership divided by two for AM/PM.
[31] Derived from actual 2011 average daily ridership provided by PRTC for these routes, divided by two for AM/PM
[32] Based on an average busload of 40 per historical data provided by Loudoun County for AM trips to DC.
[33] See note 30.
[34] See note 31
[35] Based on an average busload of 37 per historical data provided by Loudoun County for AM trips to DC

INRIX Speed Data Example – Raw Data Output

TMC Code*	Speed (mph)	Travel Time (seconds)	Road Number	First Name	County	Direction	Length (Miles)
110N04175	26	88	I-66	66 I-495/EXIT 64 FAIRFAX	FAIRFAX	EB	0.64
110-04174	59	72	I-66	VA-7/LEESBURG PIKE/EXIT 66	FAIRFAX	EB	1.17
110N04174	49	57	I-66	VA-7/LEESBURG PIKE/EXIT 66	FAIRFAX	EB	0.75
110N04173	29	28	I-66	VA-267/EXIT 67 FAIRFAX	FAIRFAX	EB	0.22

*INRIX TMC Segment - the Traffic Message Channel code that defines the beginning and ending point of the roadway segment being reported.

INRIX Speed Data Graph Example



Data Analysis

This section summarizes the analysis of the bus trip data to show on which segment of I-66 each bus is located in a given 15-minute time window, according to the schedule. The analysis involved multiple database queries to determine the bus' progression on the corridor. For every unique bus operating on the I-66 corridor, the time it entered the corridor was calculated based on its departure time, by adding the time it takes, given an average speed, to cover the distance from point of origin to the beginning of the I-66 corridor. For example, the PRTC bus M-7 departing from Williamson Boulevard & Stonehouse

Drive at 6:05 am started its route 18.2 miles from its entry point onto I-66. At an average speed of 38 miles per hour, that bus entered I-66 28.7 minutes later at 6:34 am.

The bus trips analyzed all use highways to approach I-66 inside the Beltway for the vast majority of their trip. INRIX speed data from the appropriate time period along the routes the buses utilize was used to calculate an average speed for each individual bus trip to calculate its arrival time on I-66 inside the beltway. So for the PRTC bus M-7 trip that departed at 6:05 am, INRIX speed data from the 6:00 to 6:15 am time period was used for the approach segments, and in this fashion the average speed used to calculate the arrival time of each bus trip to I-66 inside the Beltway reflects the average traffic conditions that bus would experience during its approach.

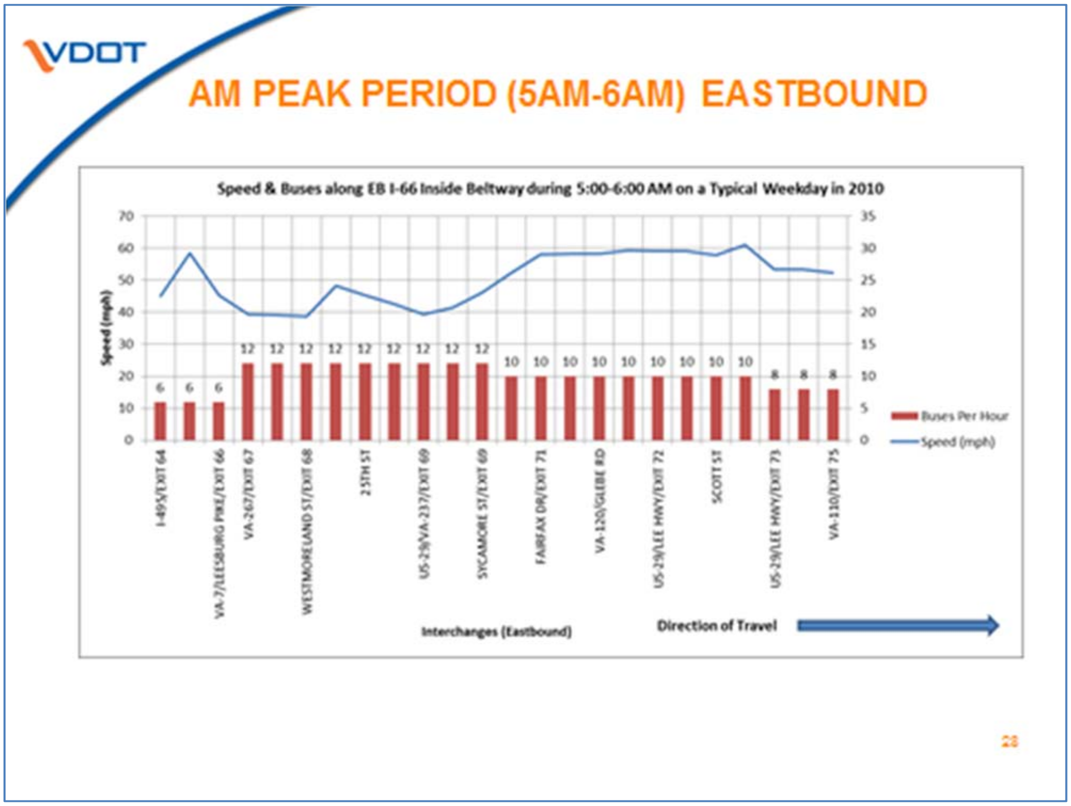
Once the entry time onto I-66 was calculated, each of the bus' TMC time positions was calculated by looking up the average speed during that 15-minute time interval and adding the travel time between TMC positions. TMC time positions are provided for each segment in the INRIX data. Continuing the example, the PRTC bus M-7 (originally departing at 6:05am) entered TMC 1 on I-66 at 6:34 am. The Access query looks up the TMC 1 speed data for the 6:30 am and 6:45 am time window. During this time window the traffic moved at an average speed of 27 miles per hour for the 0.64 mile stretch, with a travel time of 84 seconds. The query calculates that this bus would traverse that highway stretch and reach the end of TMC 1 just after 6:35 am. This analysis assumes that the buses are traveling at the same speed as general traffic as reported by the INRIX data.

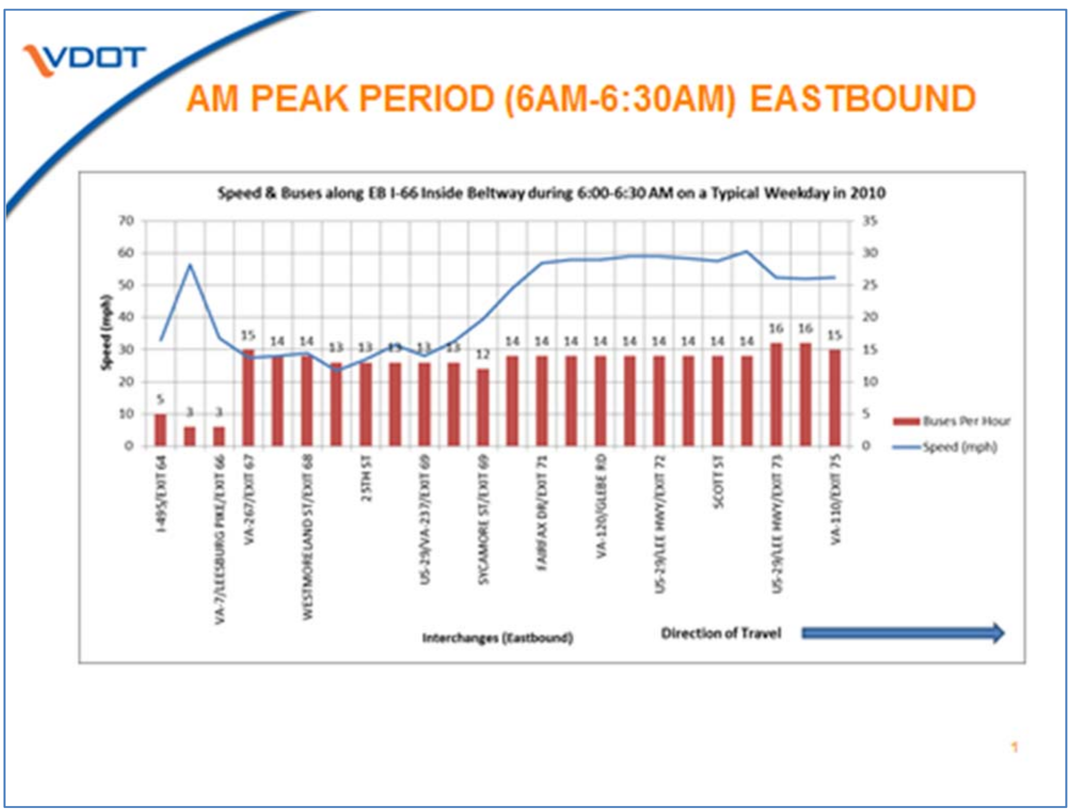
The query continues to calculate all the buses' corresponding arrival times at each TMC point along I-66. This was completed for each unique bus trip traveling through the corridor. Then, by fifteen minute increments, a count was made of the buses present within each TMC segment along I-66. In some cases a bus will traverse the entire portion of I-66 in a 15-minute time window, as the distance is approximately 10.4 miles, and in free-flow conditions this should only require a little over 10 minutes to travel. However, because each bus has a unique arrival time, they do not all begin precisely at the beginning of each 15-minute window.

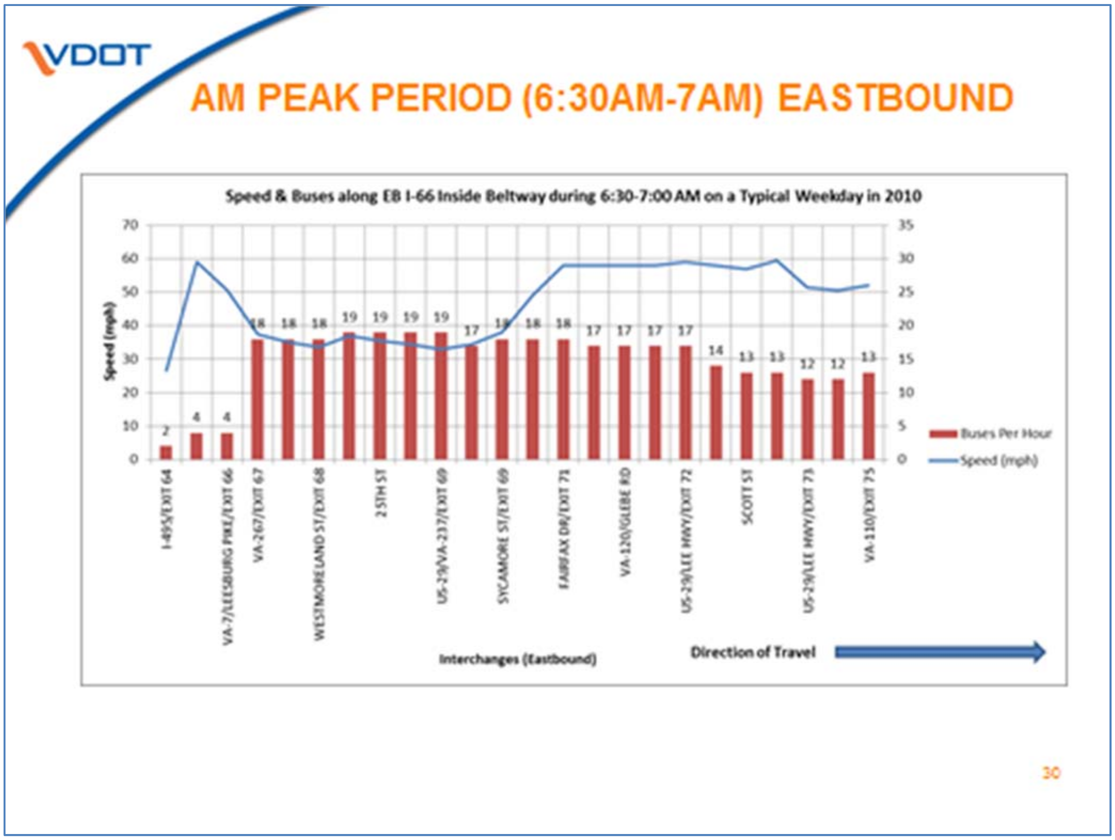
Some buses will begin their trip on I-66 in one 15-minute window but not complete it until the following 15-minute window due to slower speeds. How far a given bus progresses through the corridor depends on the speed of each segment during that 15-minute window and when the bus entered the 15-minute time window. For example, utilizing the bus speed data for the 7:00 – 07:15 am time window, a bus entering I-66 at 7:00 am will traverse the entire corridor in exactly 15 minutes, based on the speeds of each segment. A bus entering at 7:05 will not traverse the entire corridor by 7:15, perhaps only making it two-thirds of the way. As a result, the segments in the beginning of the corridor will show two bus trips while the segments towards the end will only reflect one bus trip, because only one bus made it through the entire corridor during this time window.

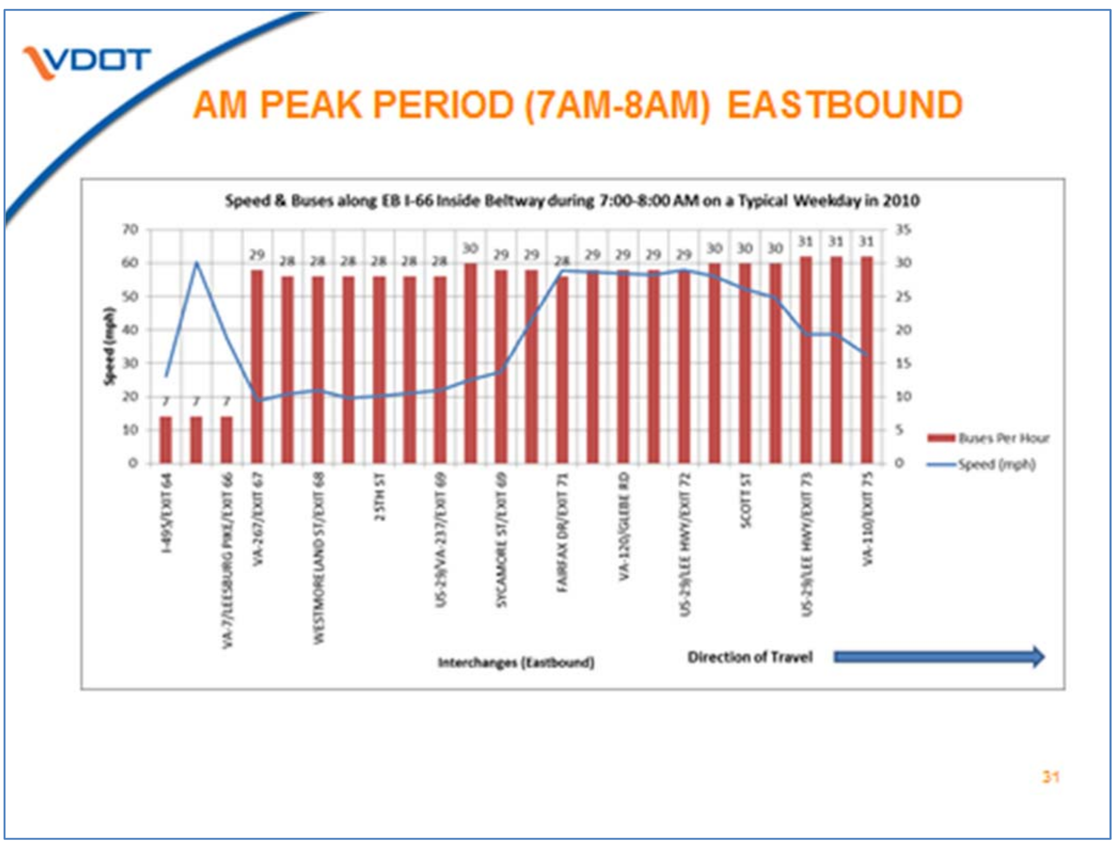
The 15 minute time slices were ultimately aggregated to successive hourly time periods, which VDOT deemed to be more appropriate for a planning level analysis. New charts were created for the hourly time periods, with 30-minute periods used for the shoulder times to the HOV restricted periods due to the extremely dynamic traffic conditions. Those charts for both the initially analyzed 2010 data and the updated 2012 data are shown on the following pages. It should be noted again that while the aggregation process for the bus volumes simply adds together the buses from each 15-minute segment and results in an hourly bus density, aggregation requires the INRIX speeds to be averaged, which masks the variability in conditions along I-66 inside the Beltway, particularly during the HOV-restricted time periods and the shoulder hours to HOV restrictions.

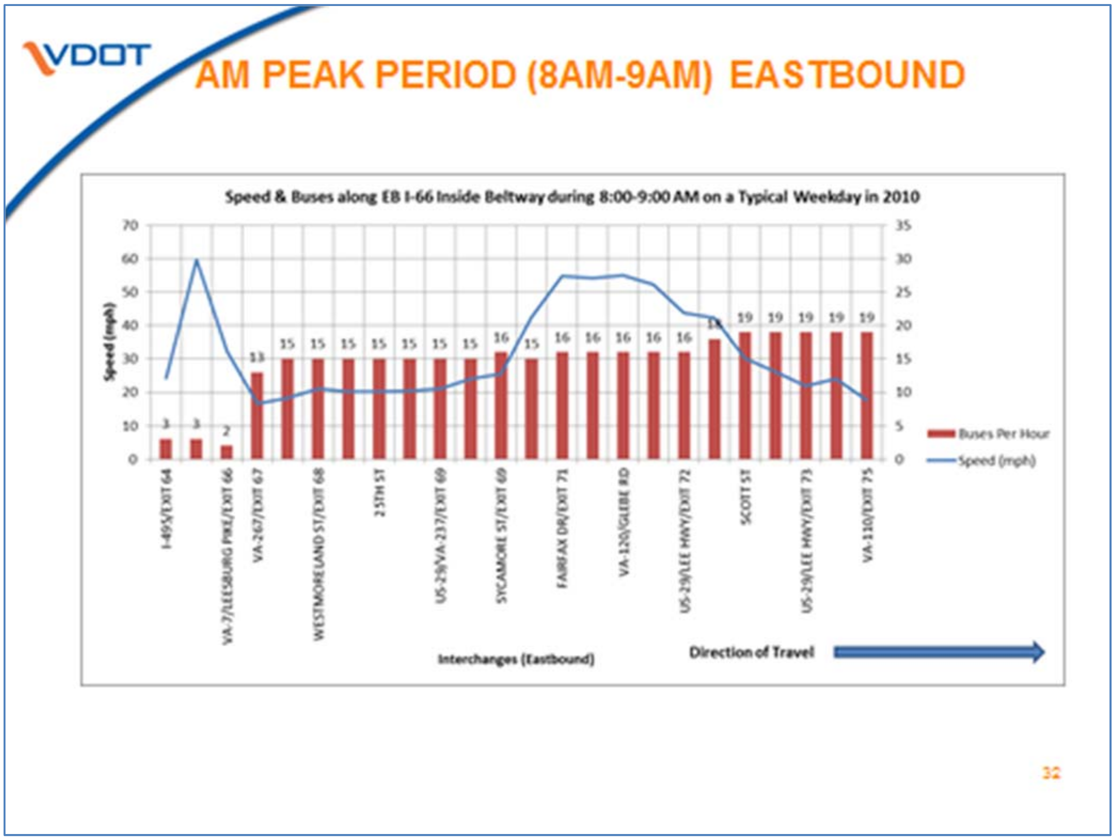
2010 Data, Peak Travel Direction






VDOT
AM PEAK PERIOD (6:30AM-7AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 6:30-7:00 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
30


VDOT
AM PEAK PERIOD (7AM-8AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 7:00-8:00 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
31


VDOT
AM PEAK PERIOD (8AM-9AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 8:00-9:00 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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SCOTT ST
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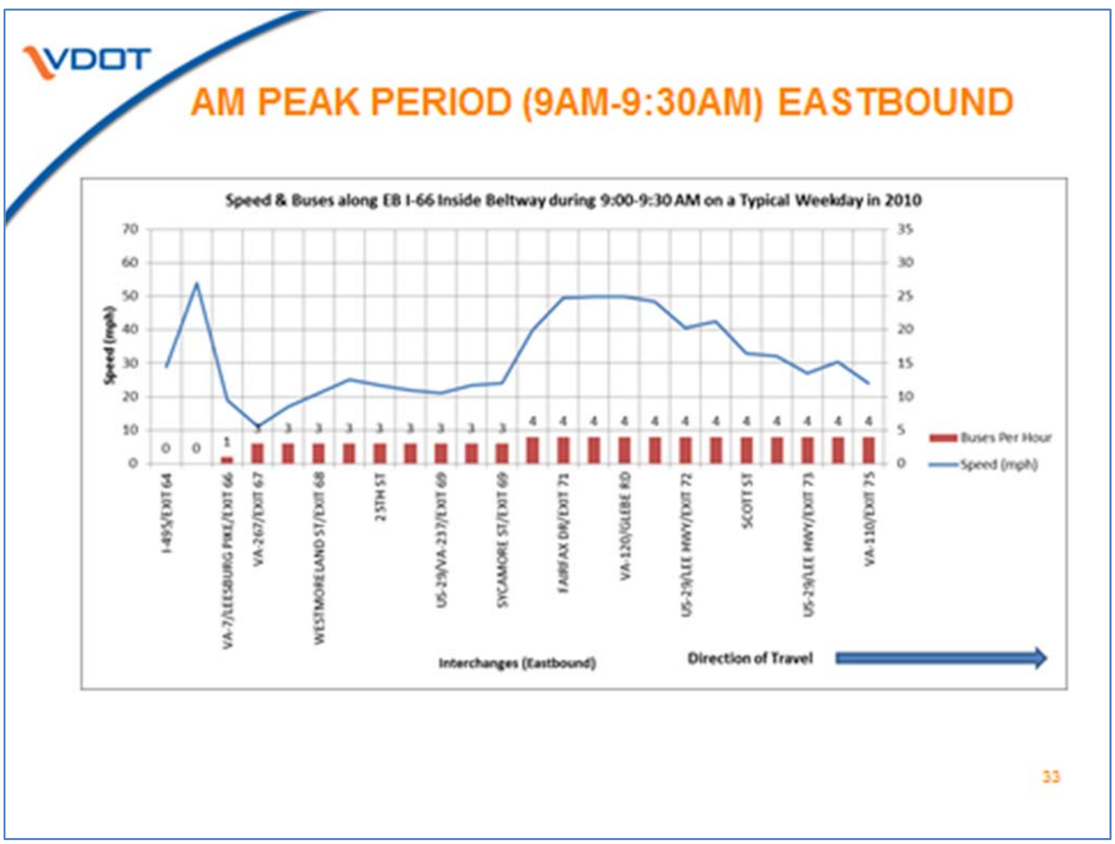
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
32


VDOT
AM PEAK PERIOD (9AM-9:30AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 9:00-9:30 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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SCOTT ST
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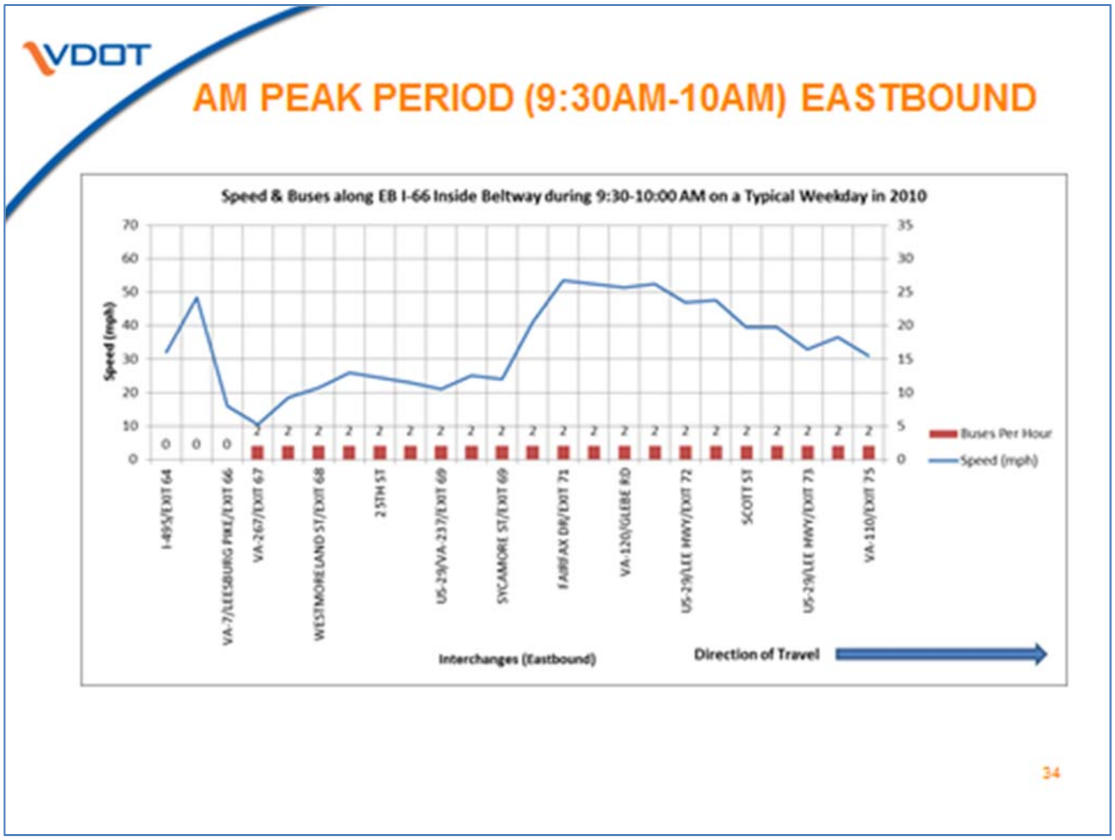
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
33


VDOT
AM PEAK PERIOD (9:30AM-10AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 9:30-10:00 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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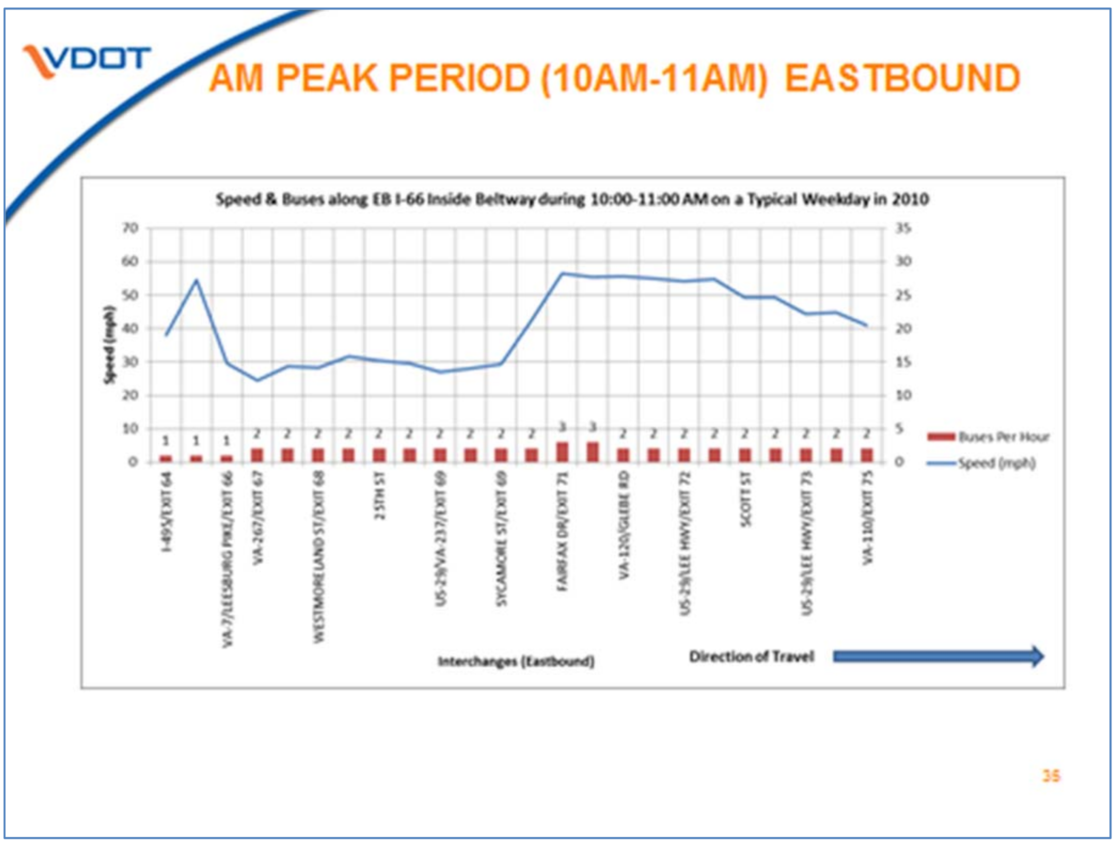
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
34


VDOT
AM PEAK PERIOD (10AM-11AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 10:00-11:00 AM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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SCOTT ST
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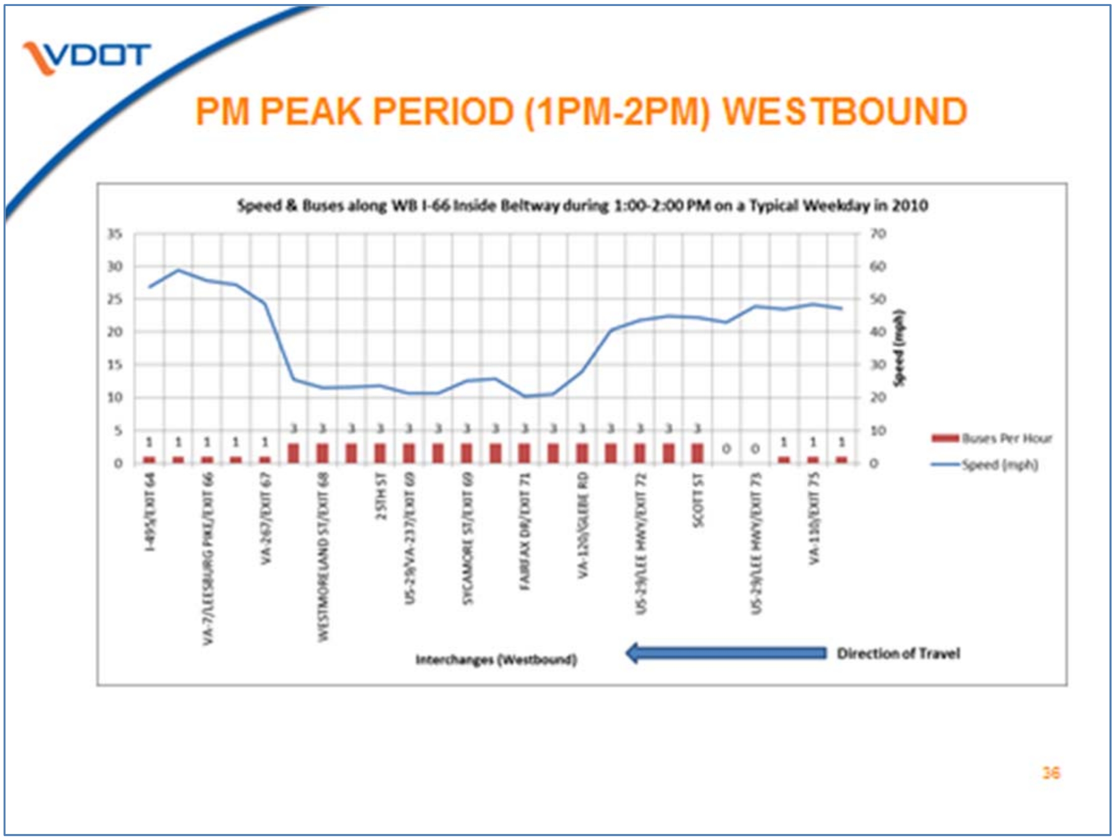
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
35


VDOT
PM PEAK PERIOD (1PM-2PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 1:00-2:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
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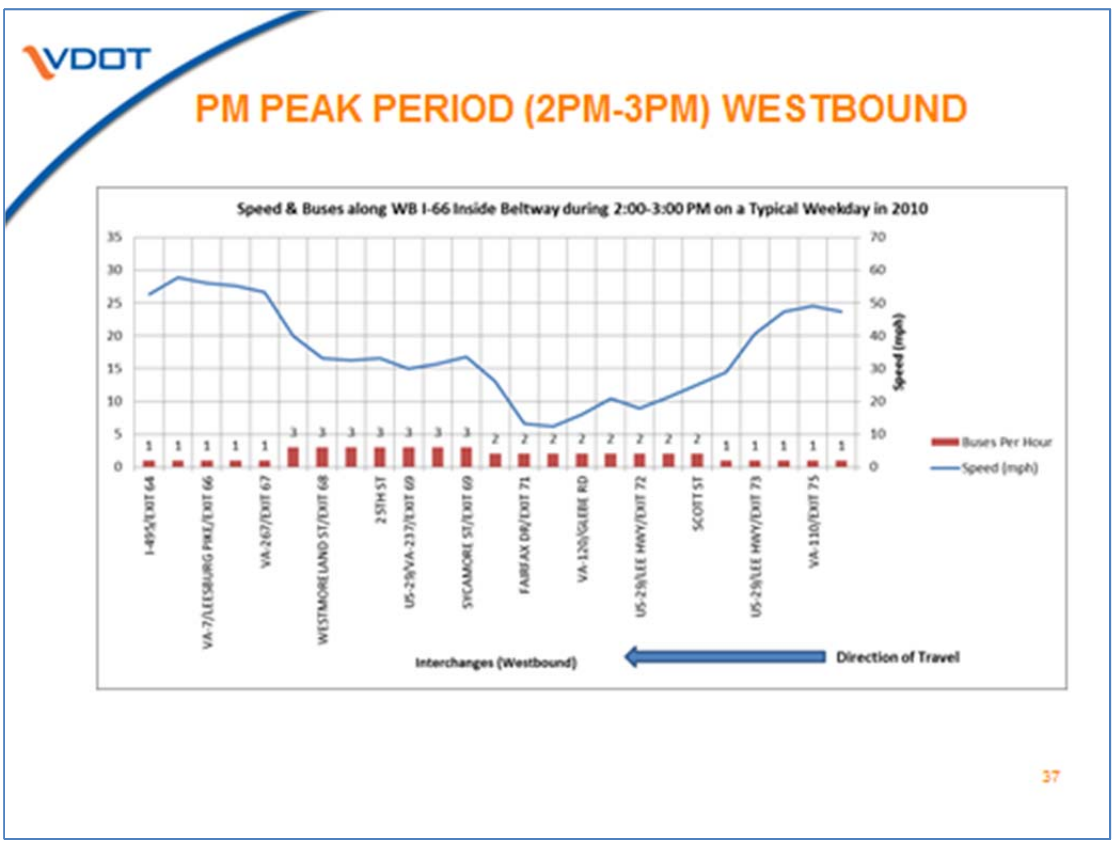
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
36


VDOT
PM PEAK PERIOD (2PM-3PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 2:00-3:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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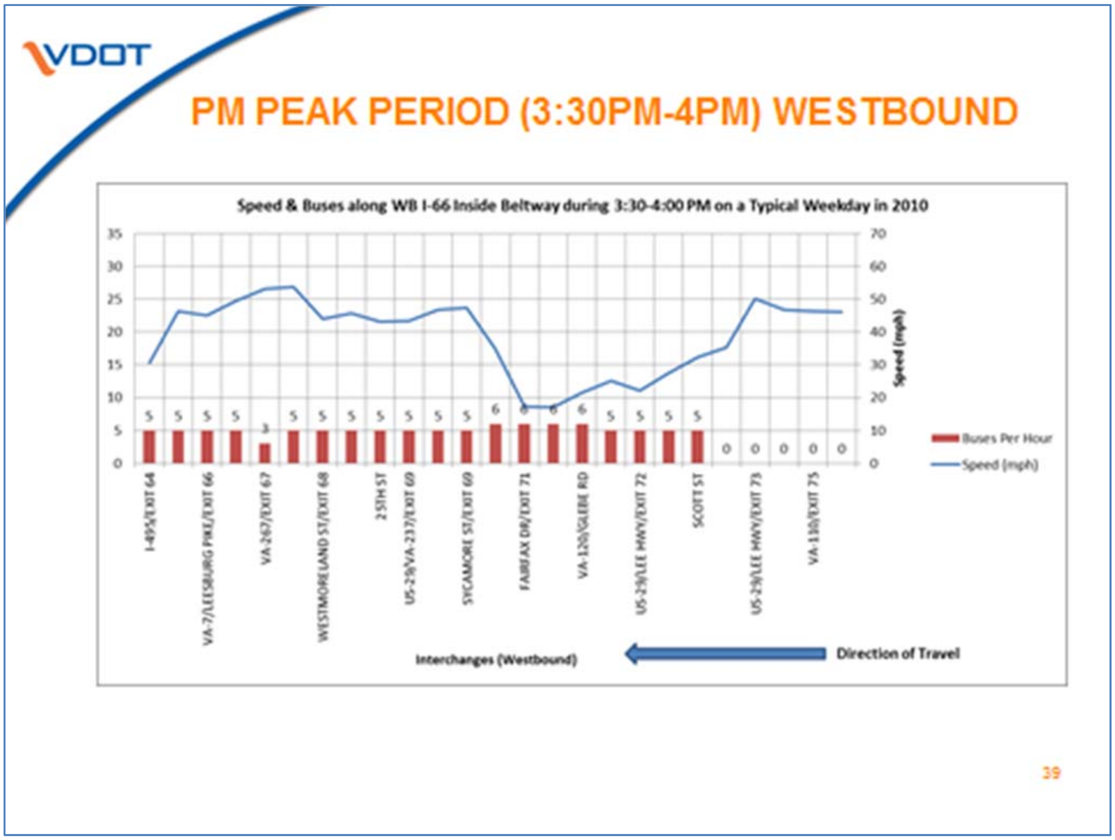
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
37


VDOT
PM PEAK PERIOD (3:30PM-4PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 3:30-4:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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SCOTT ST
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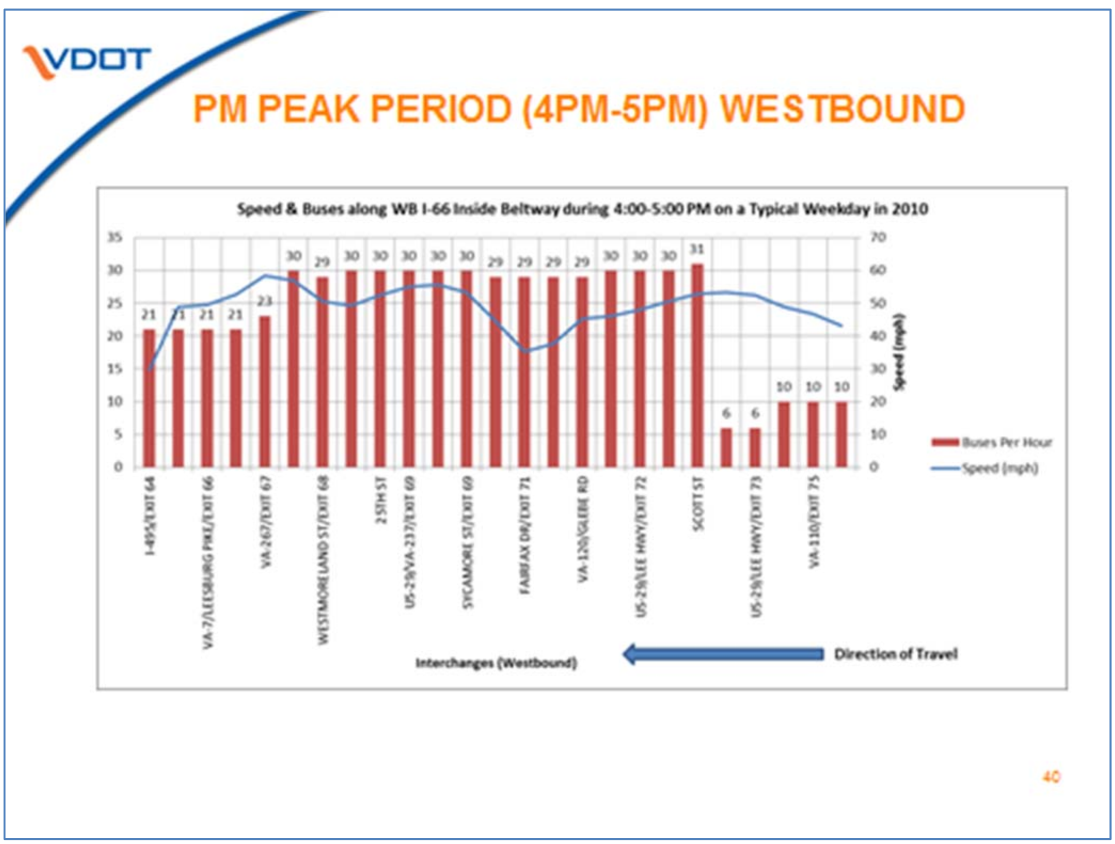
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
39


VDOT
PM PEAK PERIOD (4PM-5PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 4:00-5:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
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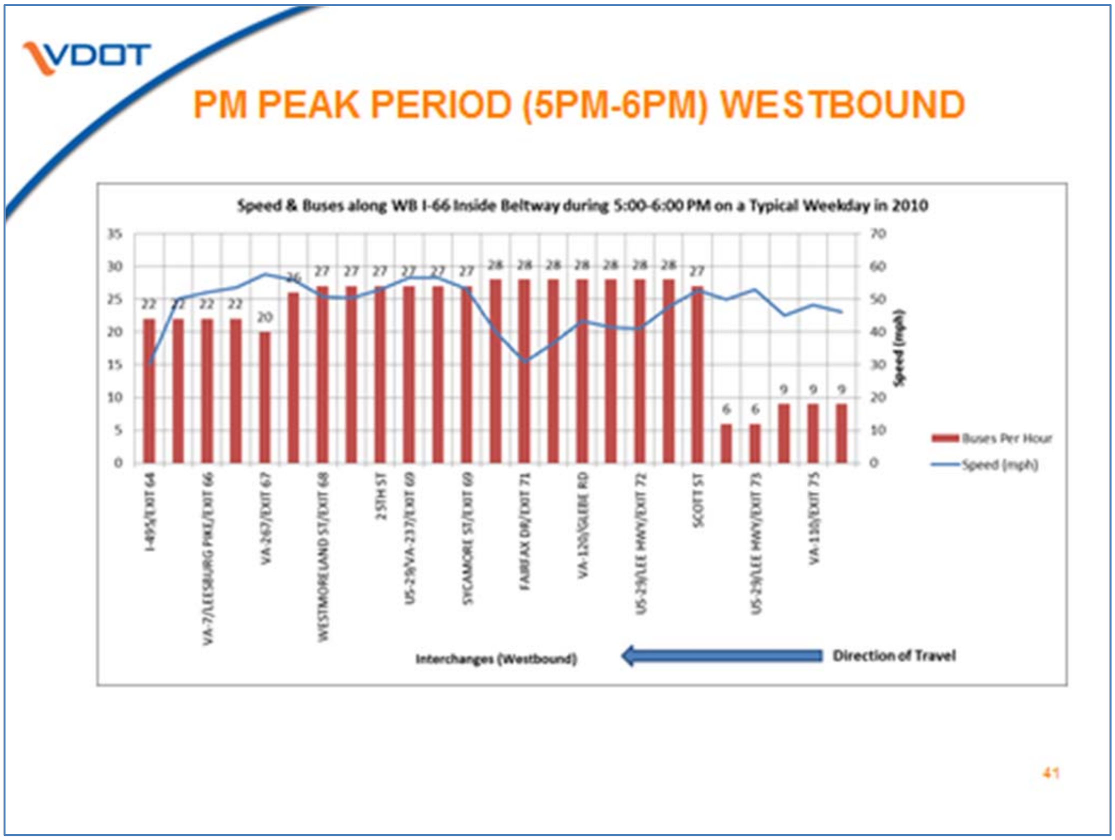
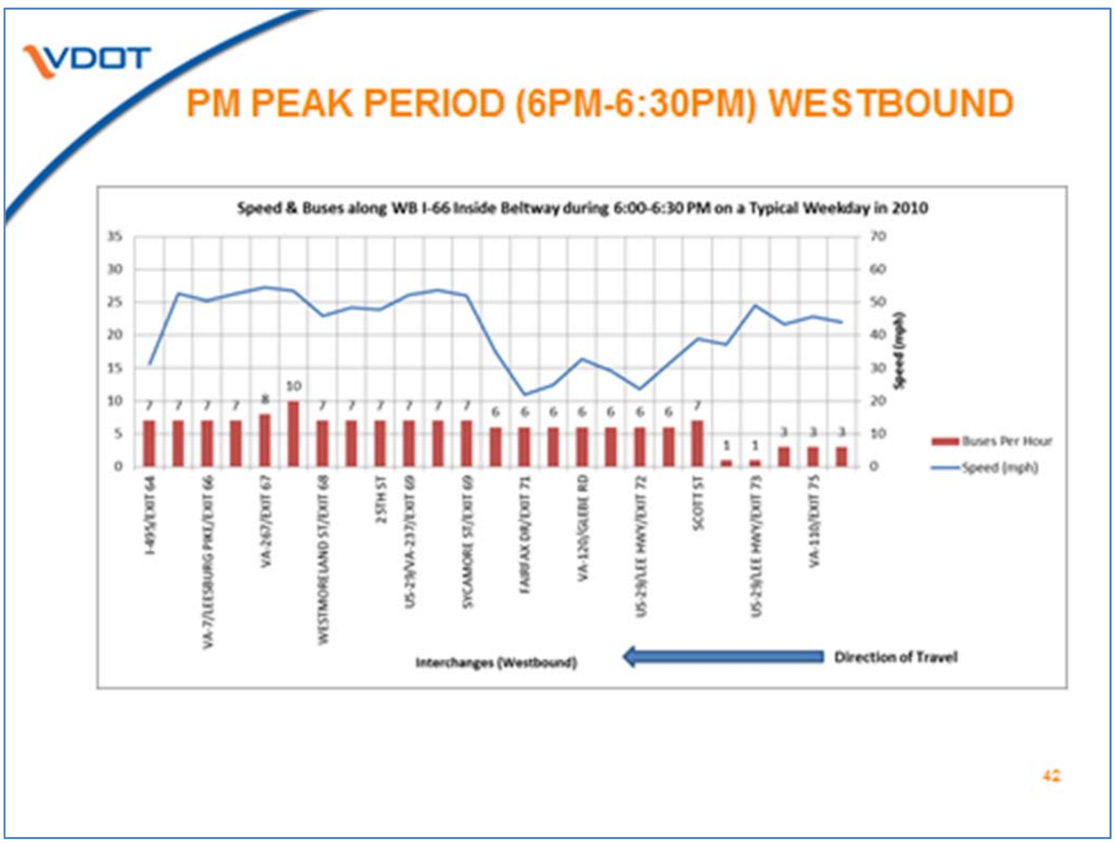
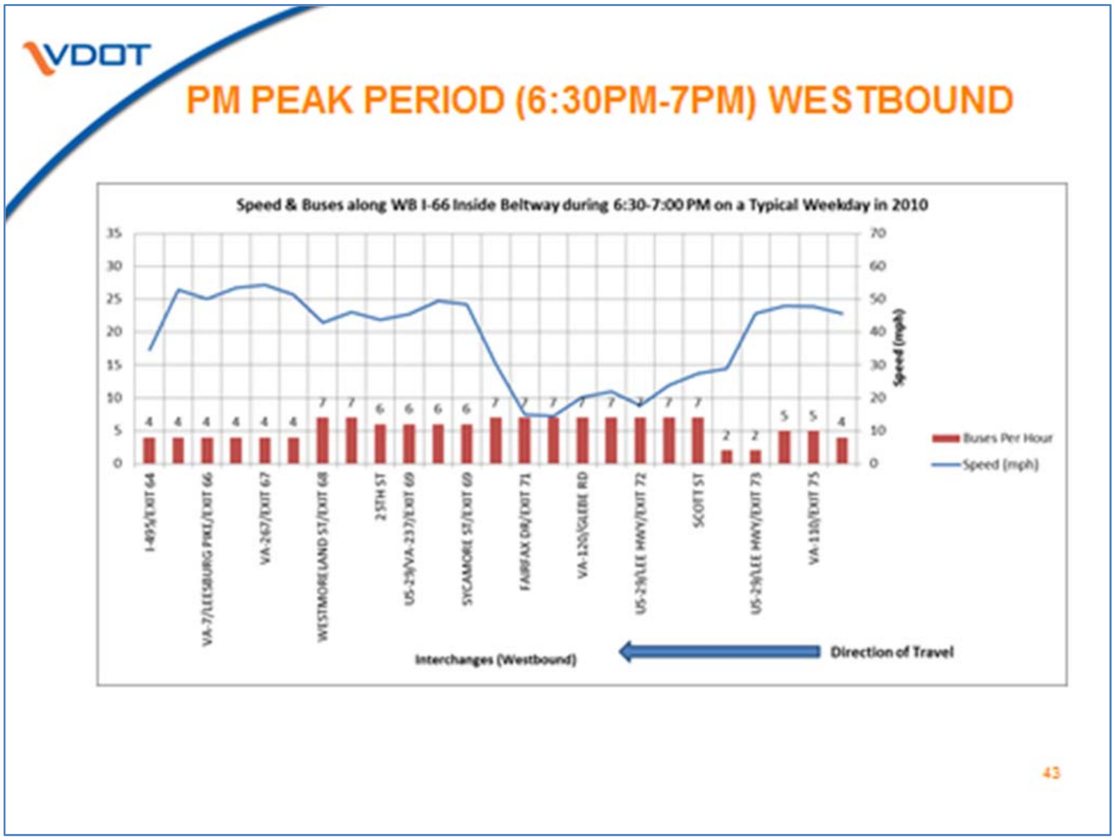
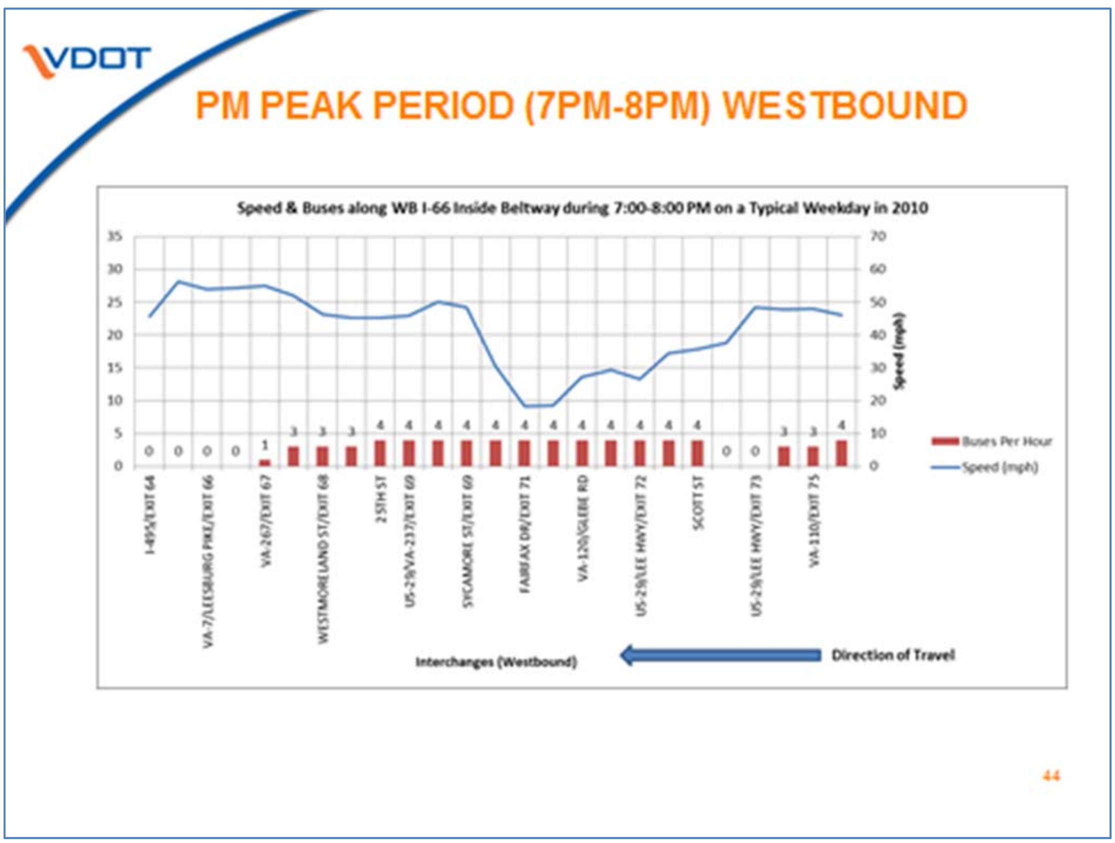
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
40

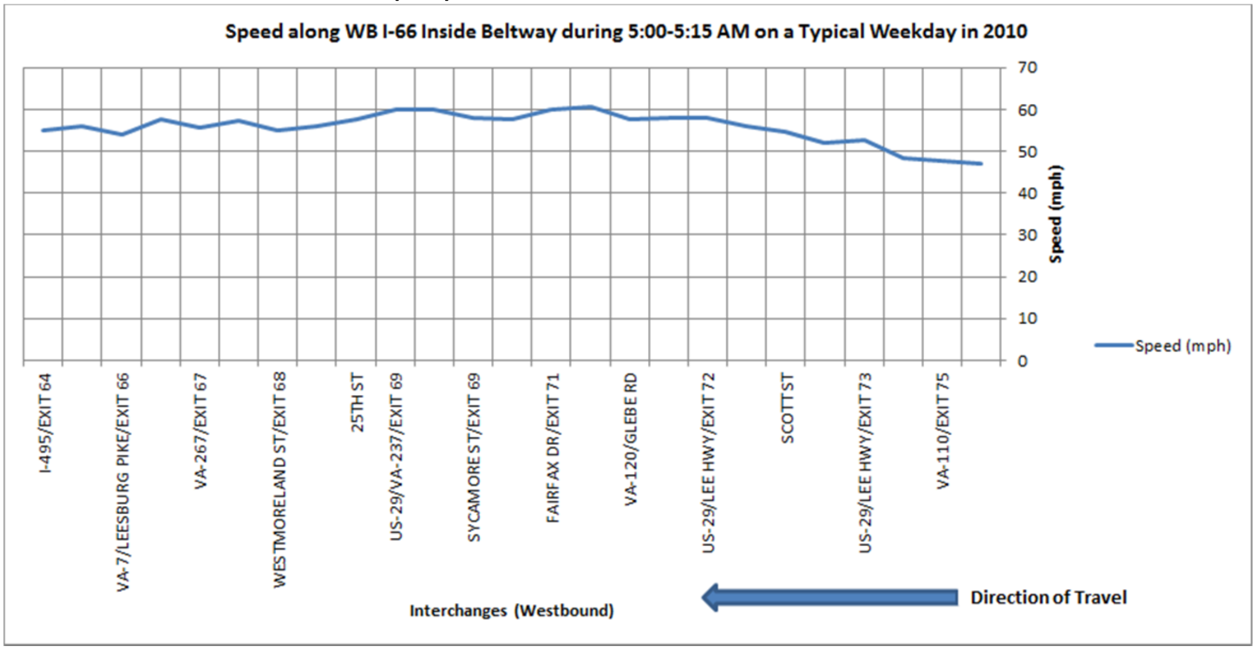

VDOT
PM PEAK PERIOD (5PM-6PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 5:00-6:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
41

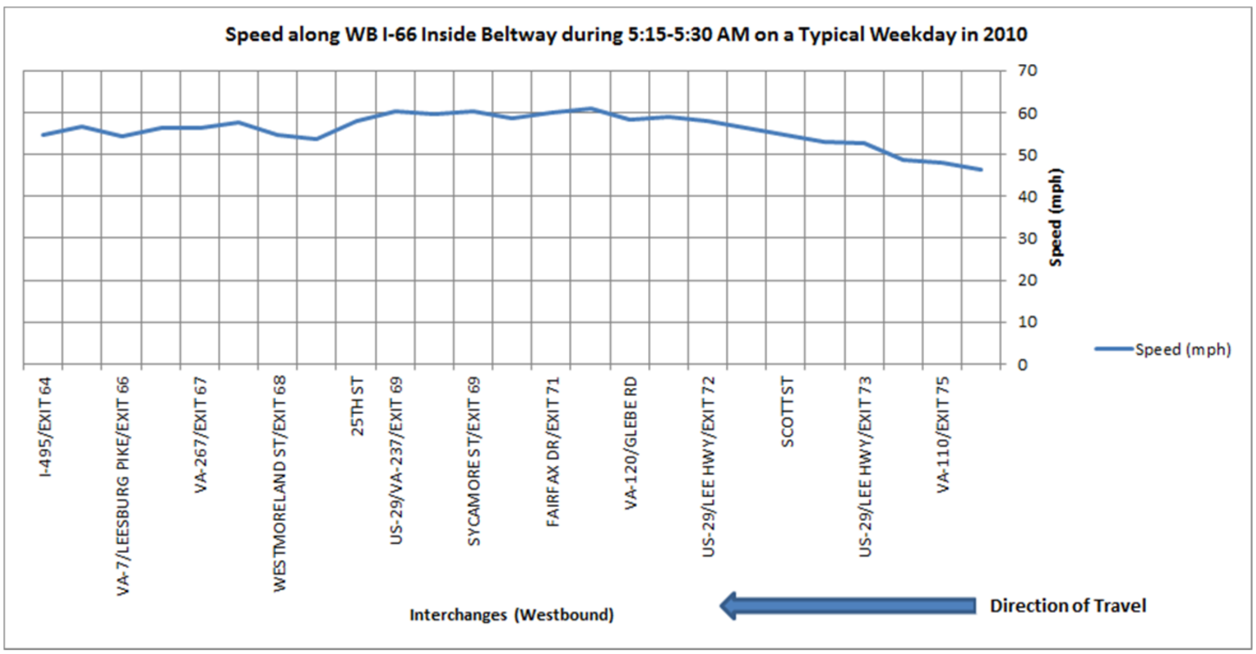

VDOT
PM PEAK PERIOD (6PM-6:30PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 6:00-6:30 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
42

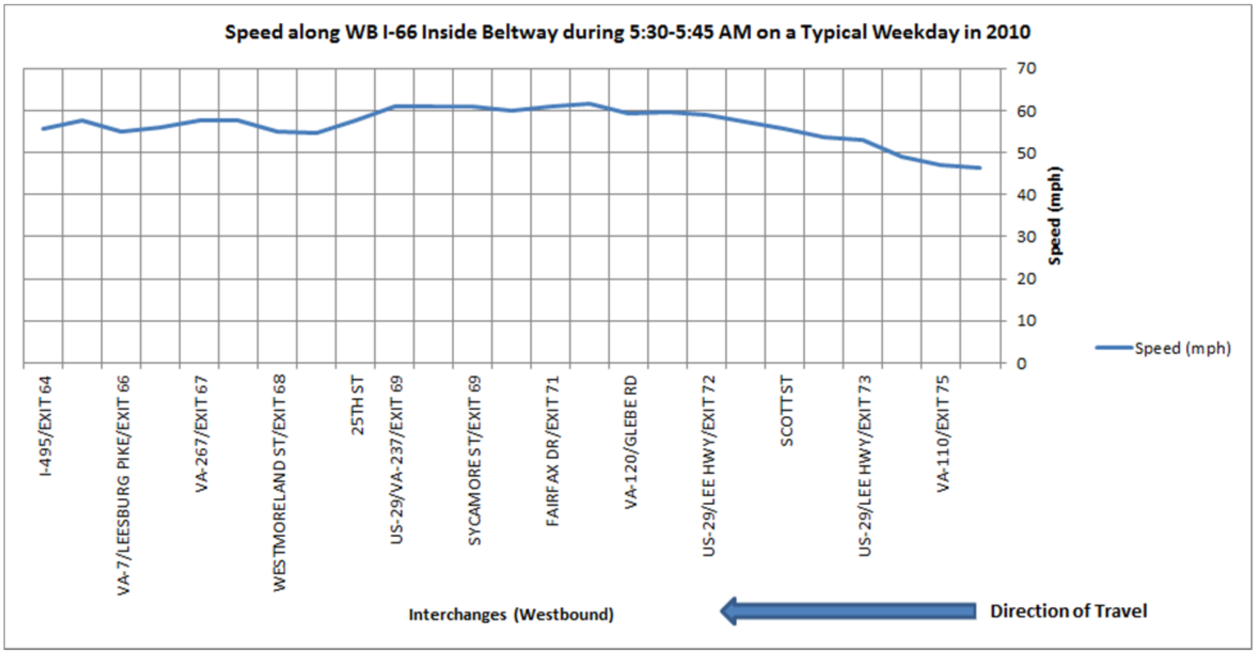

VDOT
PM PEAK PERIOD (6:30PM-7PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 6:30-7:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
43

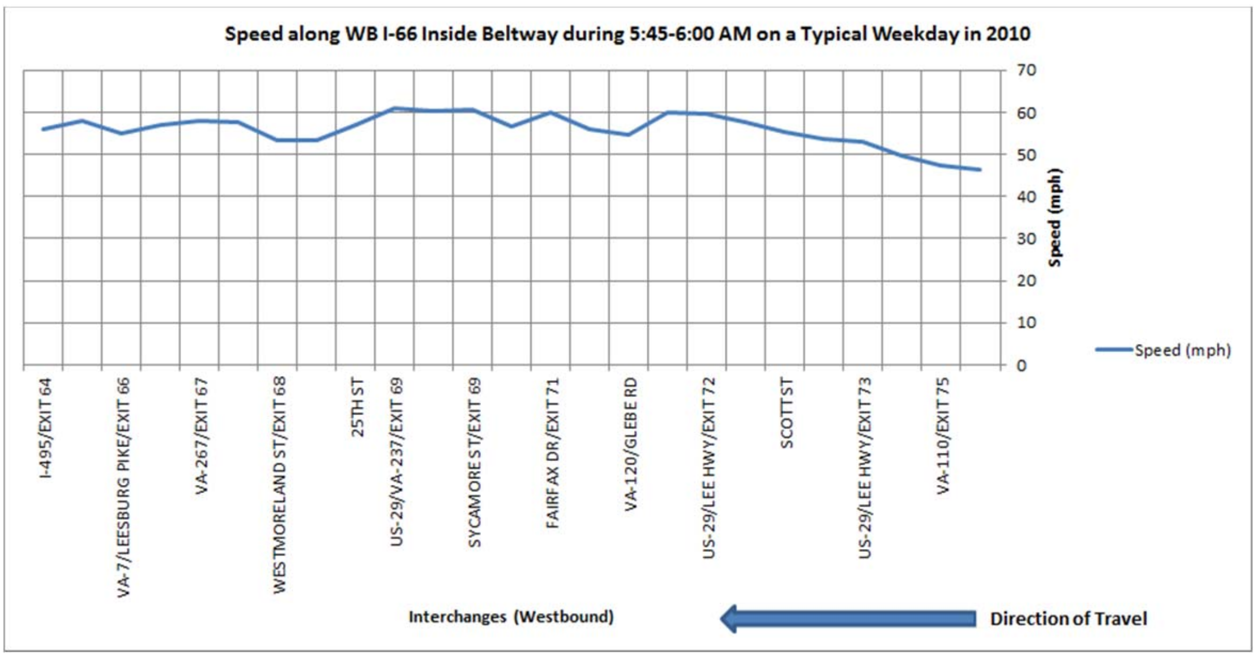

VDOT
PM PEAK PERIOD (7PM-8PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 7:00-8:00 PM on a Typical Weekday in 2010
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
44

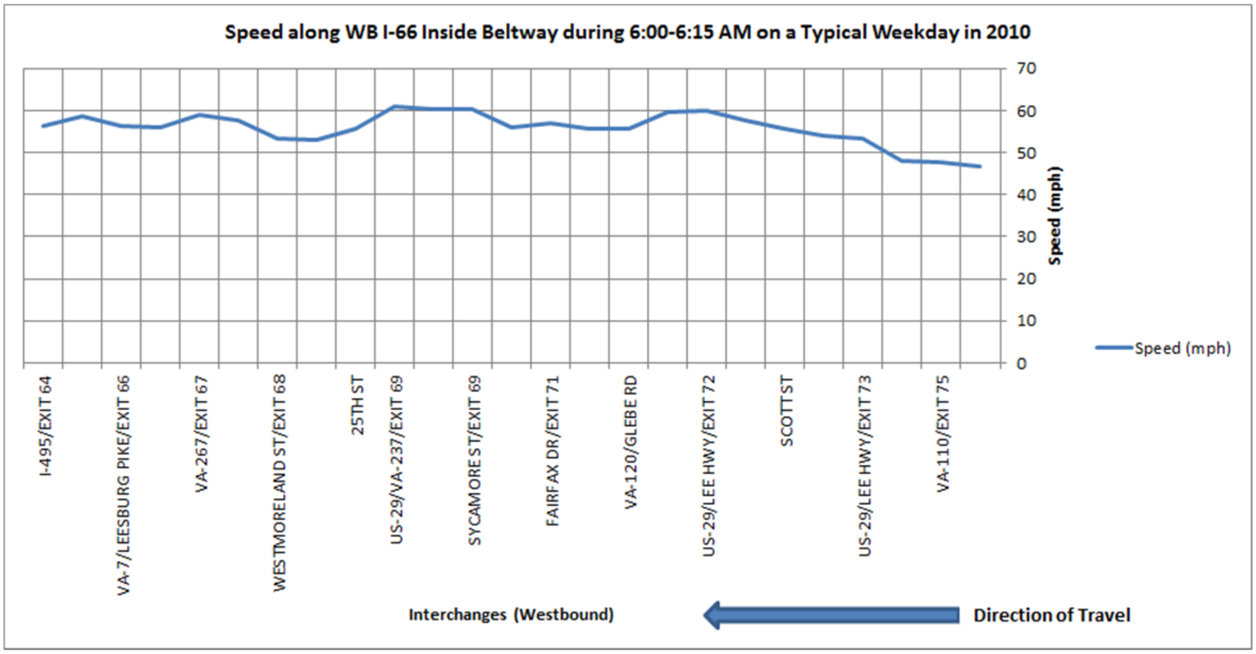
2010, Off-Peak Travel Direction (AM)

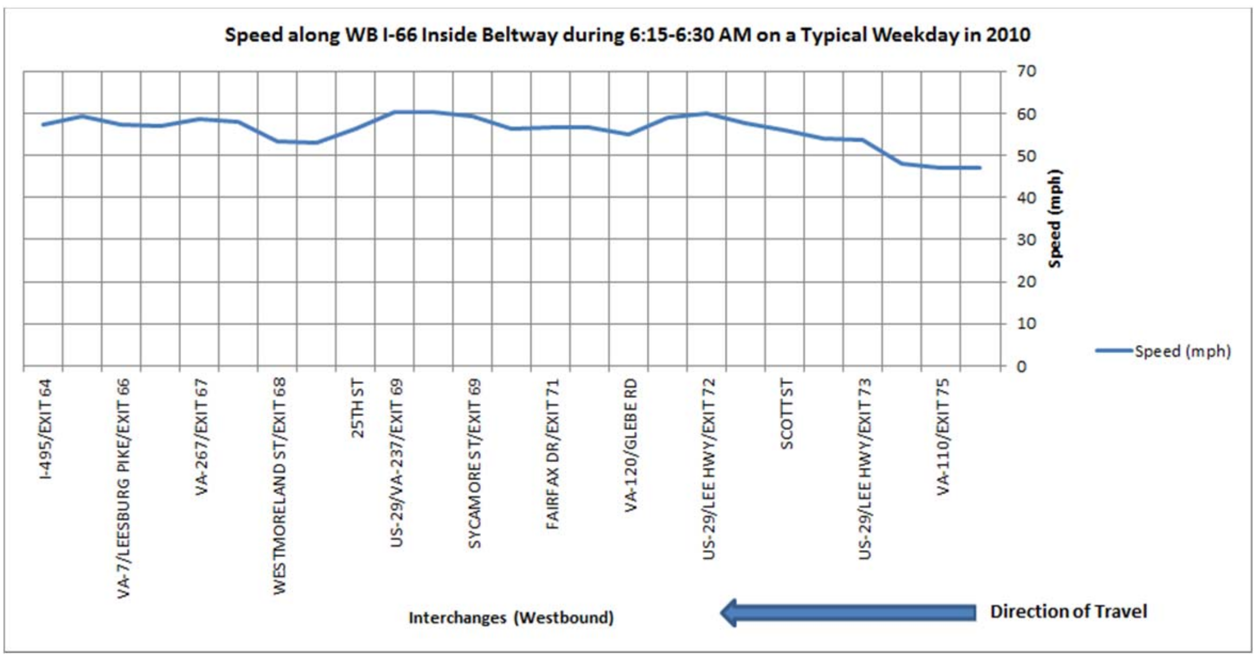


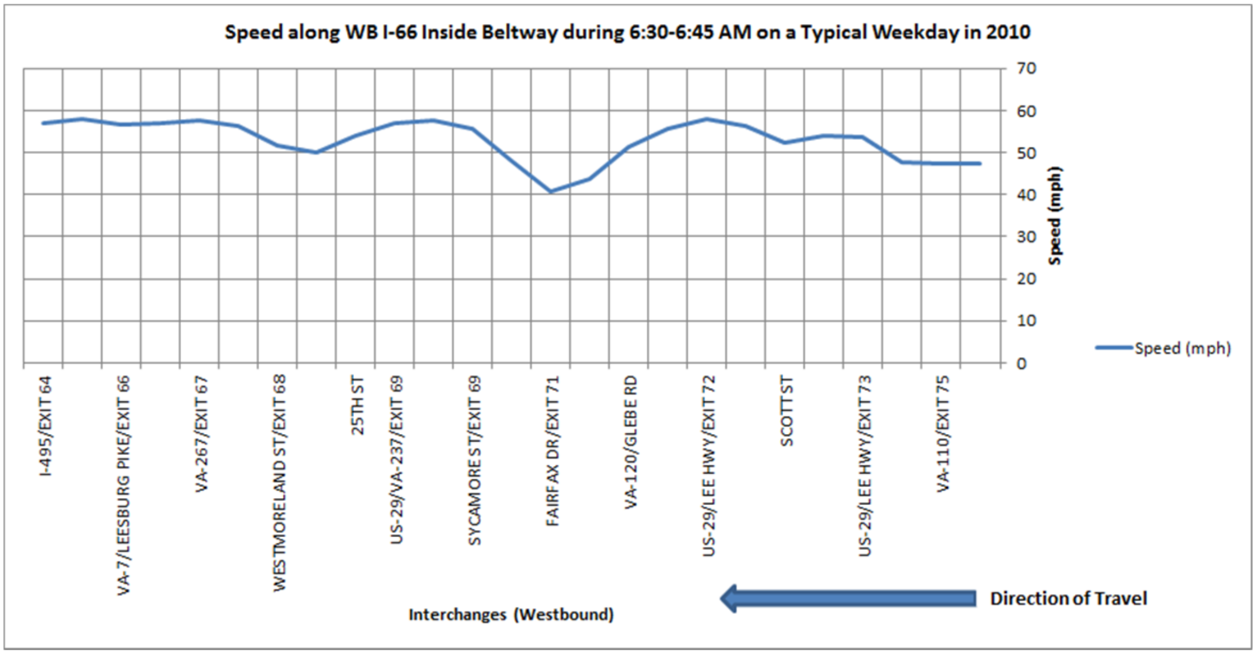


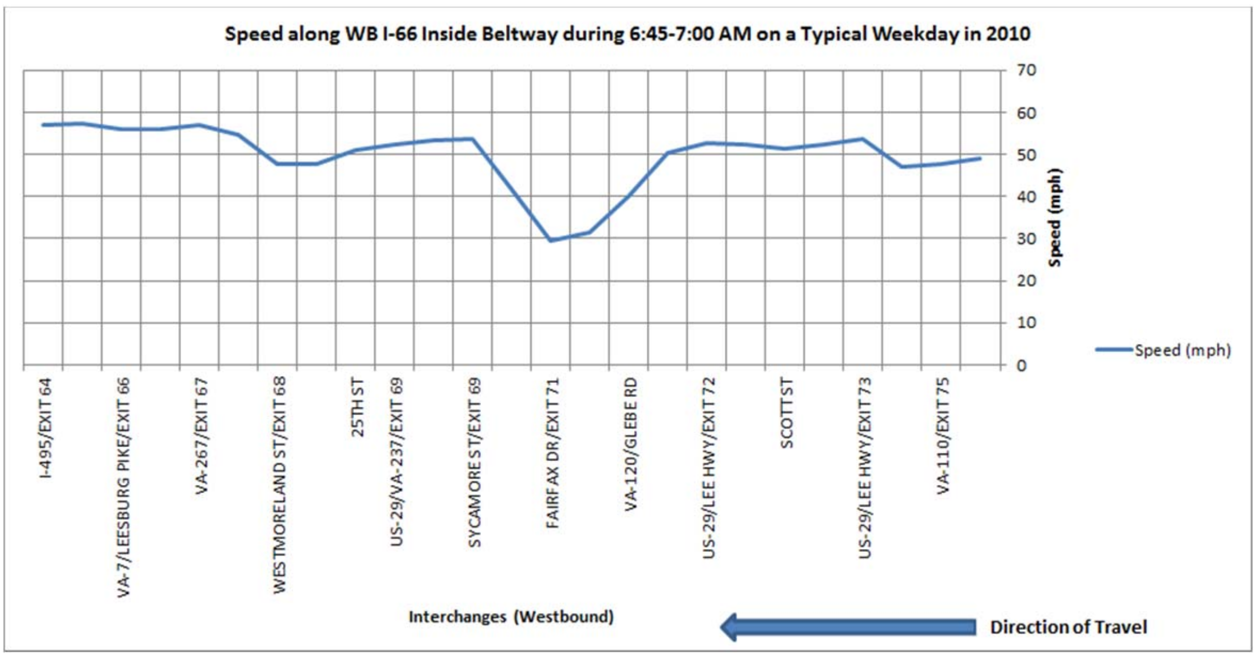

Speed along WB I-66 Inside Beltway during 5:30-5:45 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

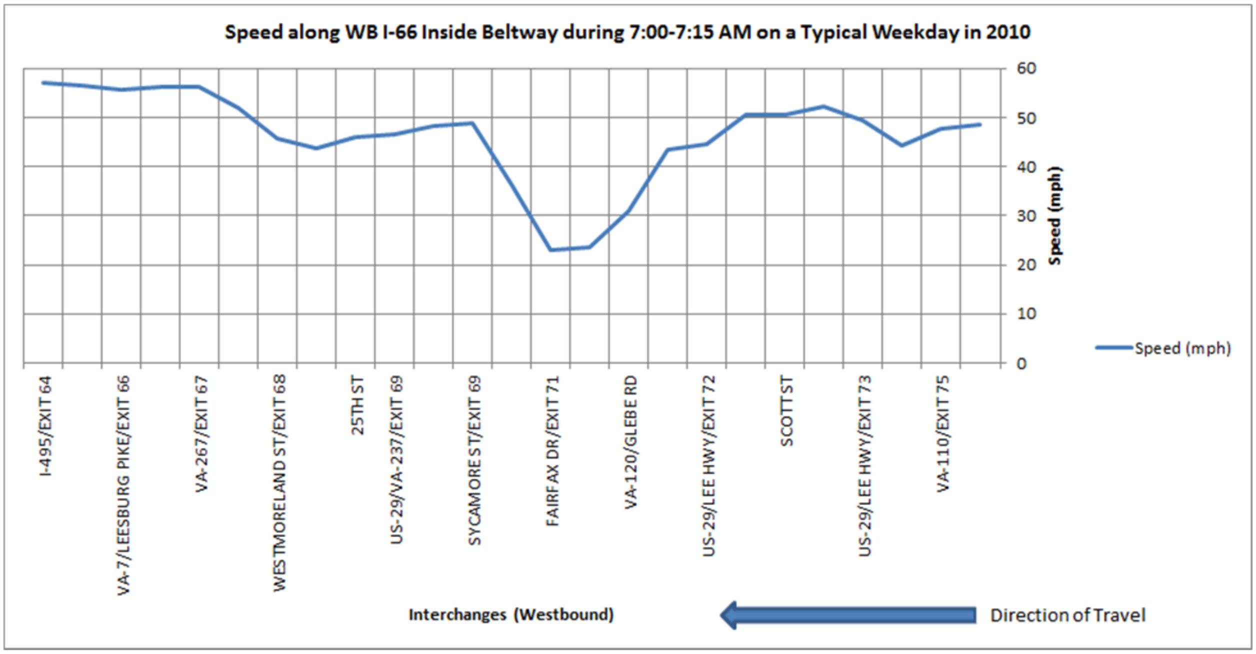

Speed along WB I-66 Inside Beltway during 5:45-6:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

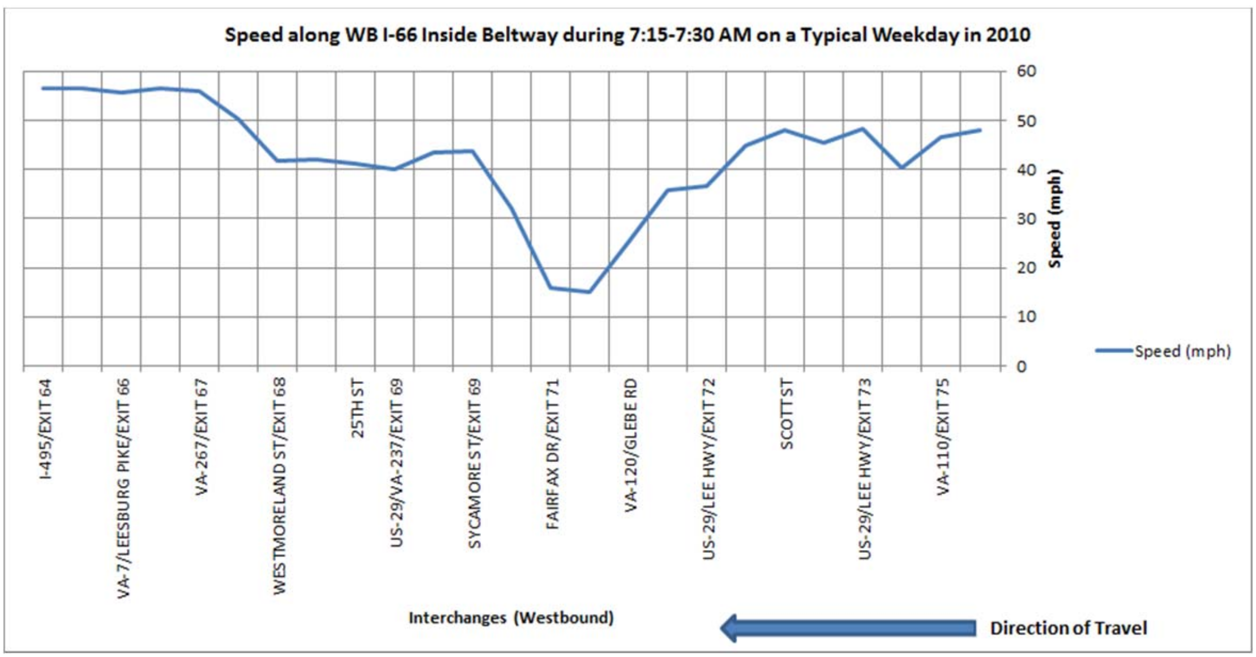

Speed along WB I-66 Inside Beltway during 6:00-6:15 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

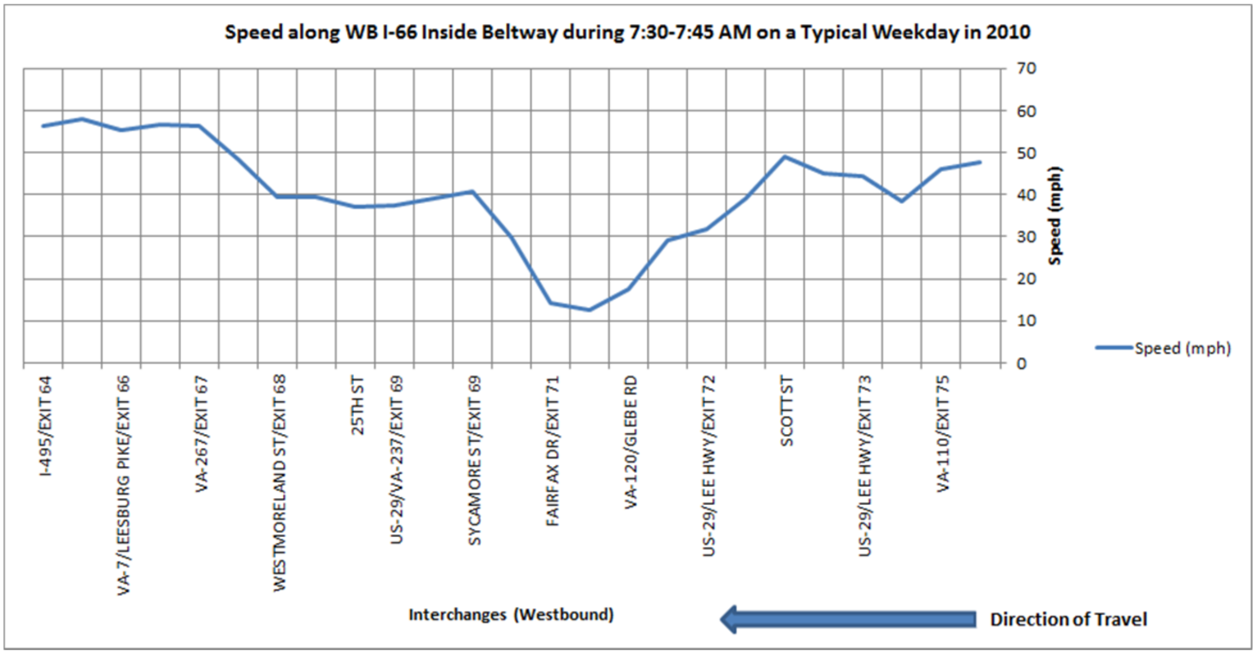

Speed along WB I-66 Inside Beltway during 6:15-6:30 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

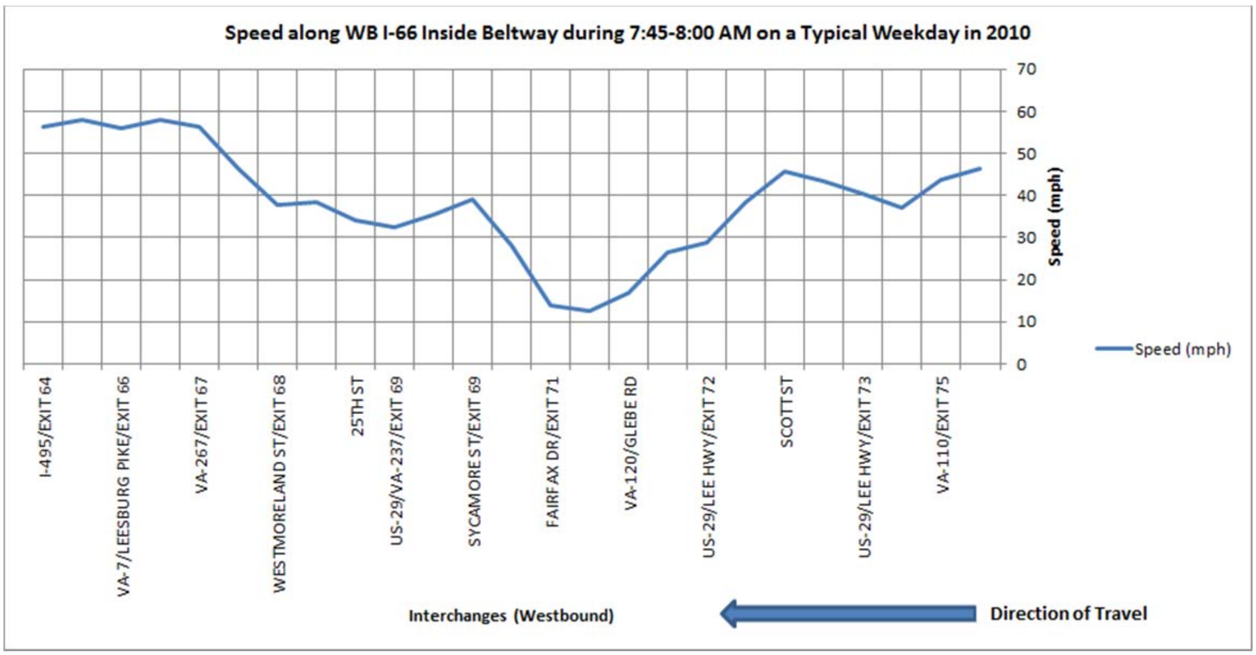

Speed along WB I-66 Inside Beltway during 6:30-6:45 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

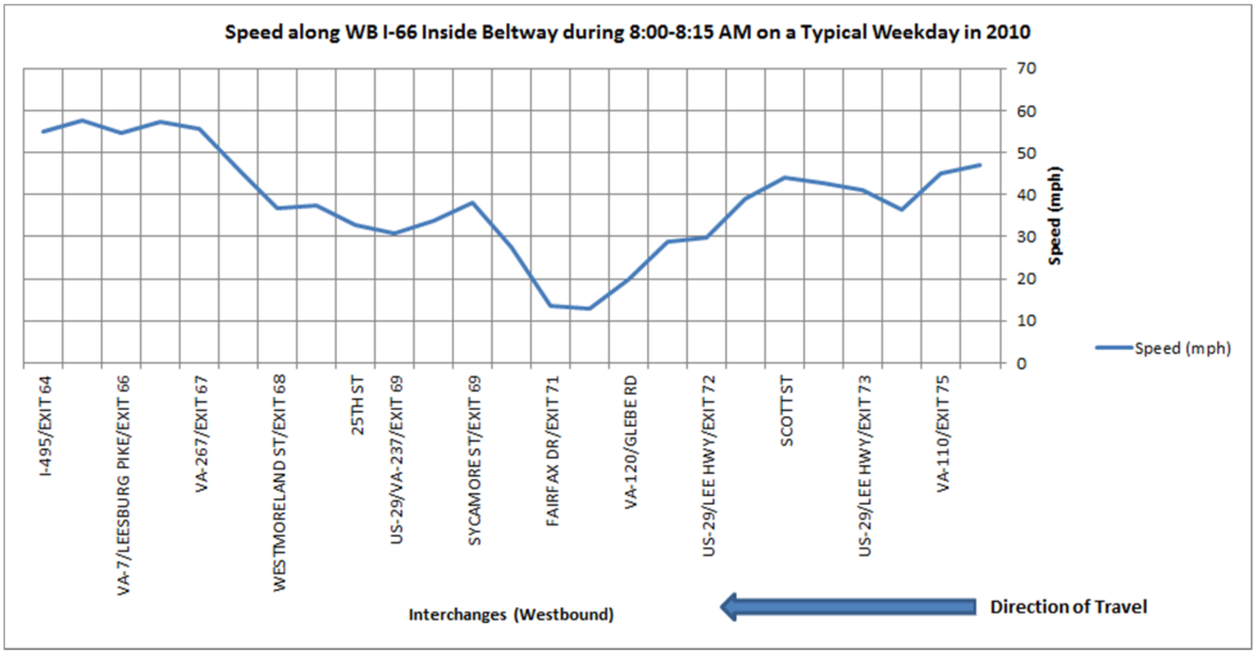

Speed along WB I-66 Inside Beltway during 6:45-7:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

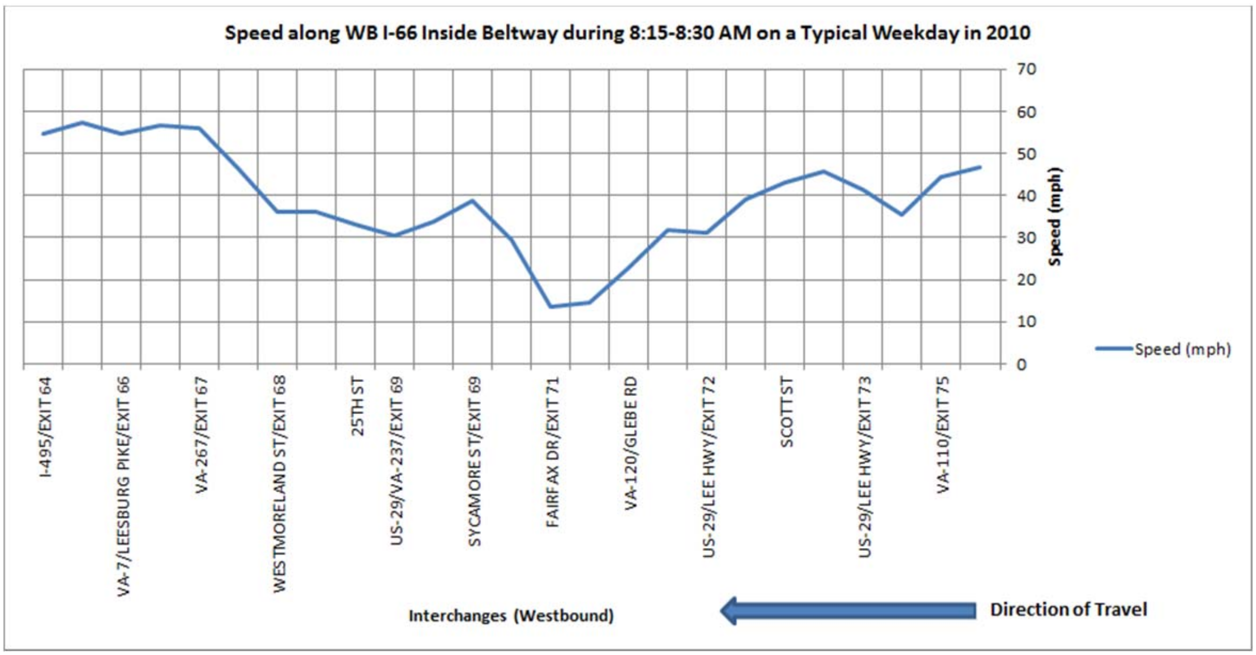

Speed along WB I-66 Inside Beltway during 7:00-7:15 AM on a Typical Weekday in 2010
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

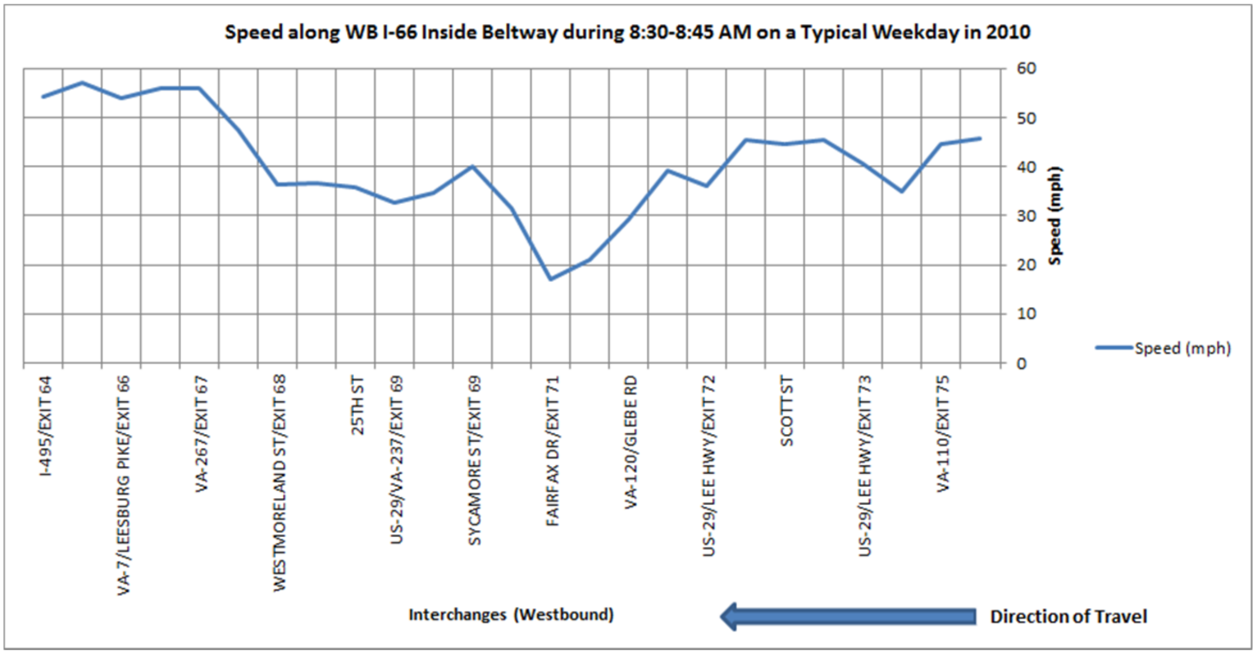

Speed along WB I-66 Inside Beltway during 7:15-7:30 AM on a Typical Weekday in 2010
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

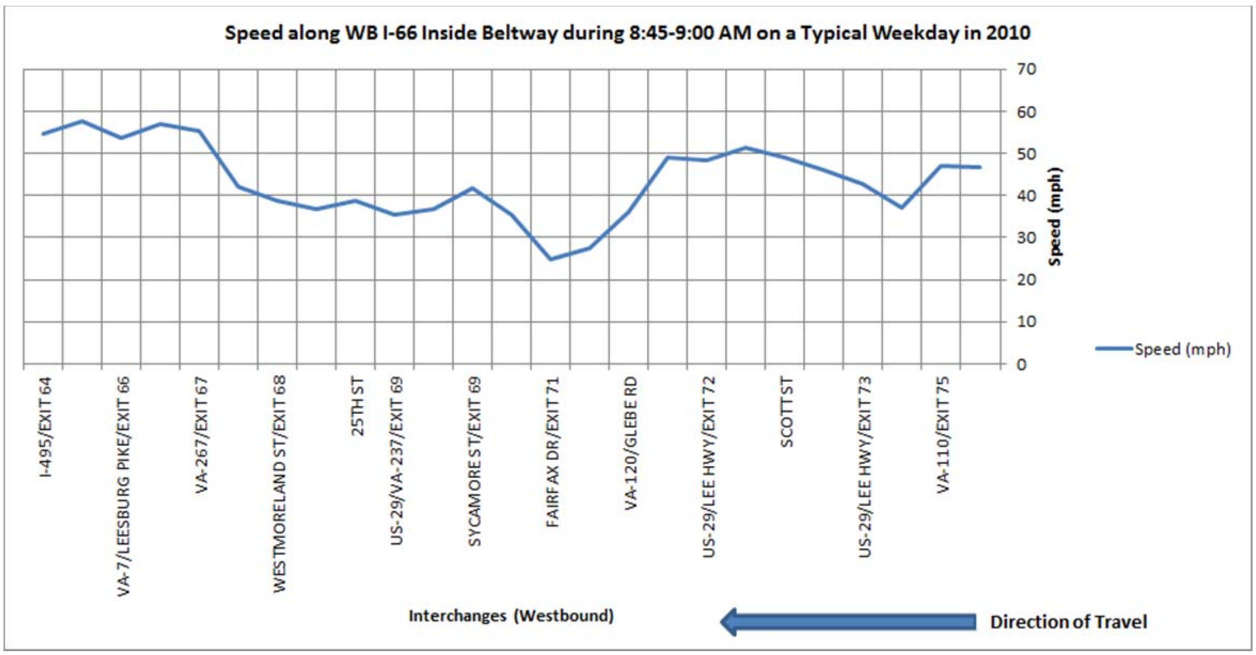

Speed along WB I-66 Inside Beltway during 7:30-7:45 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

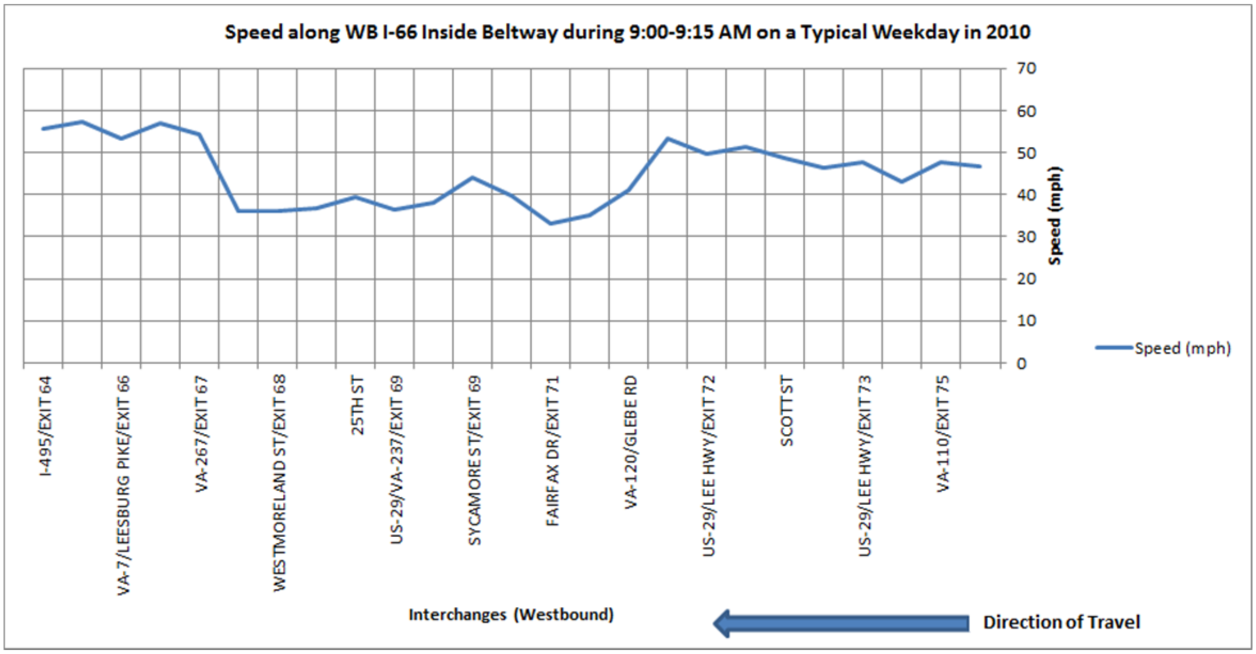

Speed along WB I-66 Inside Beltway during 7:45-8:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

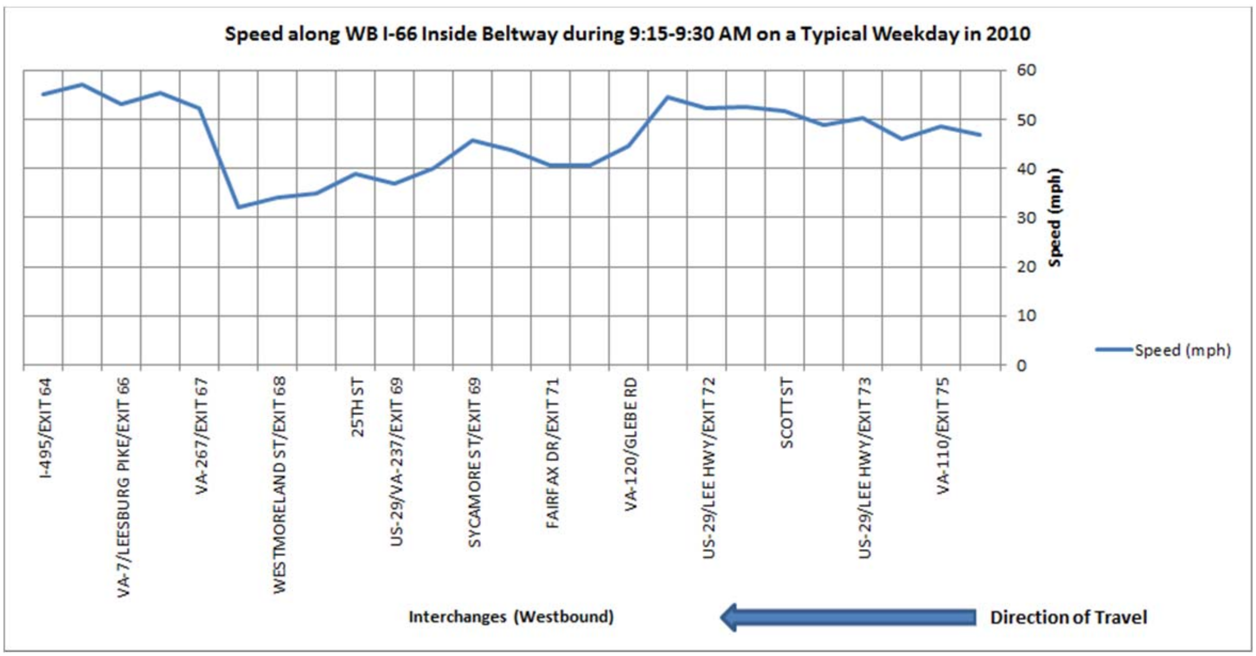

Speed along WB I-66 Inside Beltway during 8:00-8:15 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

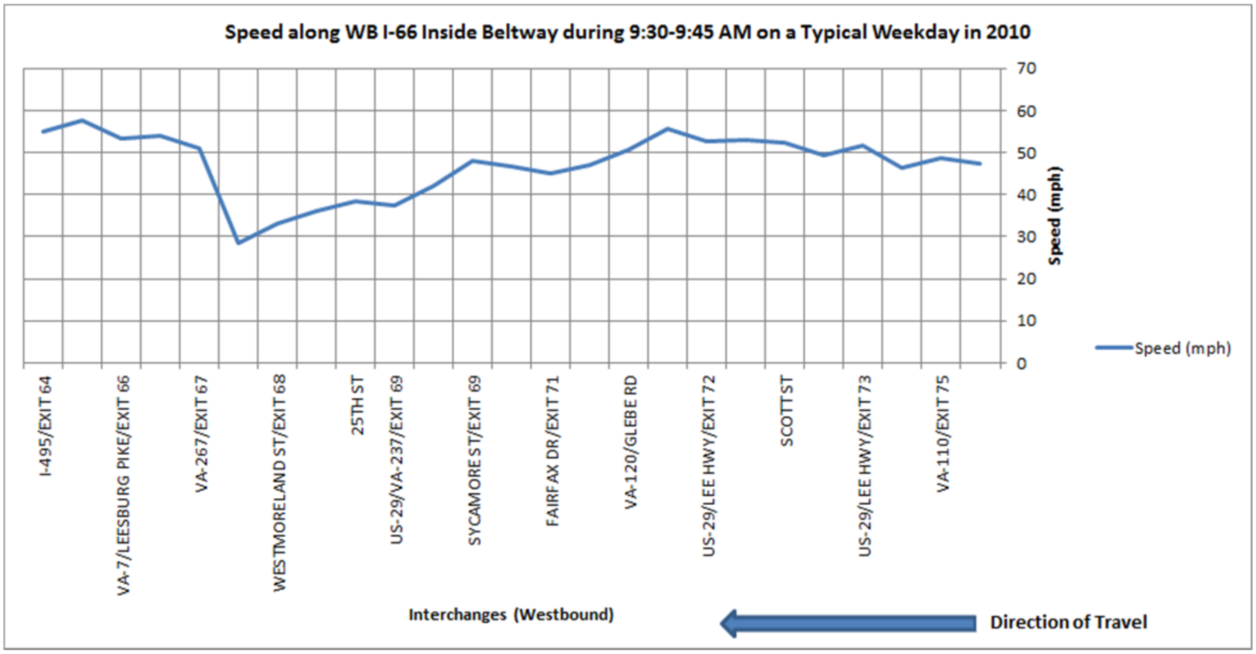

Speed along WB I-66 Inside Beltway during 8:15-8:30 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel


Speed along WB I-66 Inside Beltway during 8:30-8:45 AM on a Typical Weekday in 2010
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

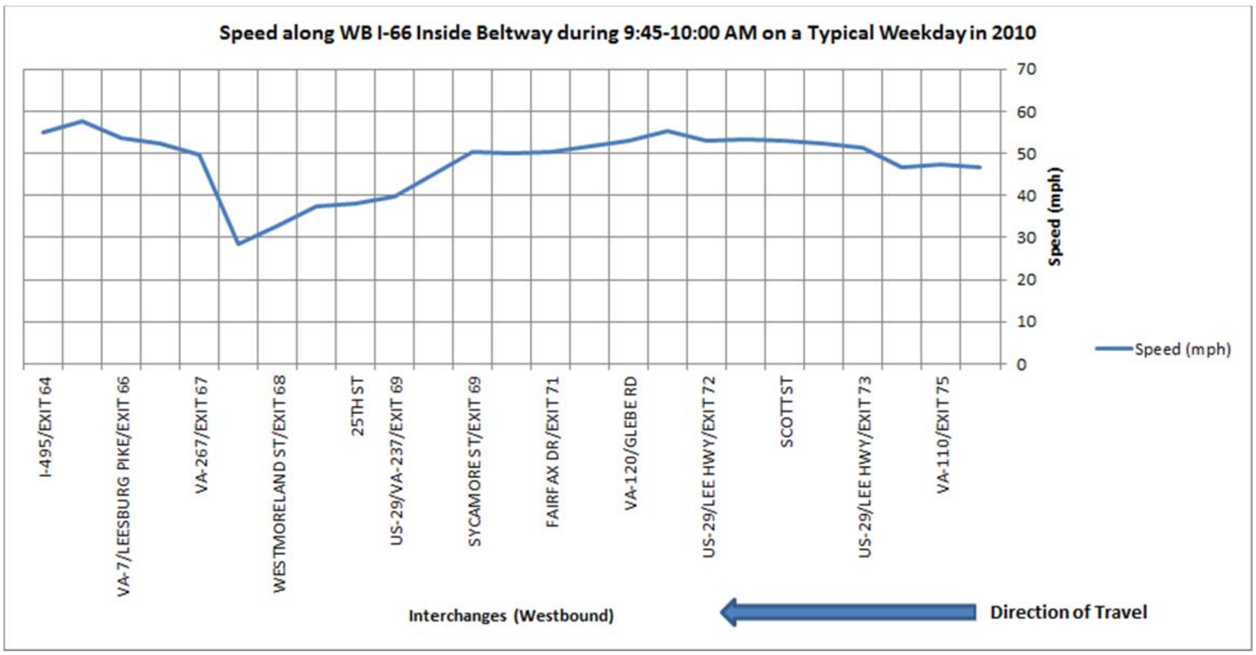

Speed along WB I-66 Inside Beltway during 8:45-9:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel


Speed along WB I-66 Inside Beltway during 9:00-9:15 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

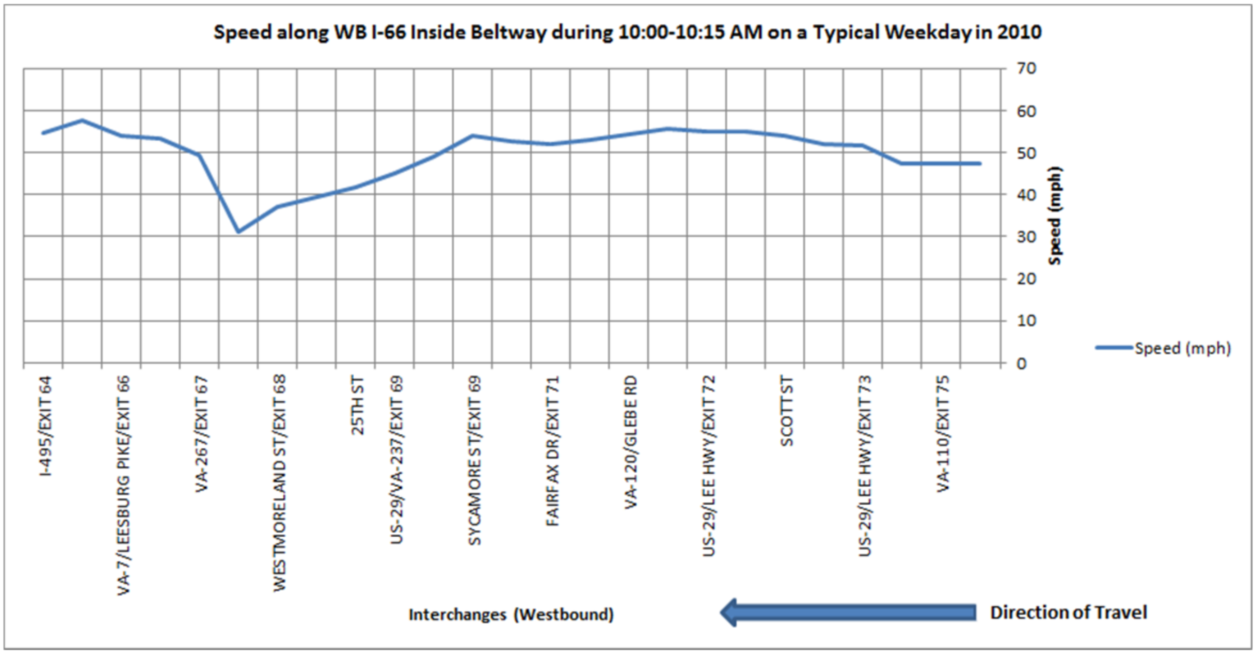

Speed along WB I-66 Inside Beltway during 9:15-9:30 AM on a Typical Weekday in 2010
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

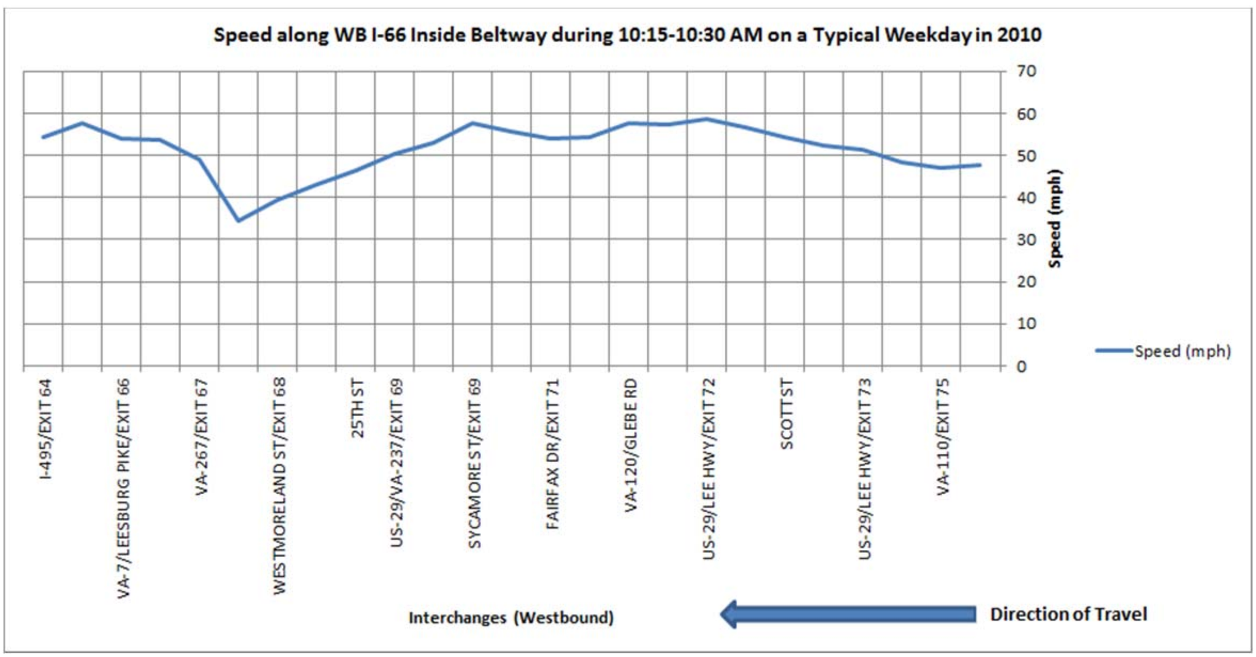


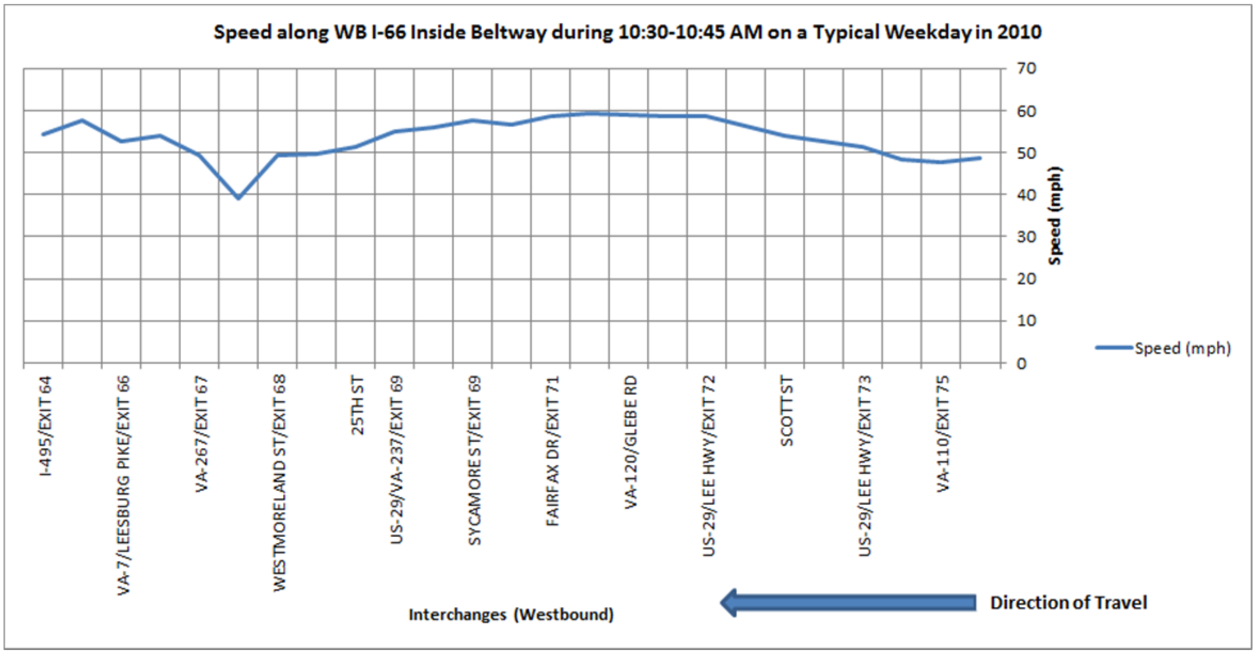
Speed along WB I-66 Inside Beltway during 9:30-9:45 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

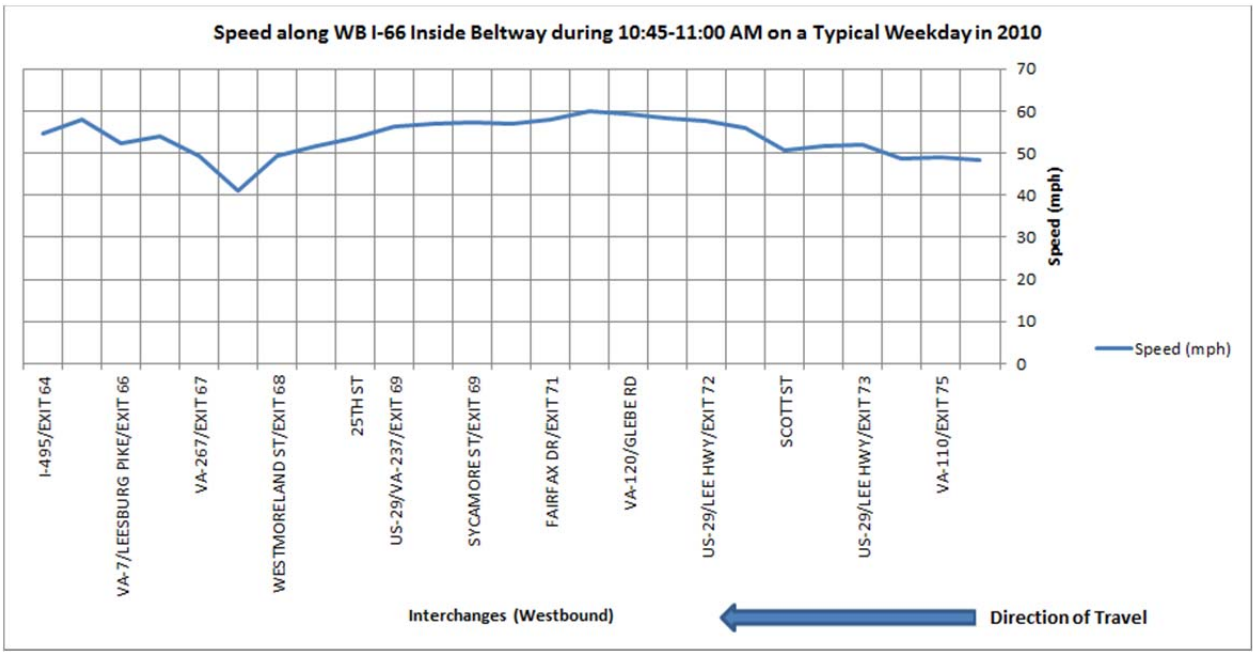


Speed along WB I-66 Inside Beltway during 9:45-10:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

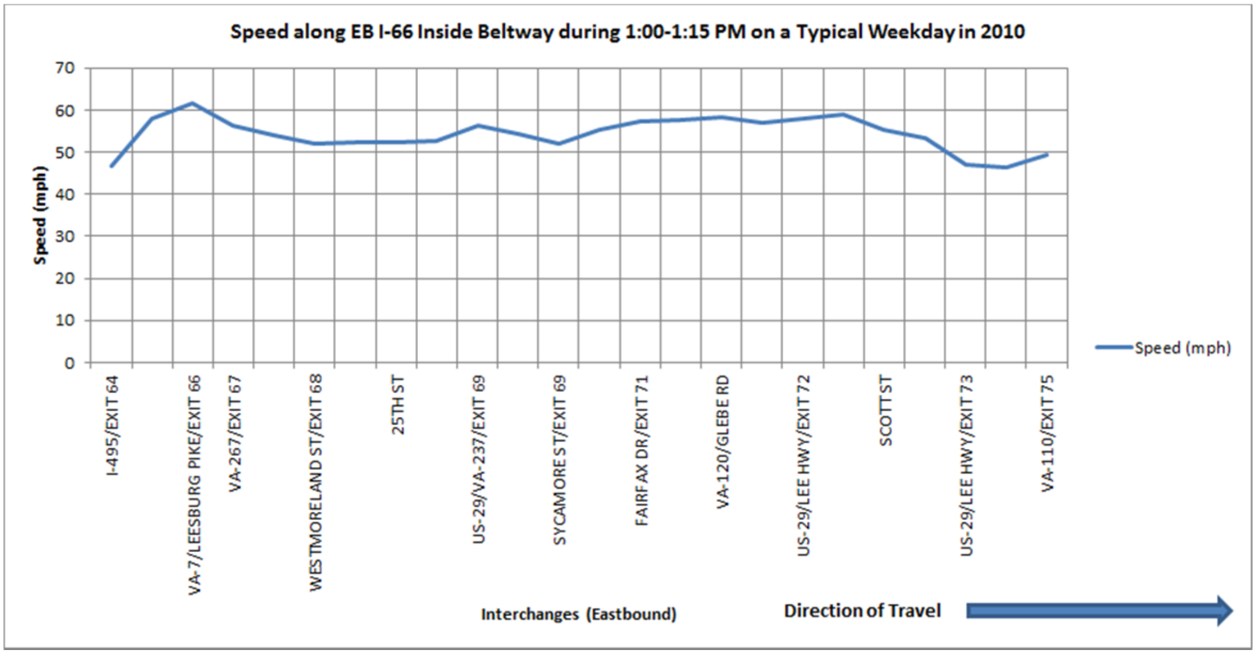

Speed along WB I-66 Inside Beltway during 10:00-10:15 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

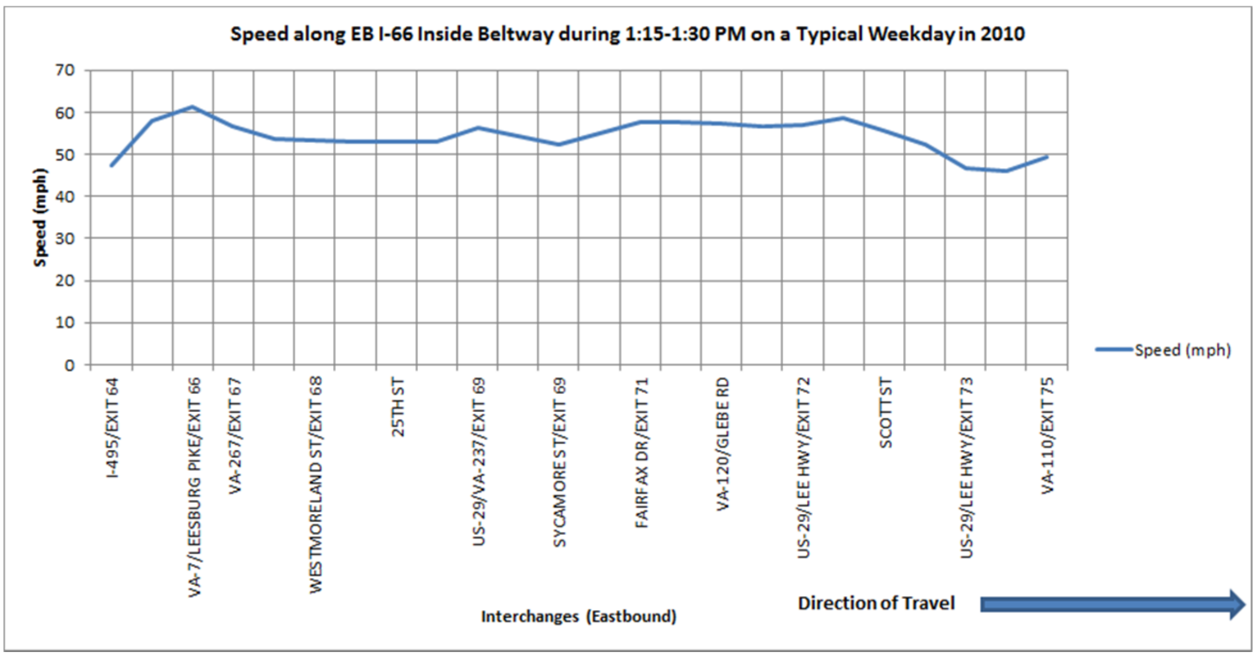

Speed along WB I-66 Inside Beltway during 10:15-10:30 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

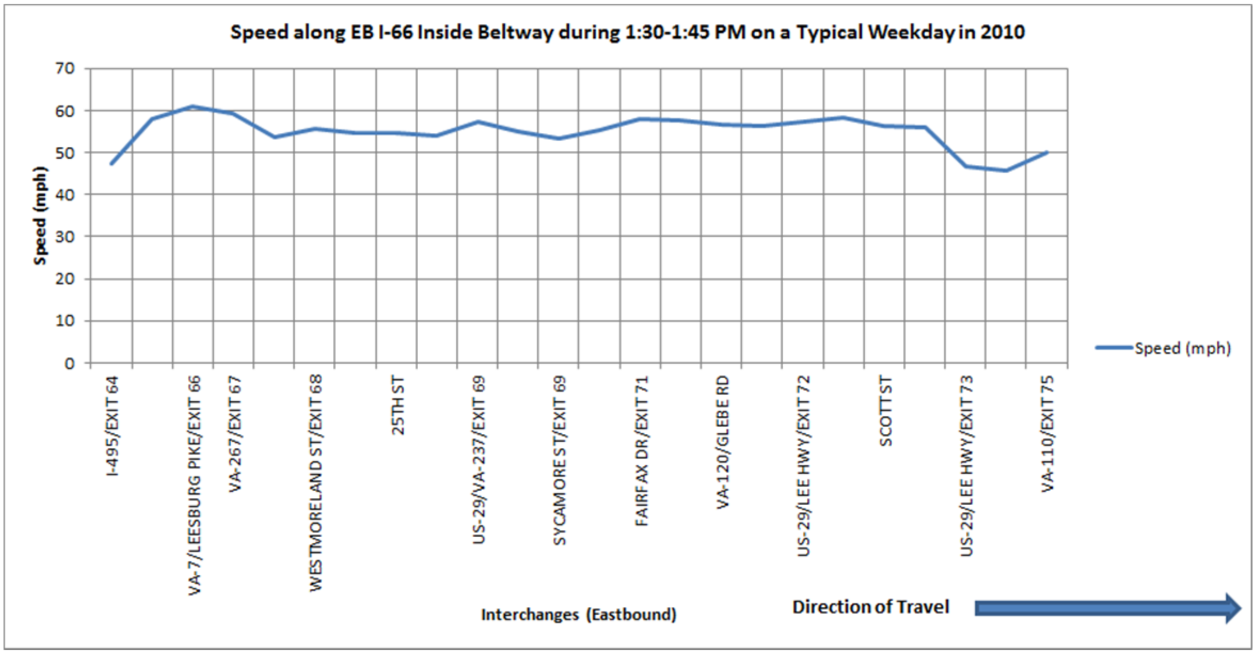

Speed along WB I-66 Inside Beltway during 10:30-10:45 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel


Speed along WB I-66 Inside Beltway during 10:45-11:00 AM on a Typical Weekday in 2010
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

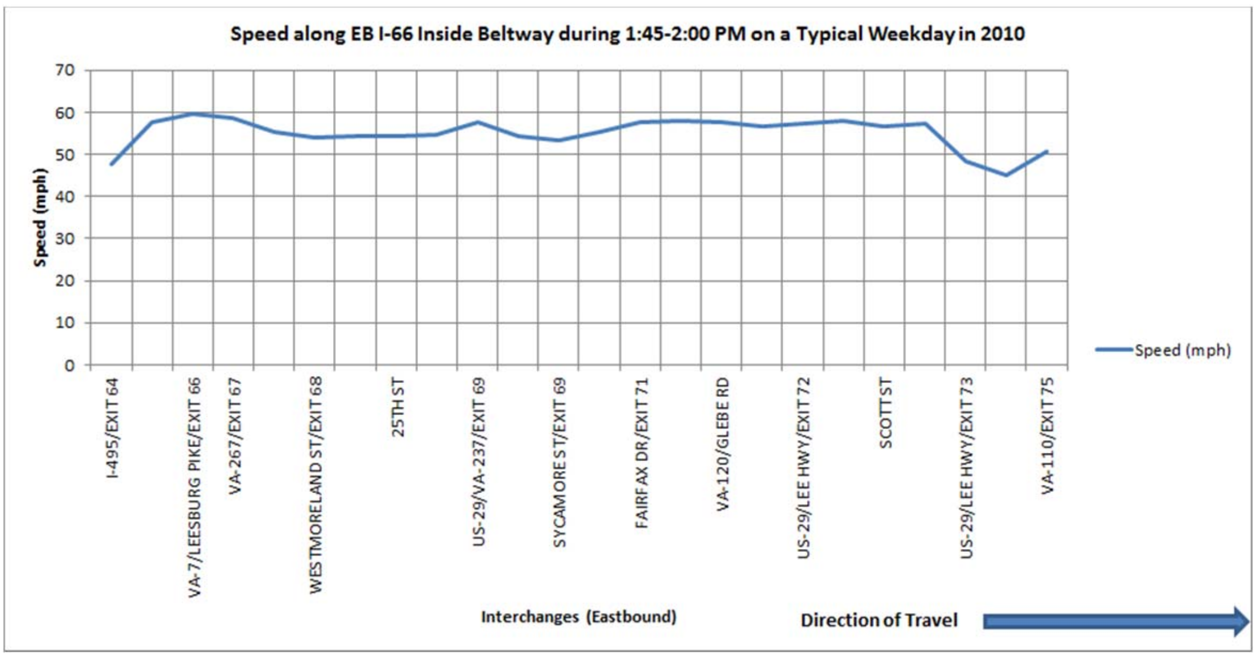
2010, Off-Peak Travel Direction (PM)



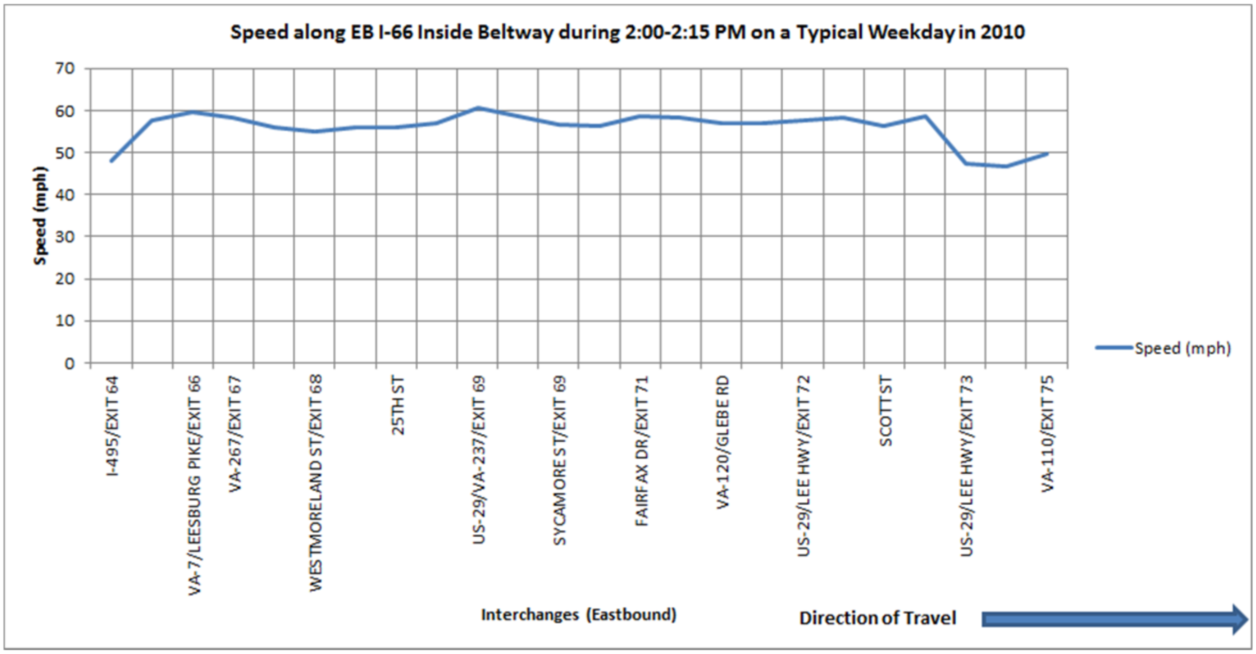


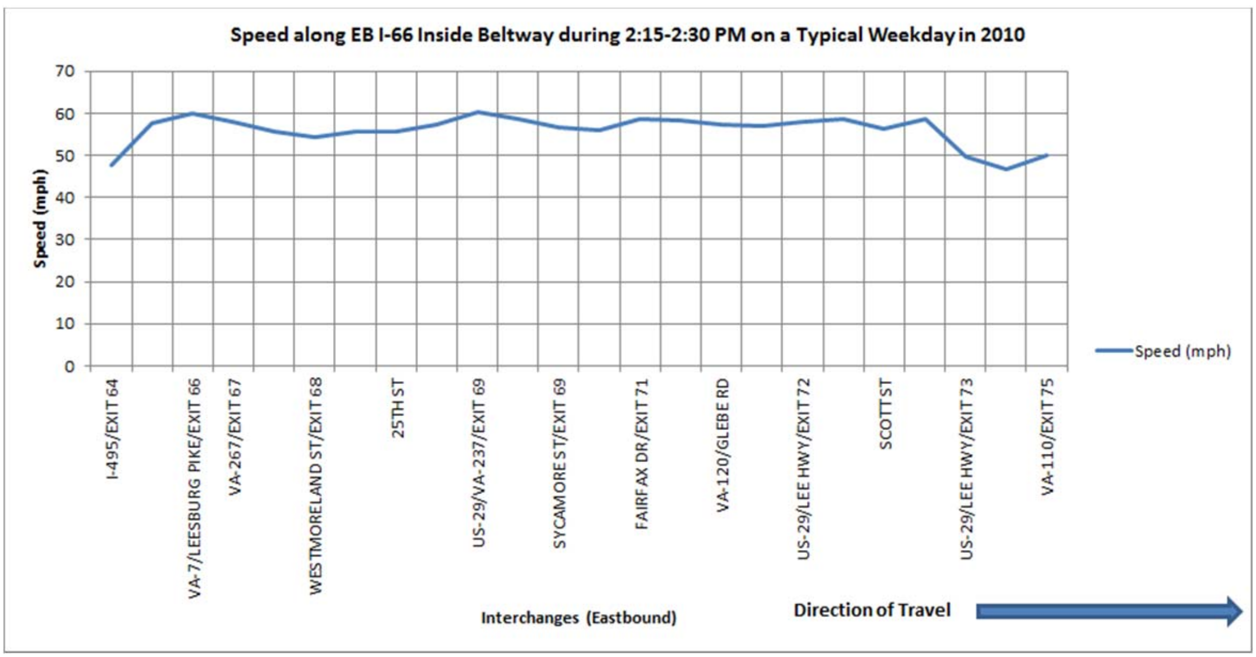


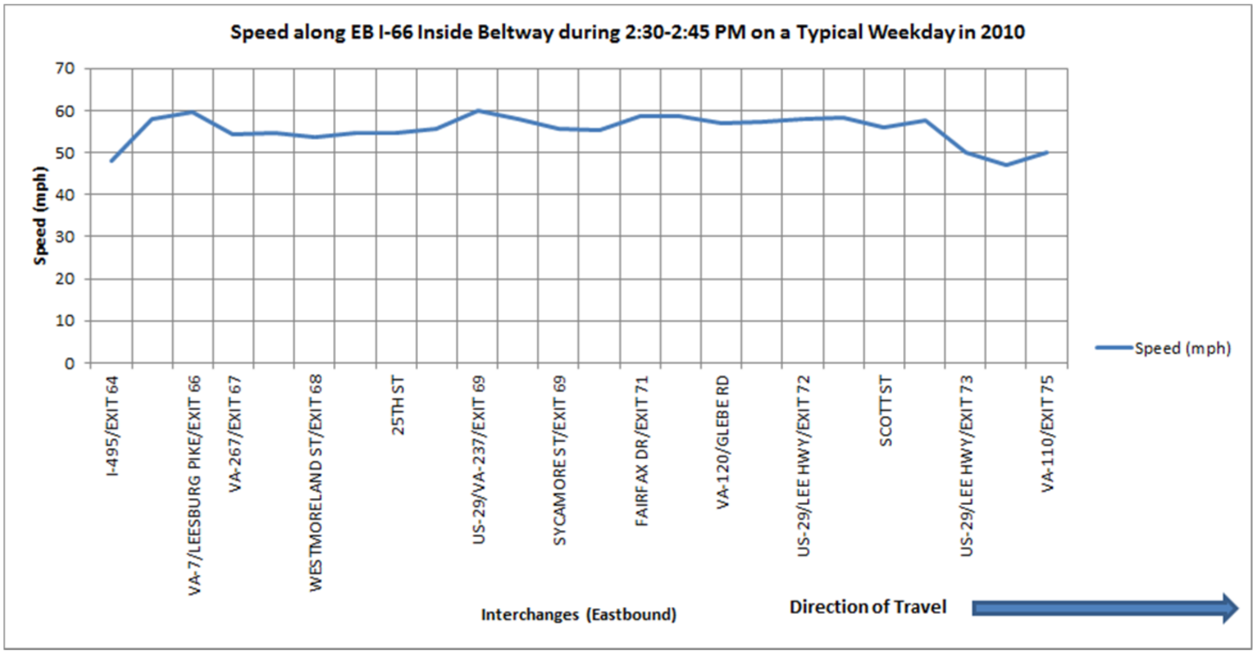
Speed along EB I-66 Inside Beltway during 1:30-1:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

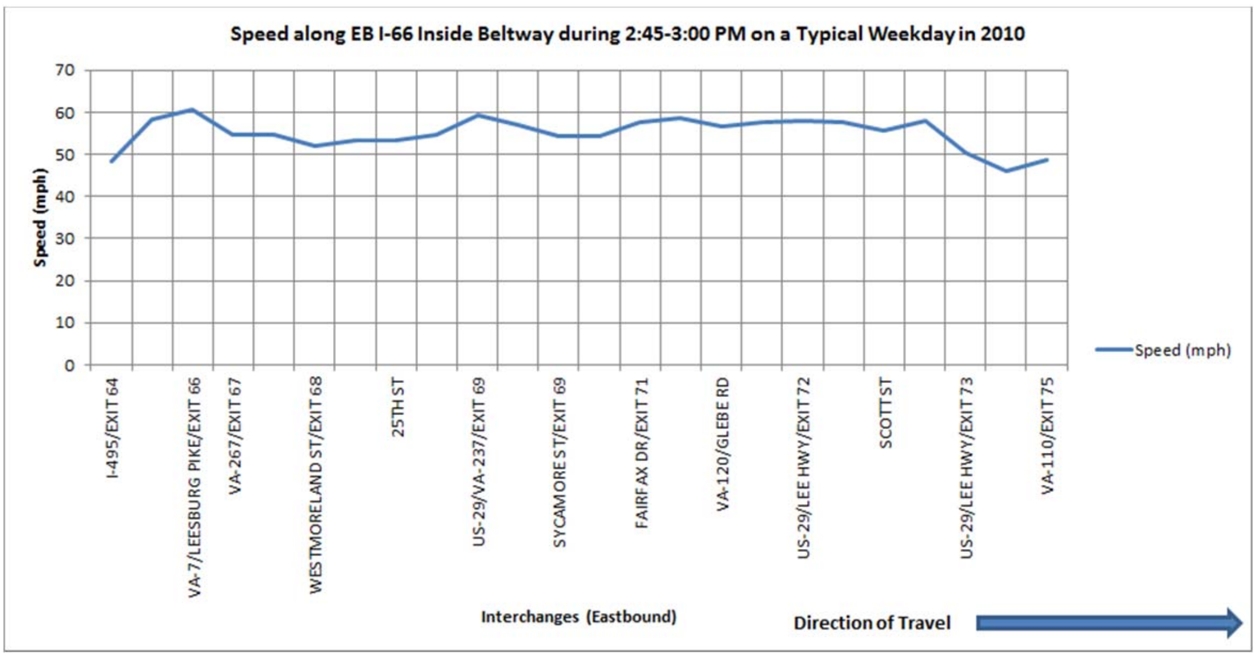


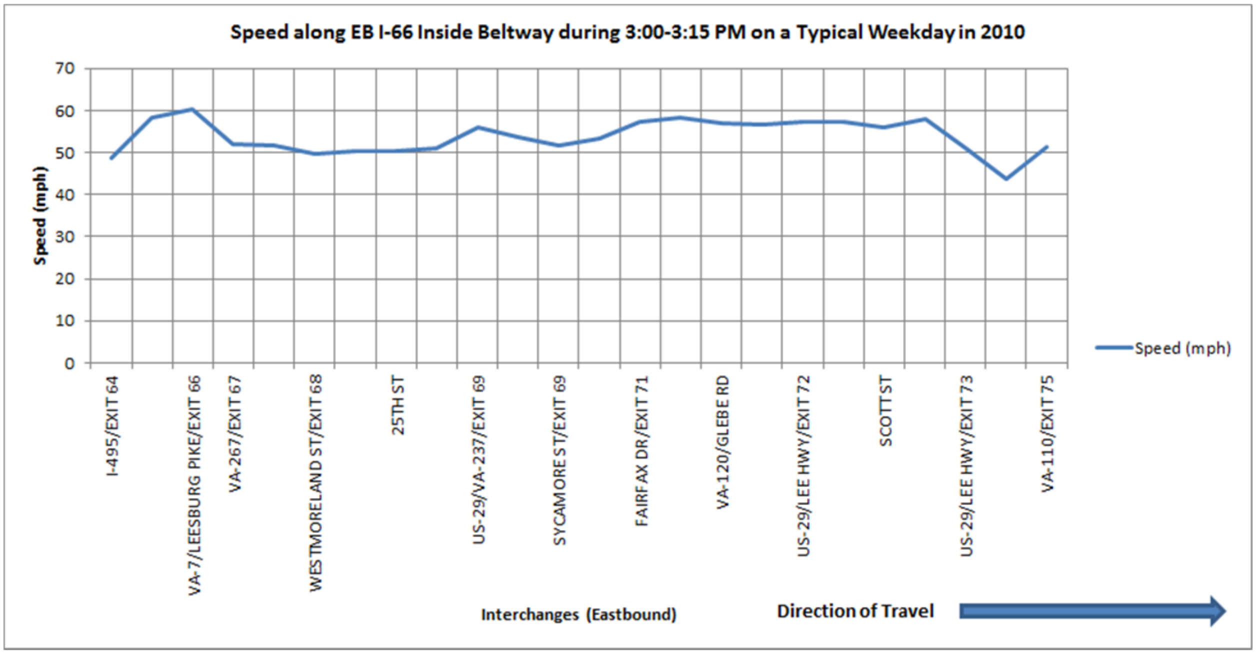
Speed along EB I-66 Inside Beltway during 1:45-2:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

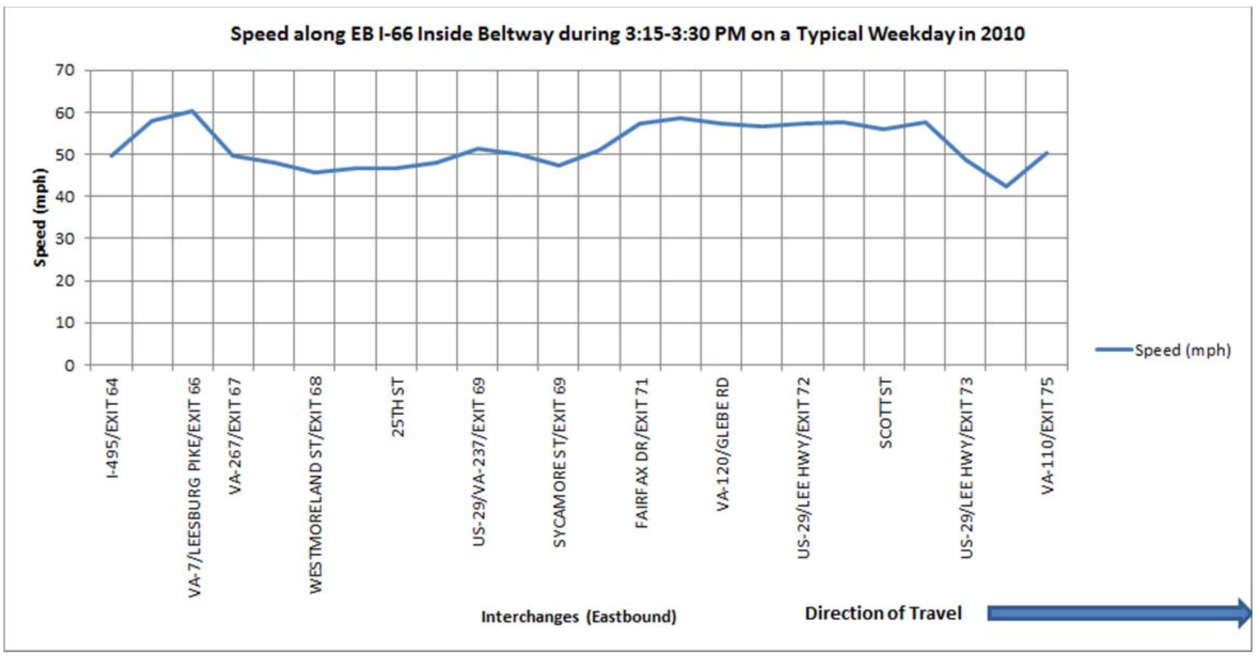

Speed along EB I-66 Inside Beltway during 2:00-2:15 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

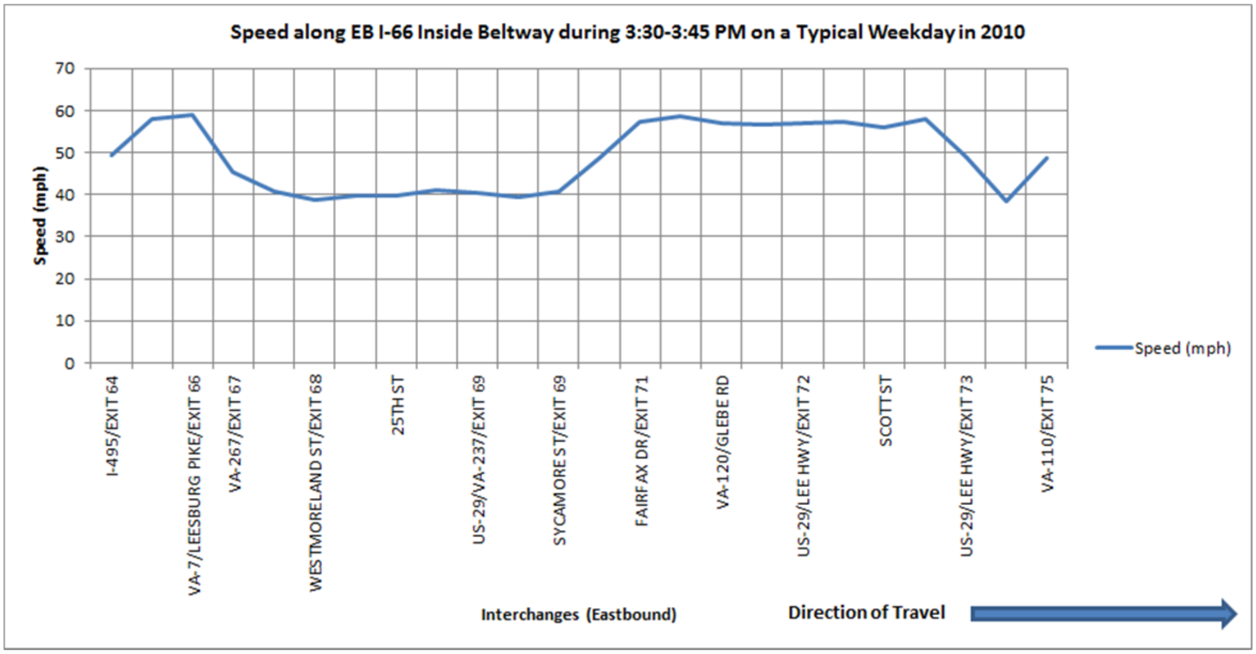

Speed along EB I-66 Inside Beltway during 2:15-2:30 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

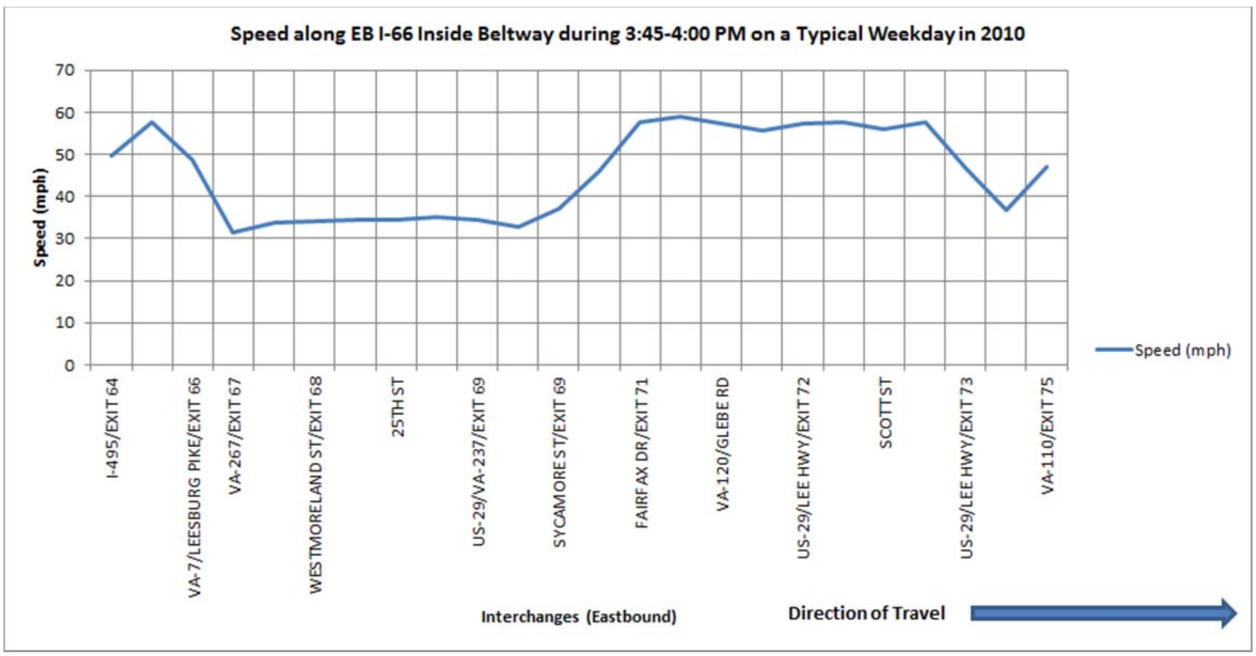

Speed along EB I-66 Inside Beltway during 2:30-2:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

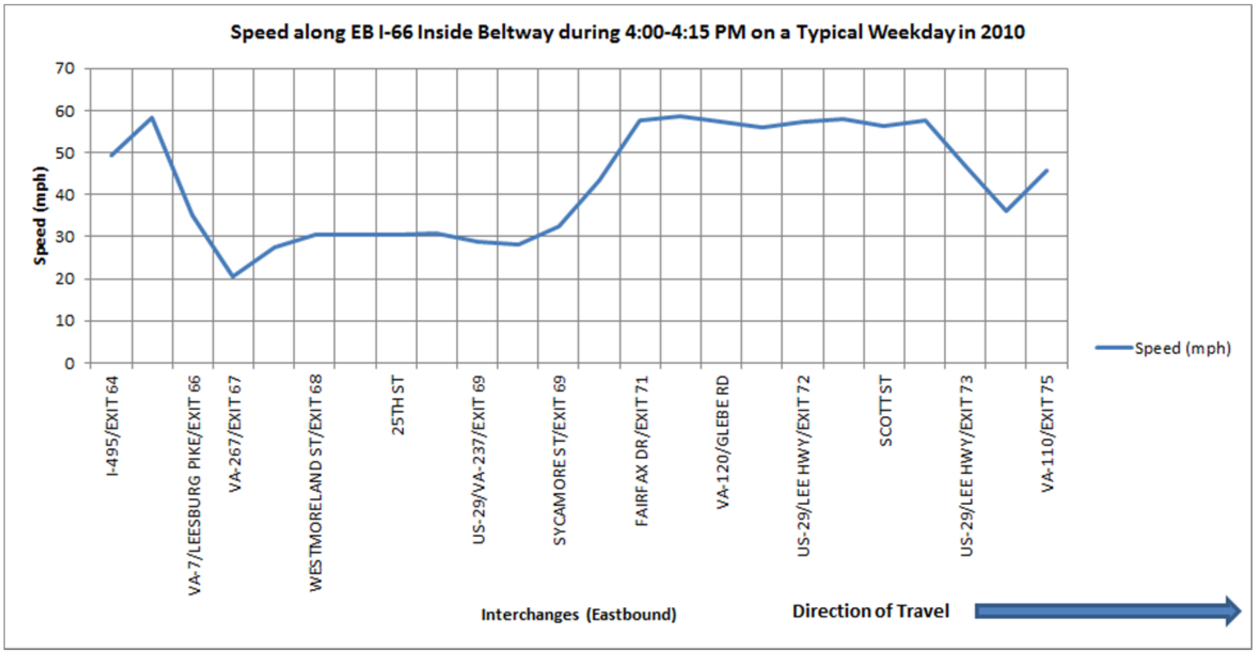

Speed along EB I-66 Inside Beltway during 2:45-3:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

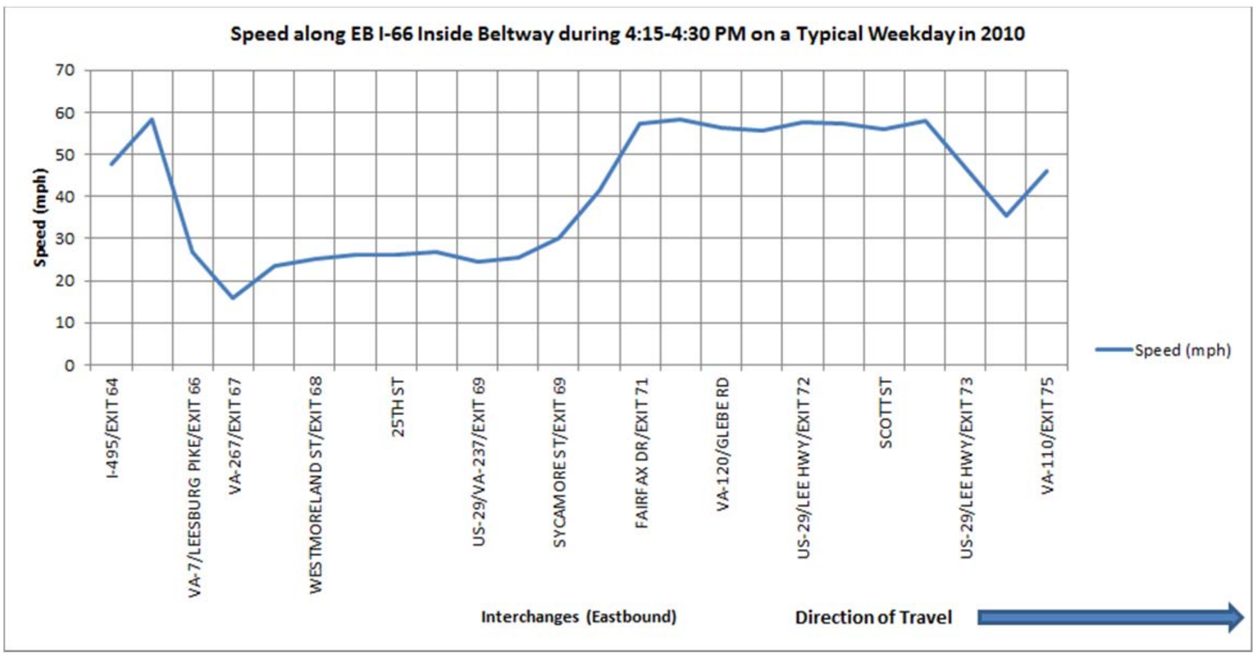

Speed along EB I-66 Inside Beltway during 3:00-3:15 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

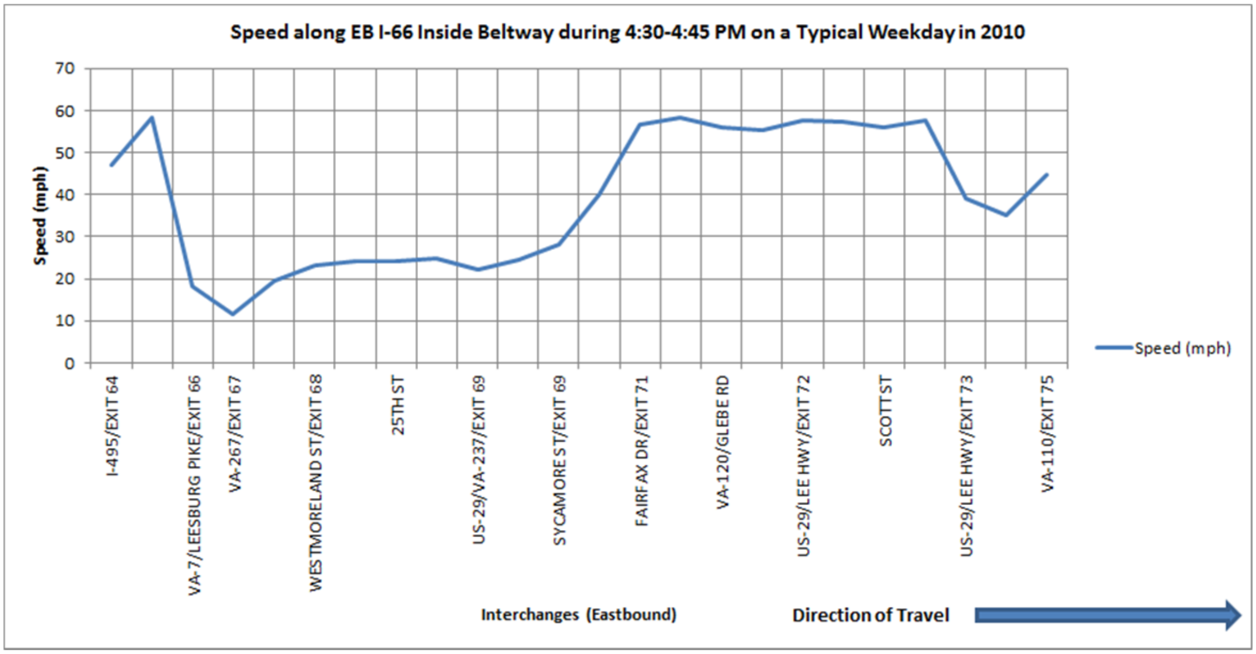

Speed along EB I-66 Inside Beltway during 3:15-3:30 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

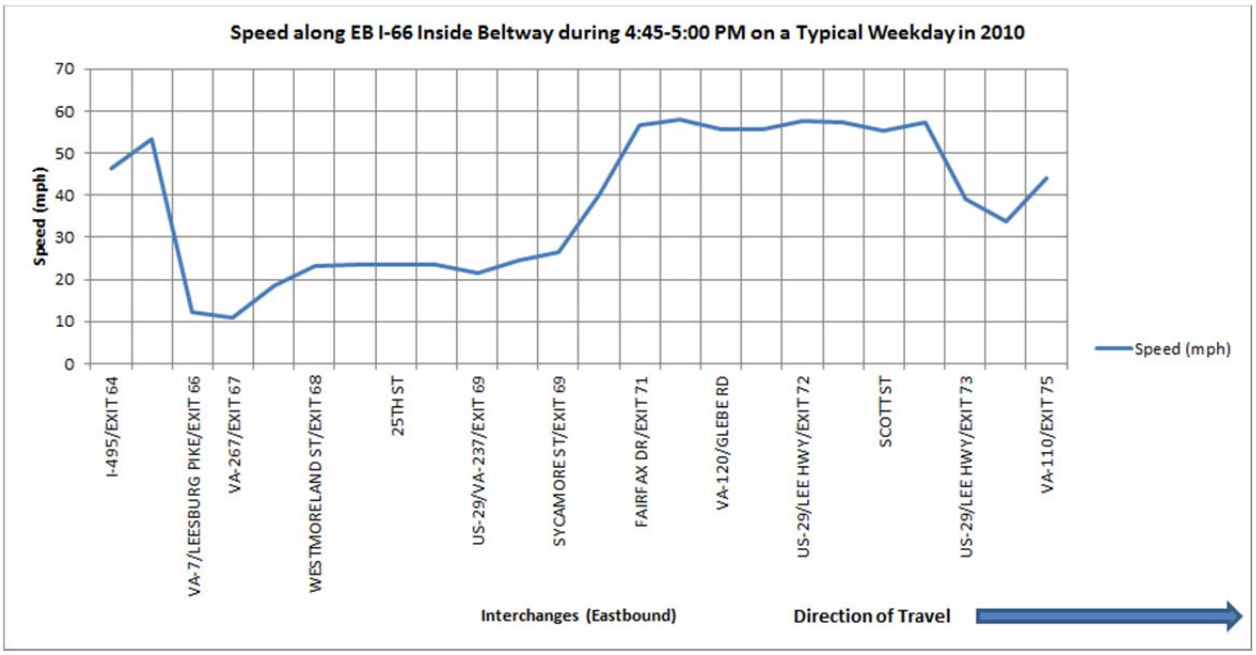

Speed along EB I-66 Inside Beltway during 3:30-3:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

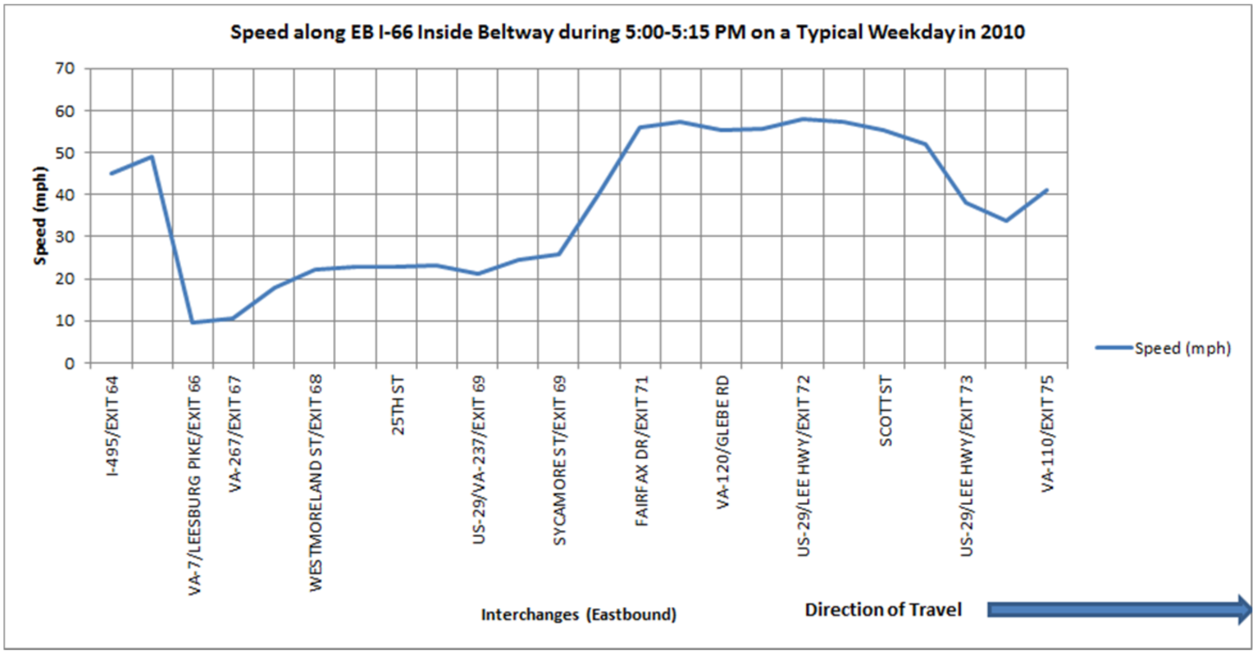

Speed along EB I-66 Inside Beltway during 3:45-4:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

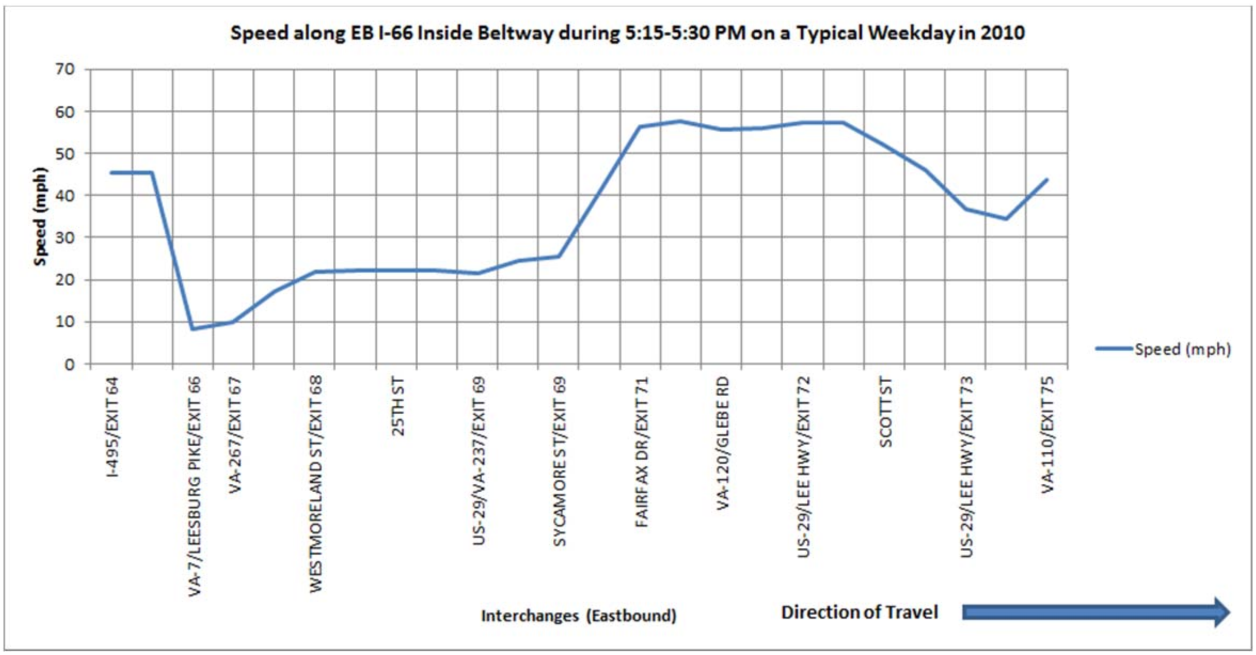

Speed along EB I-66 Inside Beltway during 4:00-4:15 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

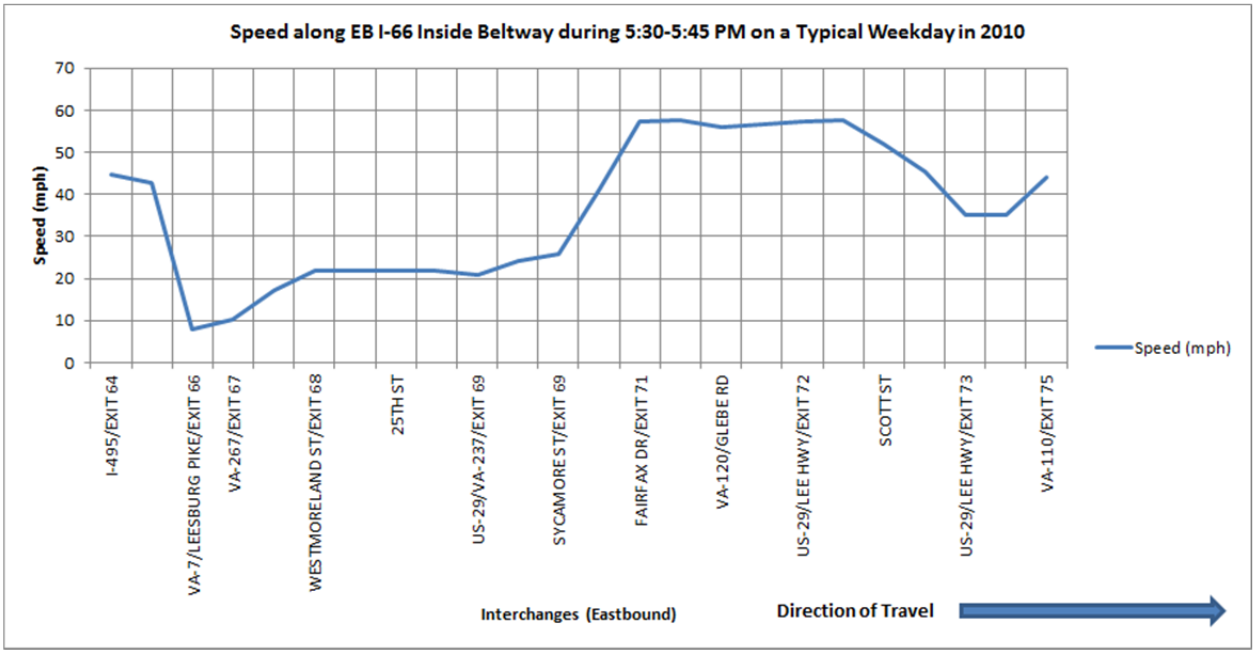

Speed along EB I-66 Inside Beltway during 4:15-4:30 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

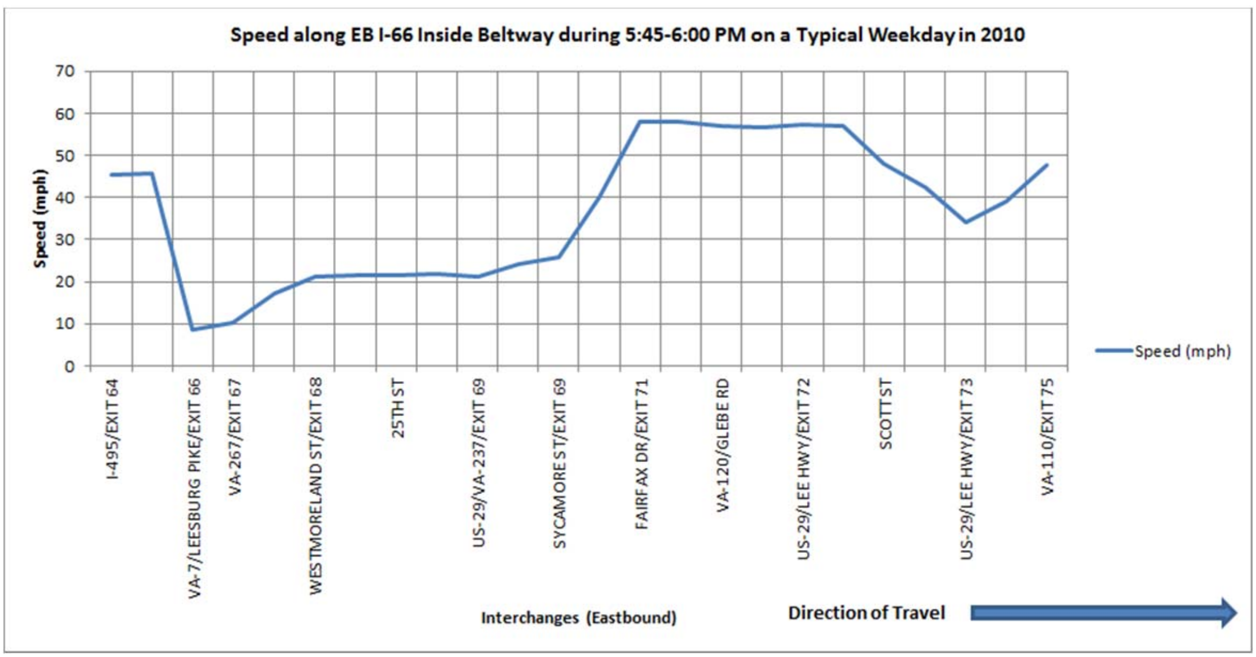

Speed along EB I-66 Inside Beltway during 4:30-4:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

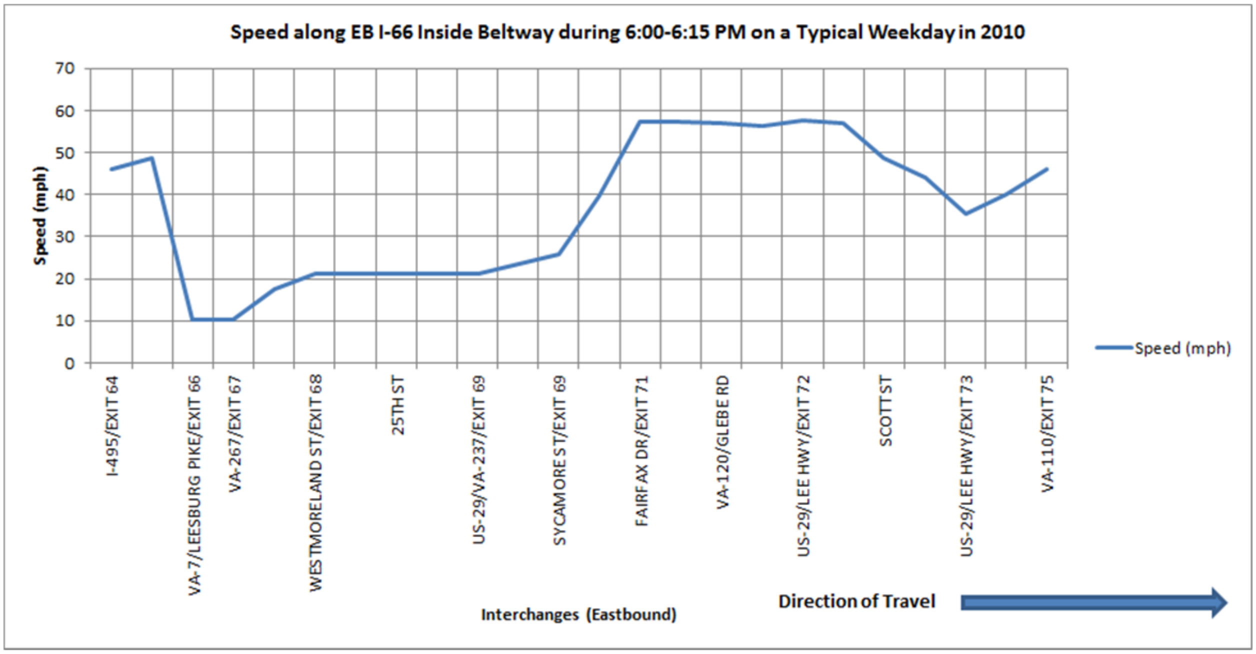

Speed along EB I-66 Inside Beltway during 4:45-5:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

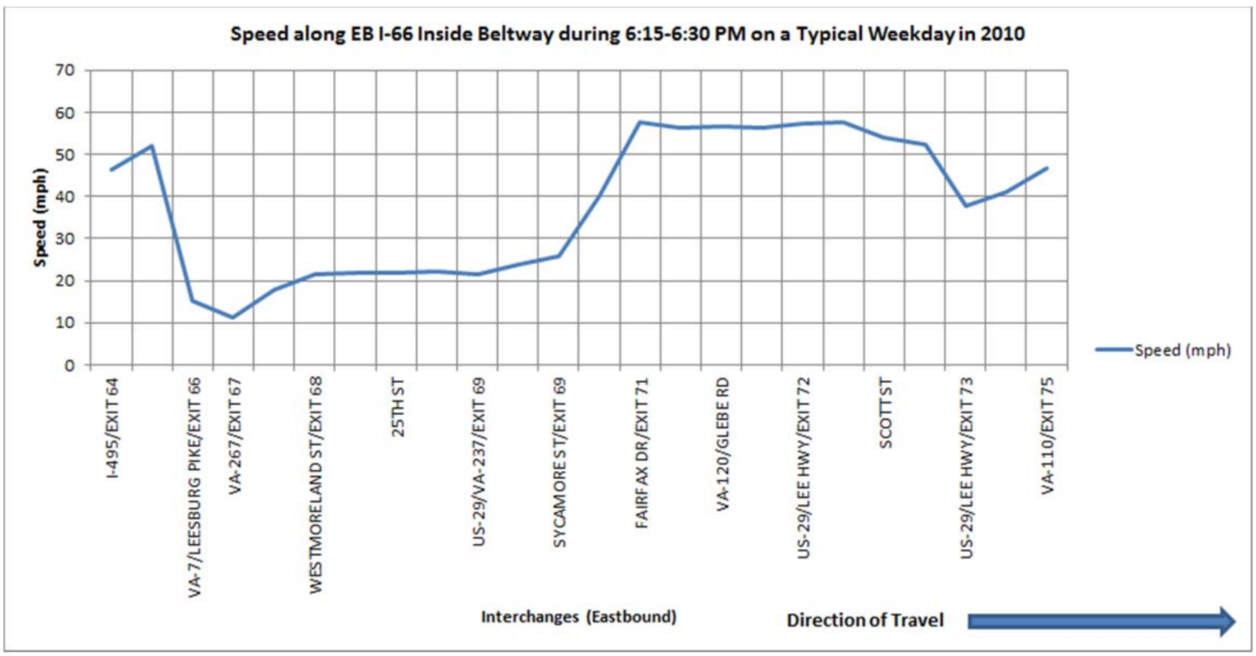

Speed along EB I-66 Inside Beltway during 5:00-5:15 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

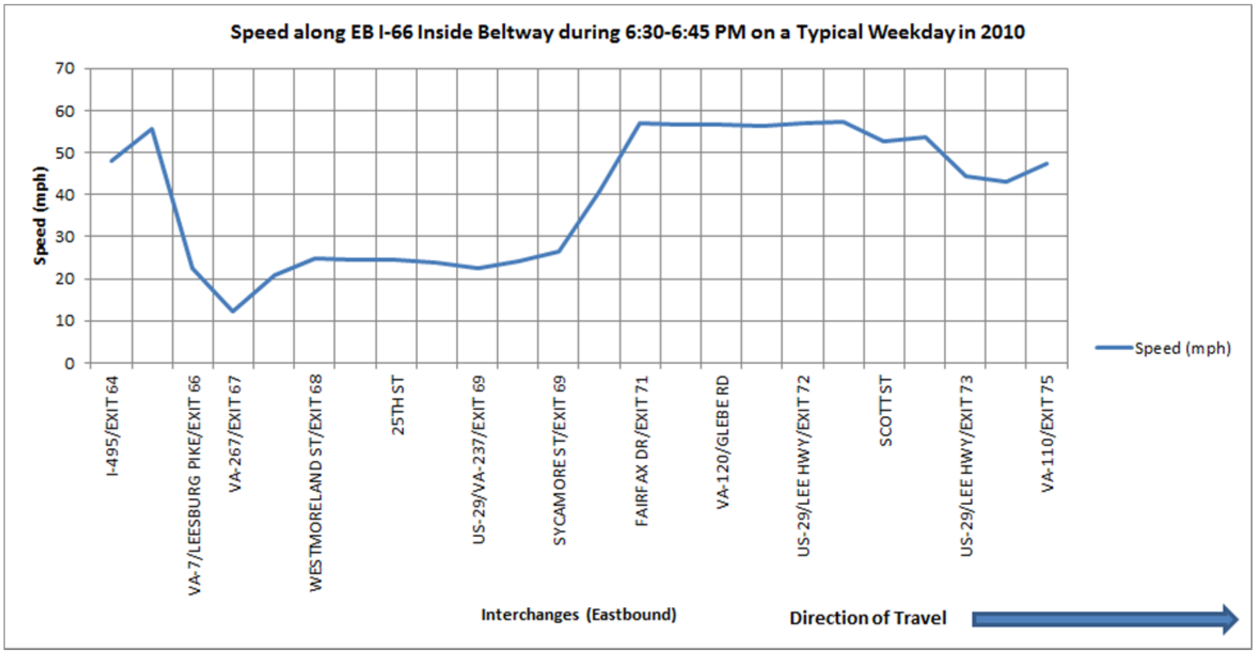

Speed along EB I-66 Inside Beltway during 5:15-5:30 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

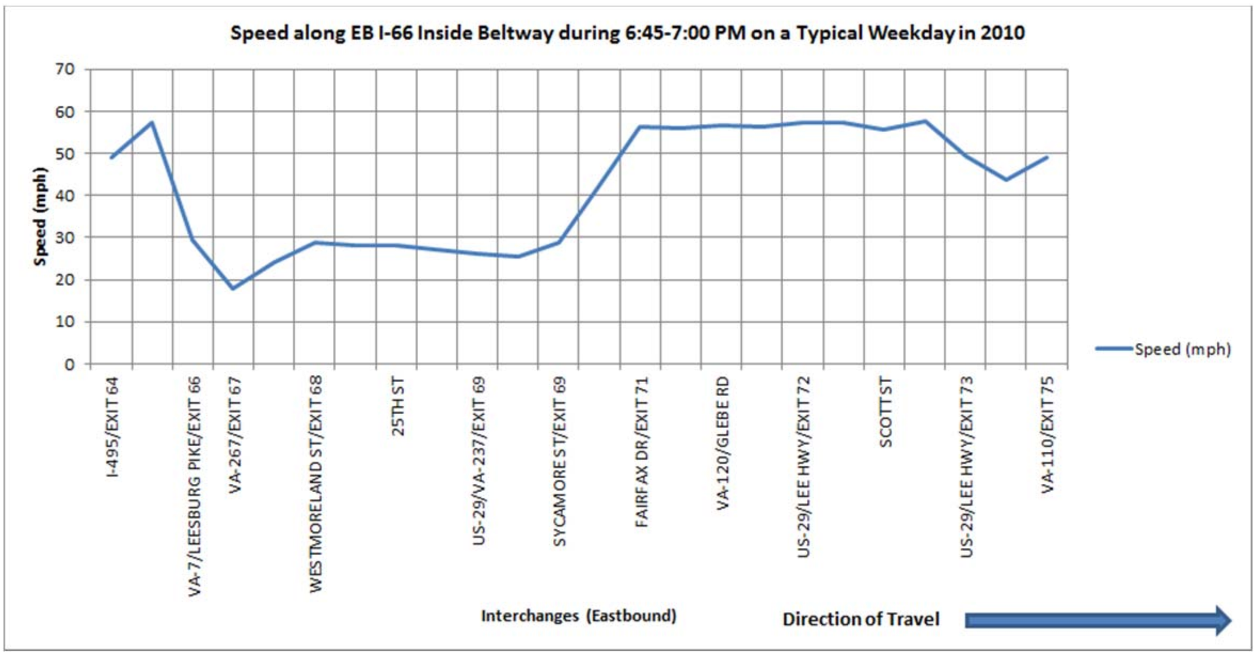

Speed along EB I-66 Inside Beltway during 5:30-5:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

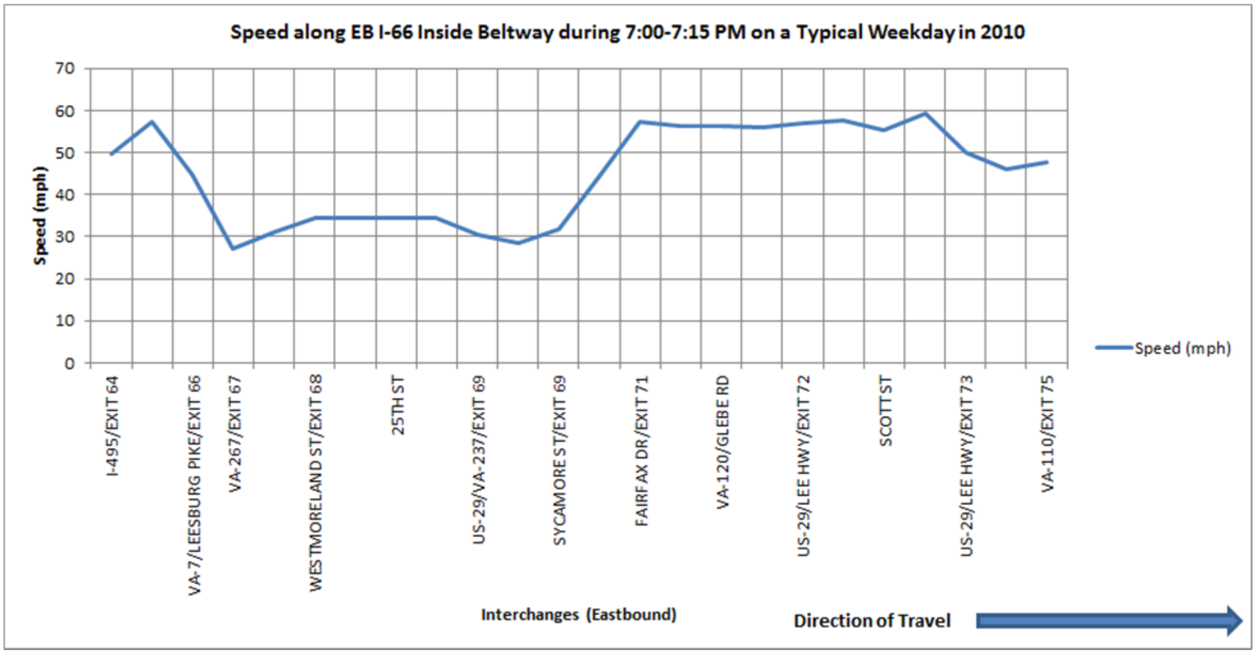

Speed along EB I-66 Inside Beltway during 5:45-6:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

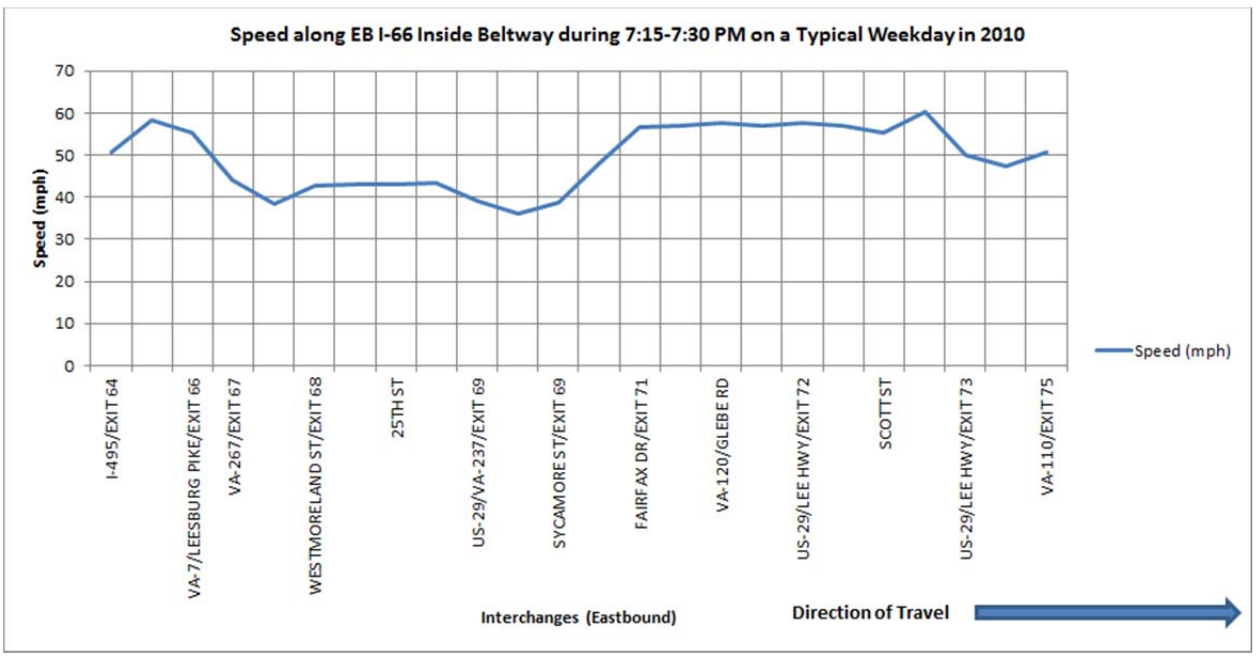

Speed along EB I-66 Inside Beltway during 6:00-6:15 PM on a Typical Weekday in 2010
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

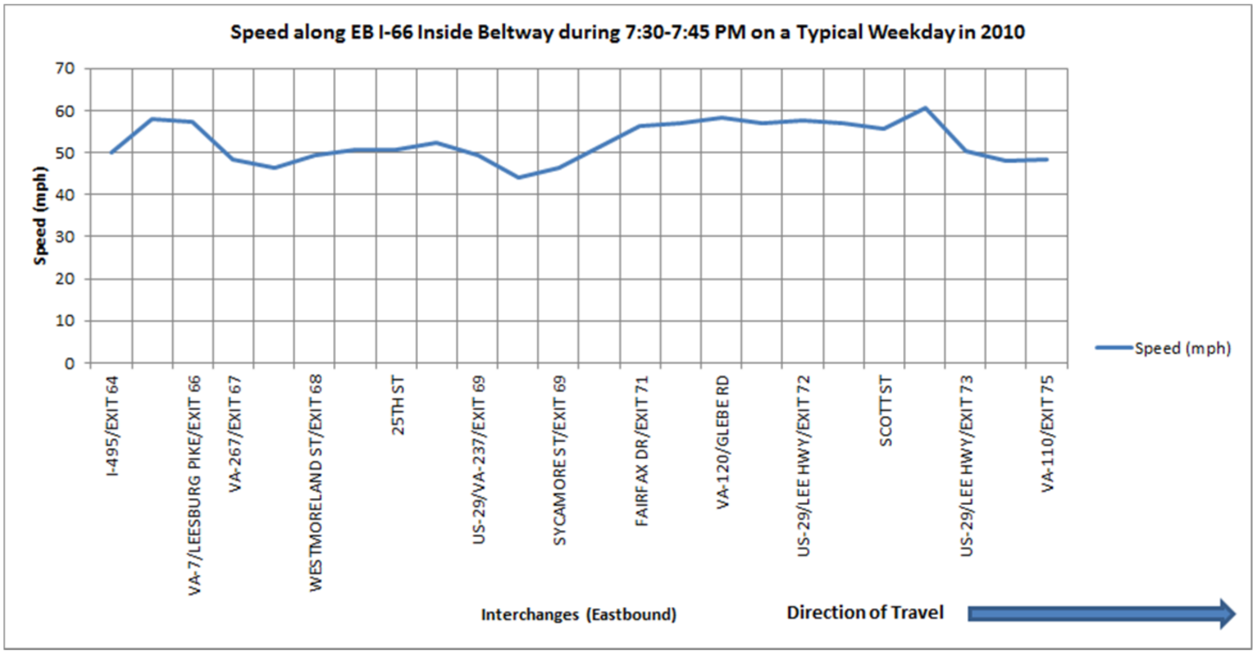

Speed along EB I-66 Inside Beltway during 6:15-6:30 PM on a Typical Weekday in 2010
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

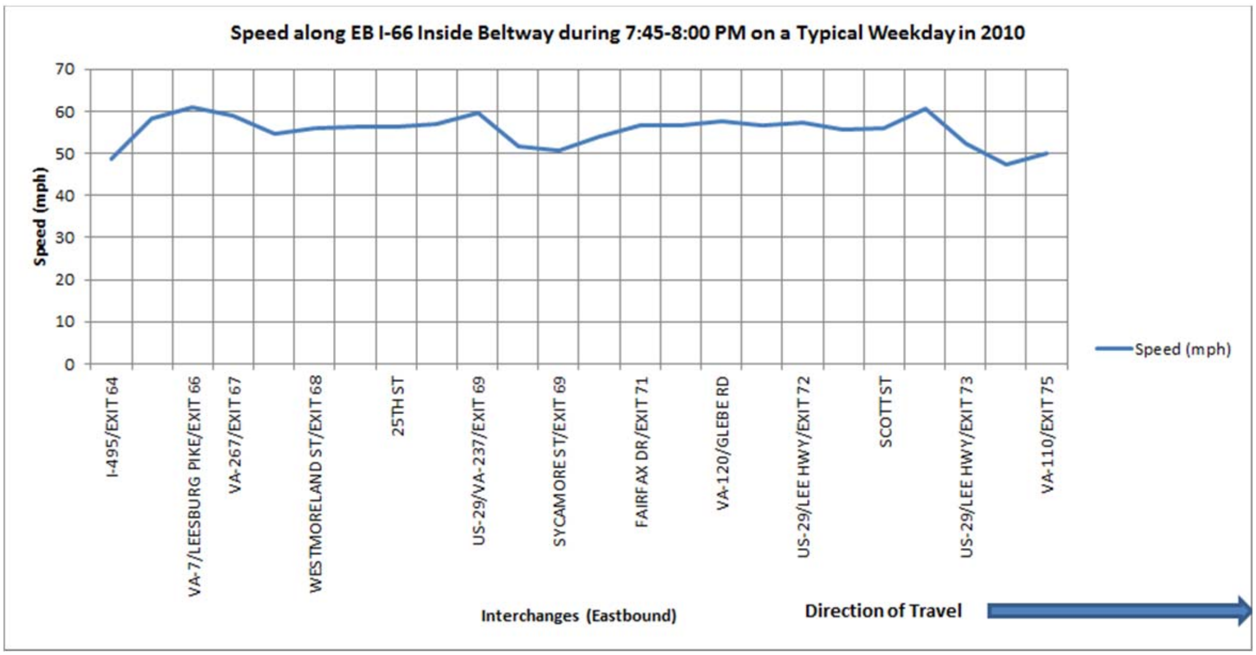

Speed along EB I-66 Inside Beltway during 6:30-6:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel


Speed along EB I-66 Inside Beltway during 6:45-7:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

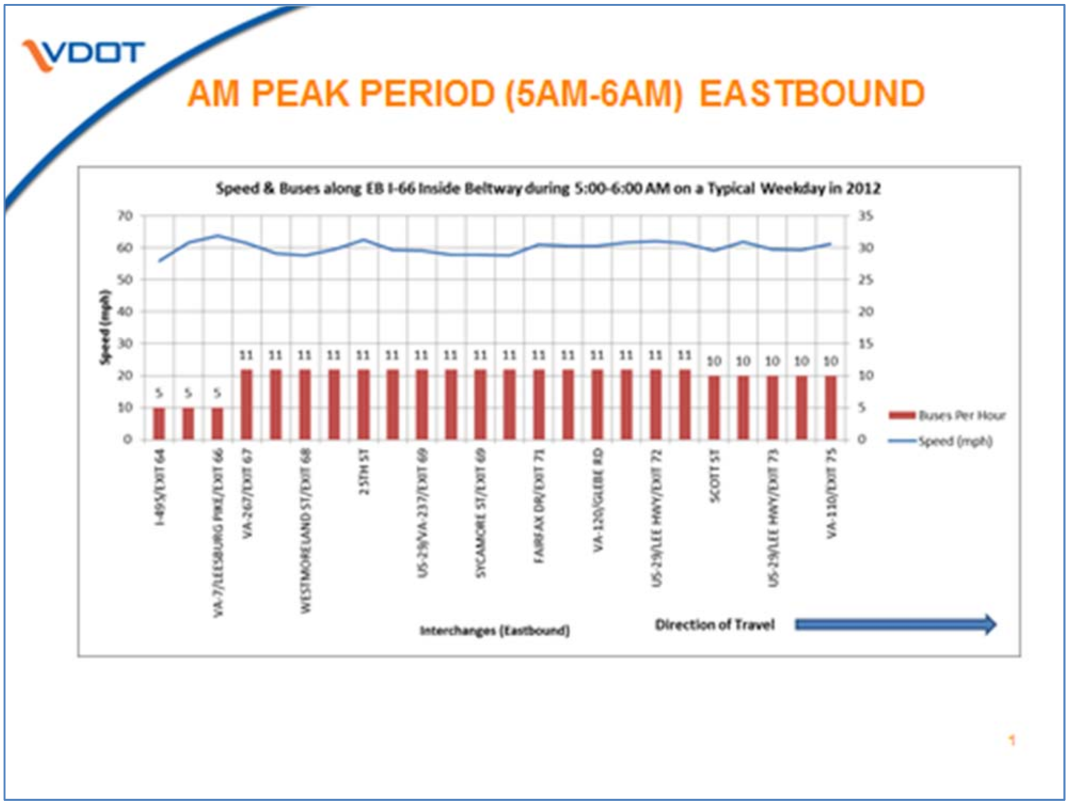

Speed along EB I-66 Inside Beltway during 7:00-7:15 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

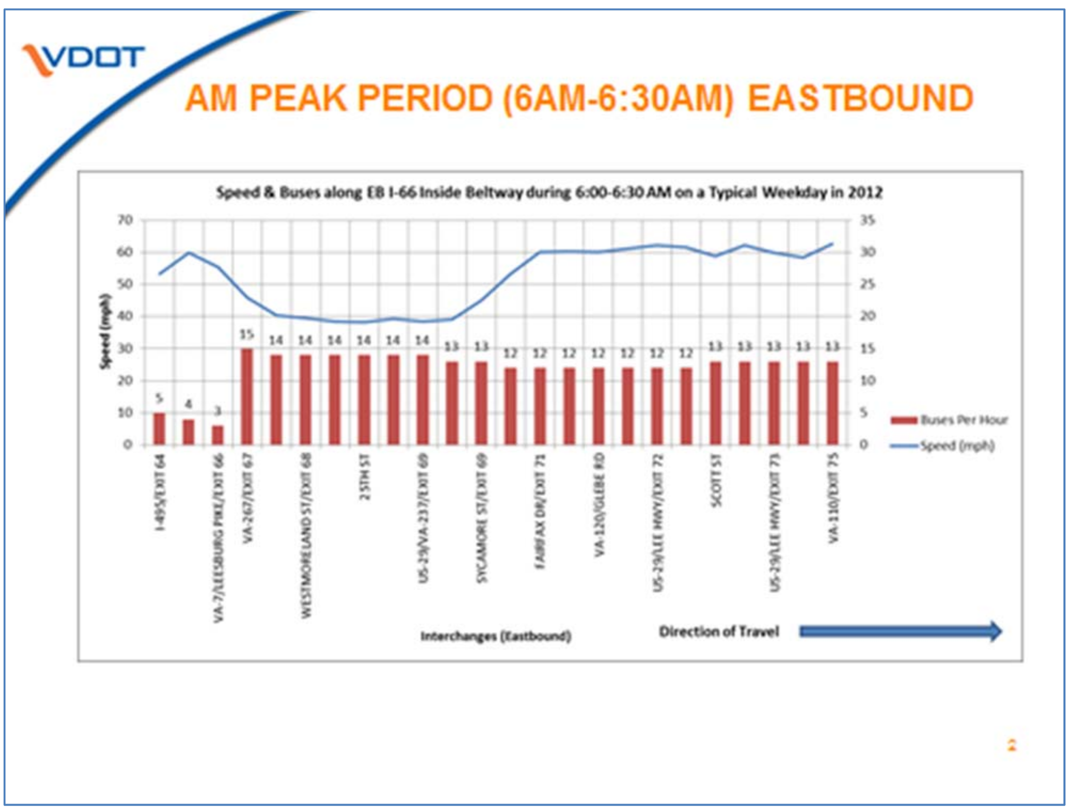

Speed along EB I-66 Inside Beltway during 7:15-7:30 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

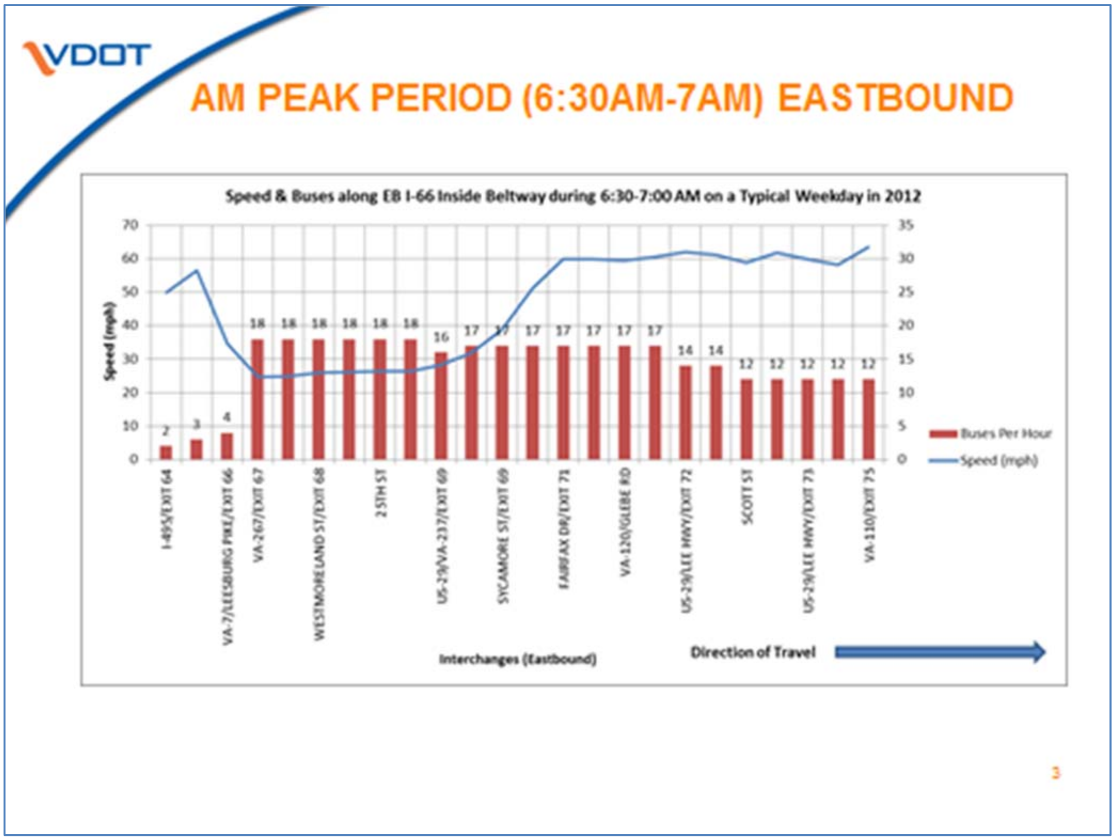

Speed along EB I-66 Inside Beltway during 7:30-7:45 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

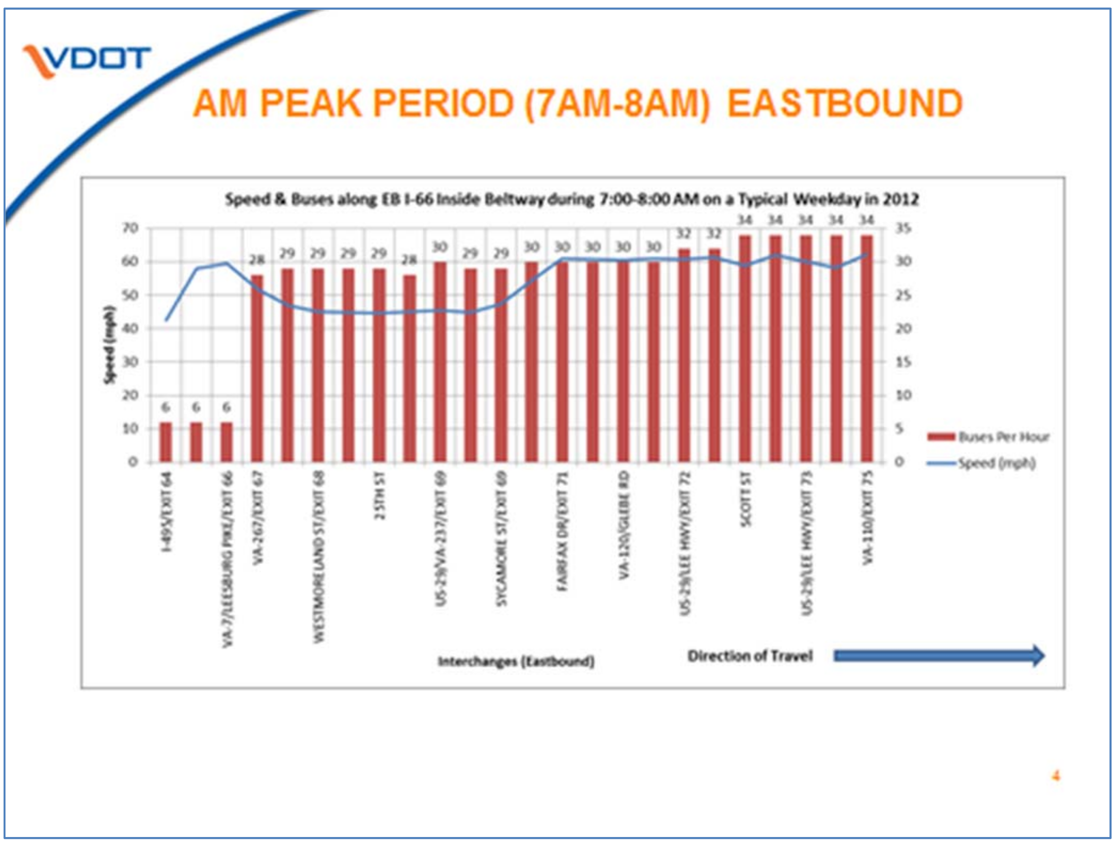

Speed along EB I-66 Inside Beltway during 7:45-8:00 PM on a Typical Weekday in 2010
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

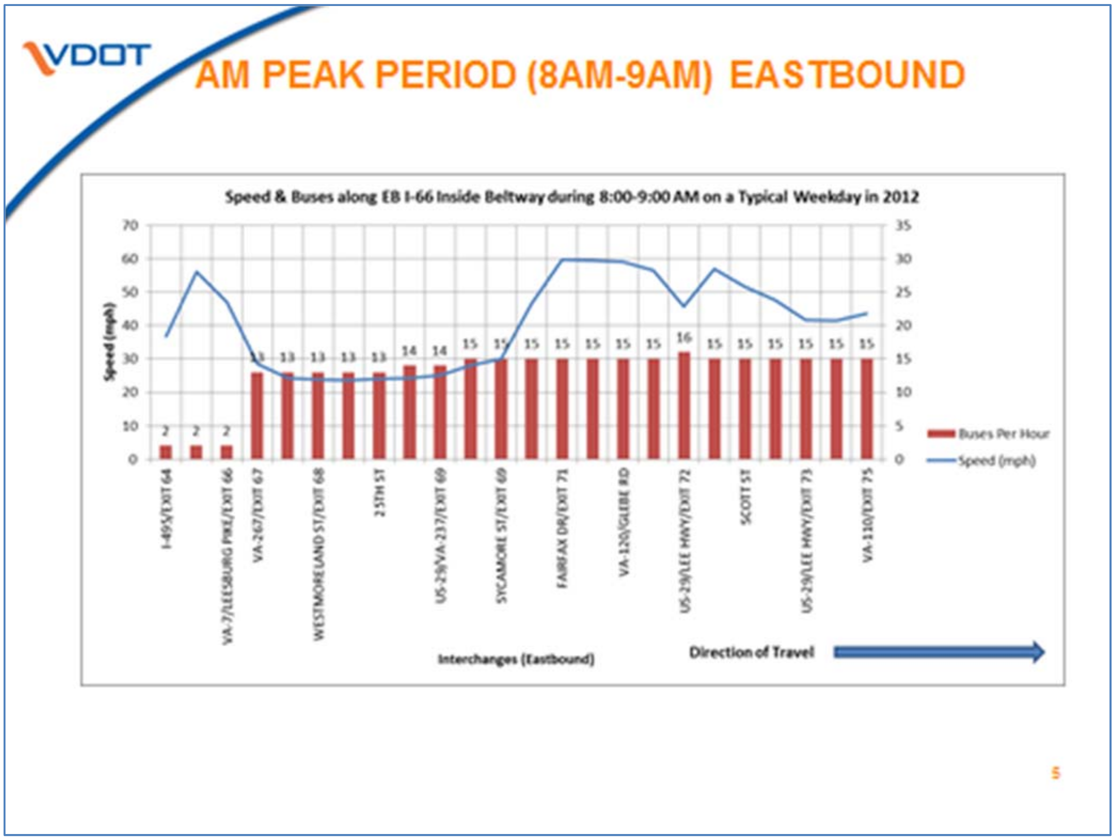
2012 Data, Peak Travel Direction

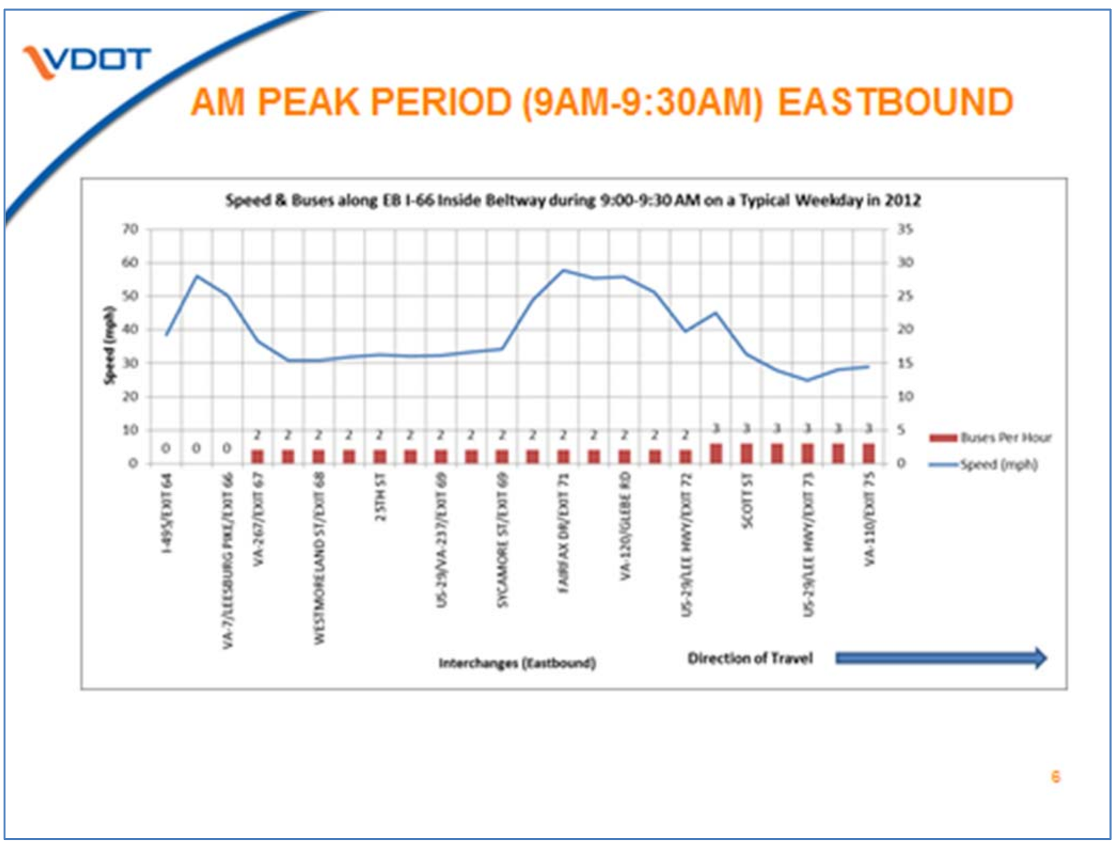


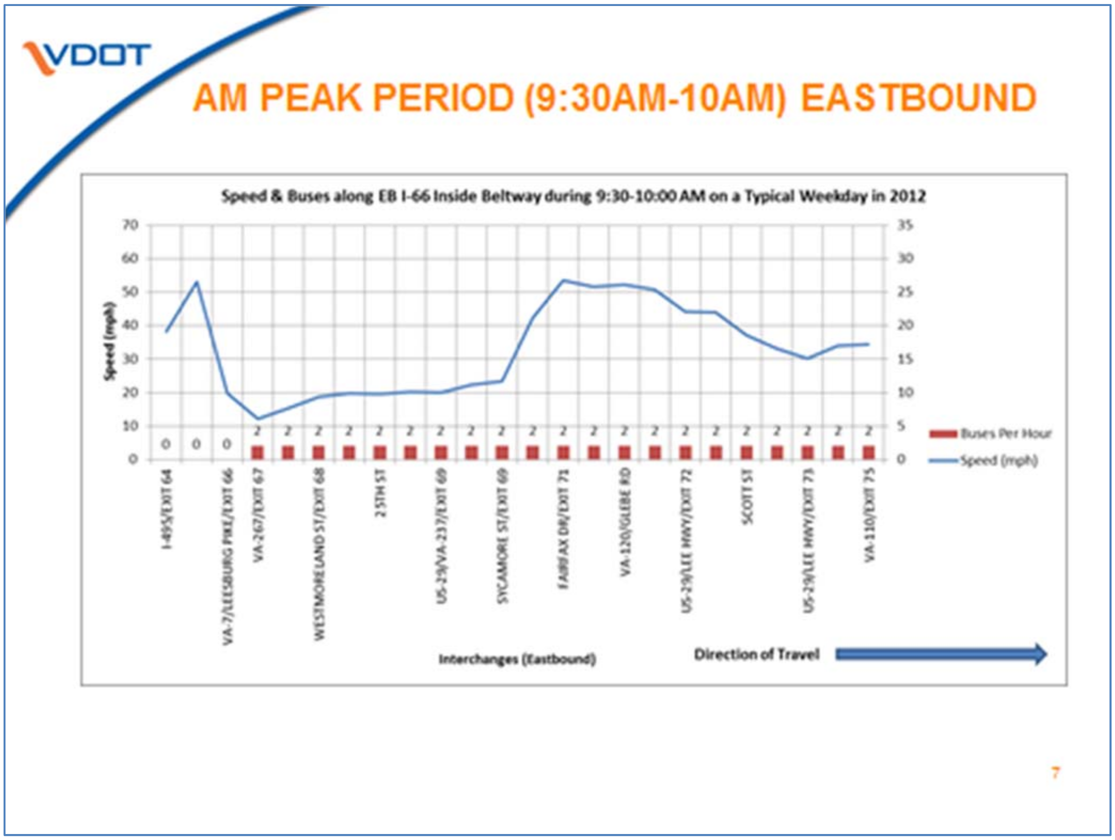


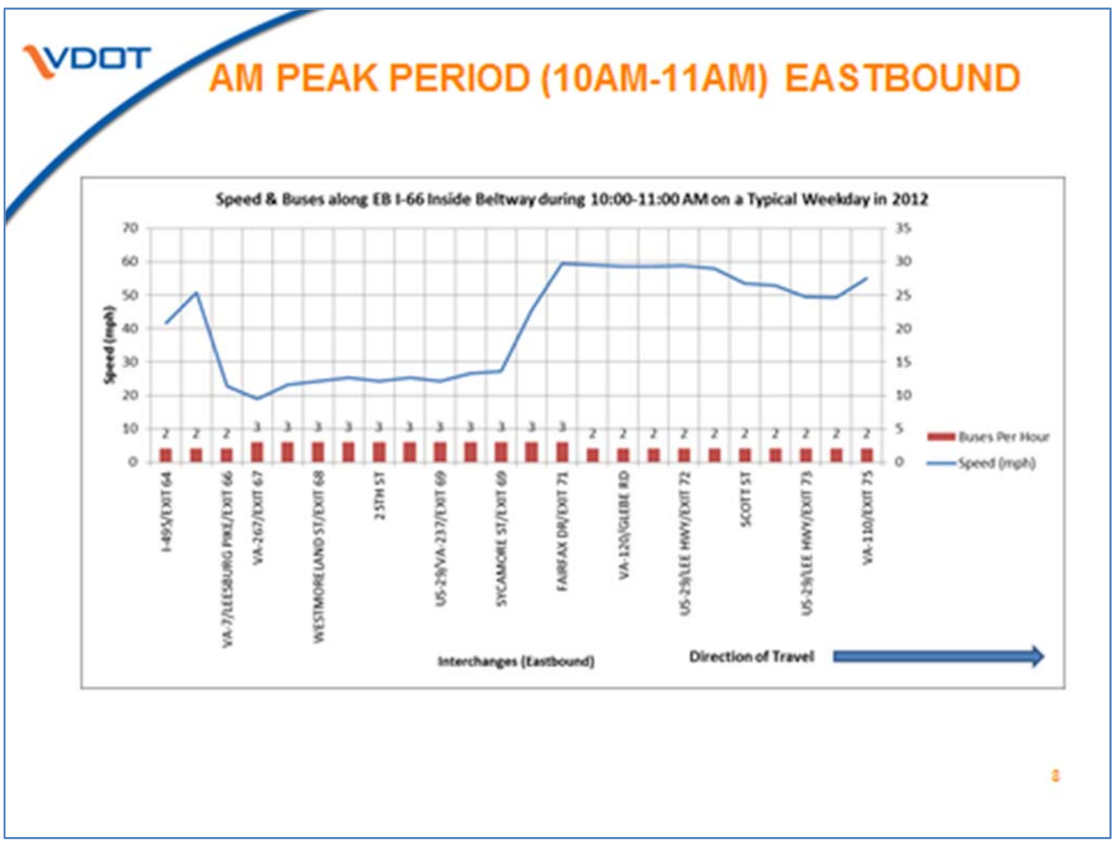

VDOT
AM PEAK PERIOD (6:30AM-7AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 6:30-7:00 AM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
35
30
25
20
15
10
5
0
2
3
4
18
18
18
18
18
18
16
17
17
17
17
17
17
17
14
14
12
12
12
12
12
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Buses Per Hour
Speed (mph)
Interchanges (Eastbound)
Direction of Travel
3

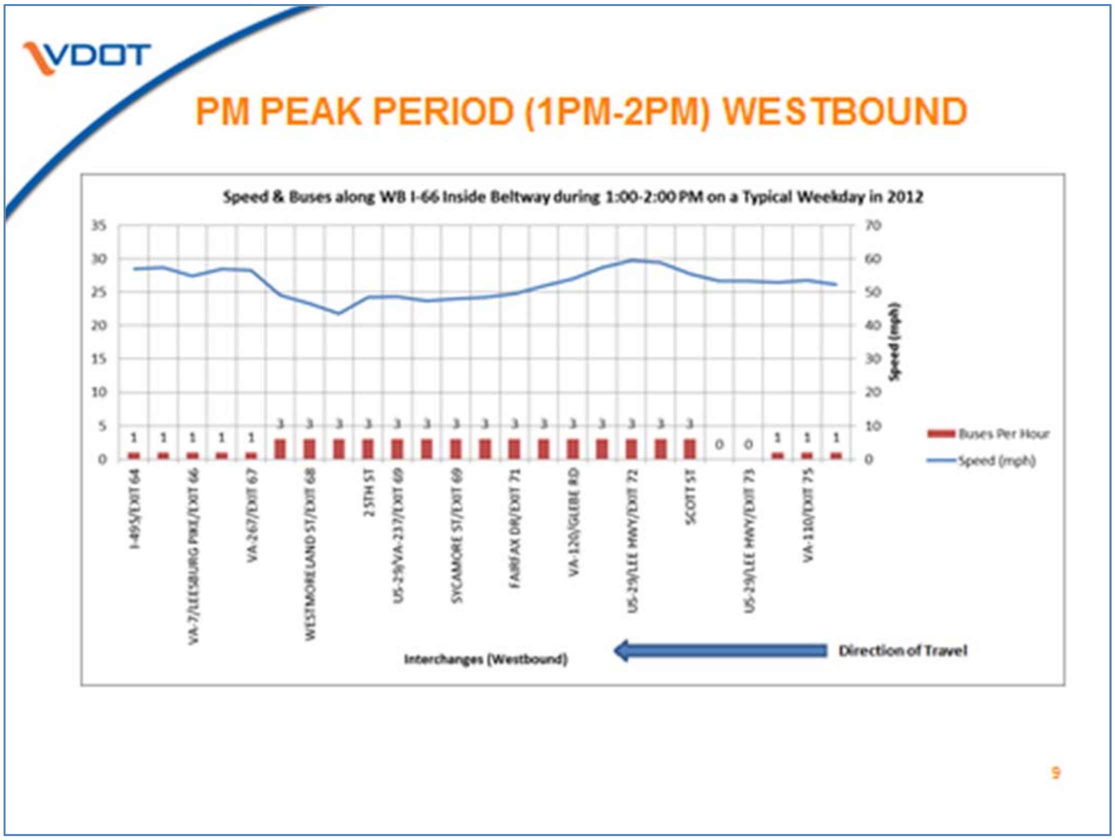

VDOT
AM PEAK PERIOD (7AM-8AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 7:00-8:00 AM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
35
30
25
20
15
10
5
0
6
6
6
28
29
29
29
29
28
30
29
29
30
30
30
30
30
32
32
34
34
34
34
34
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Buses Per Hour
Speed (mph)
Interchanges (Eastbound)
Direction of Travel
4

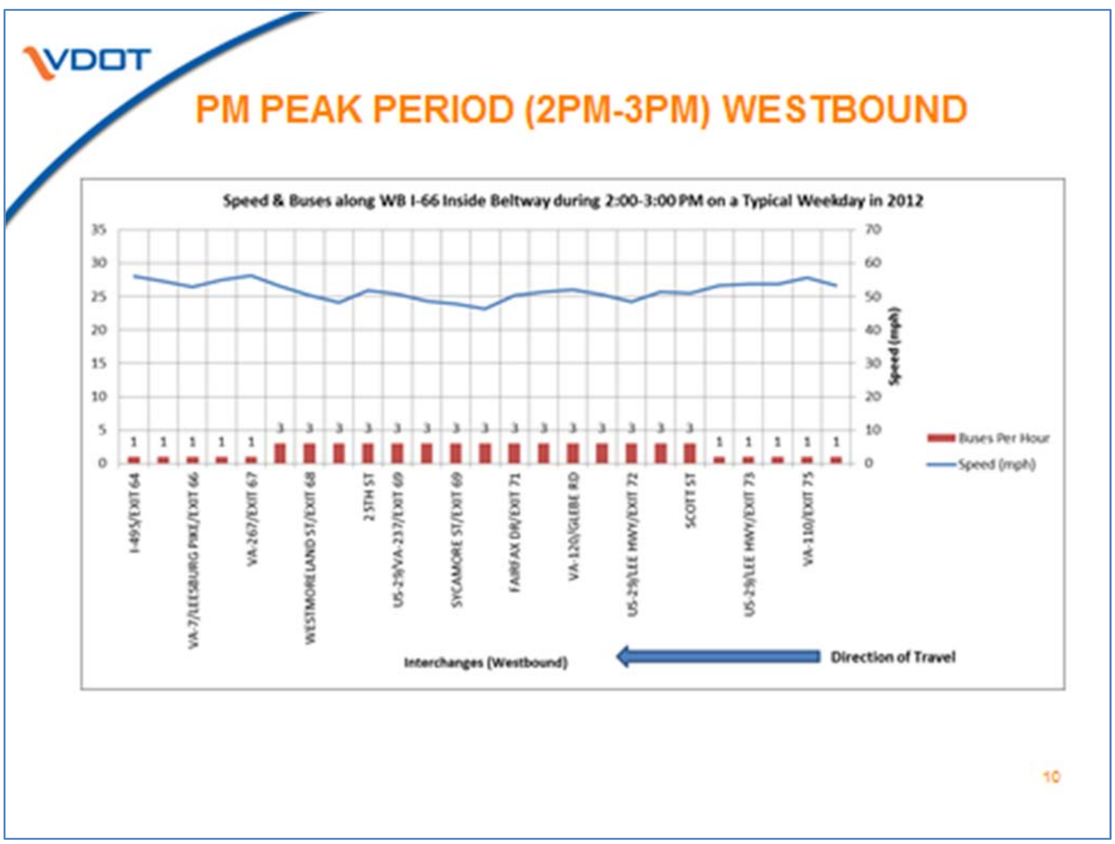

VDOT
AM PEAK PERIOD (8AM-9AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 8:00-9:00 AM on a Typical Weekday in 2012
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Buses Per Hour
Speed (mph)
Interchanges (Eastbound)
Direction of Travel
5

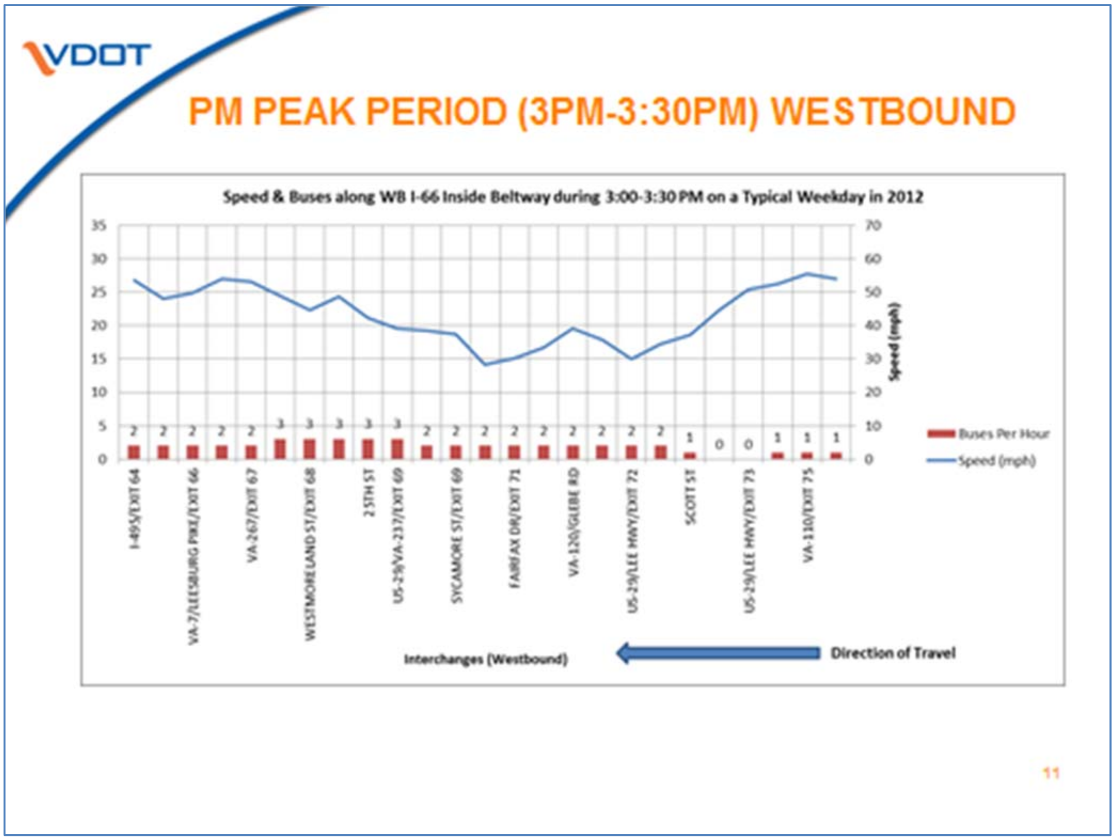

VDOT
AM PEAK PERIOD (9AM-9:30AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 9:00-9:30 AM on a Typical Weekday in 2012
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Buses Per Hour
Speed (mph)
Interchanges (Eastbound)
Direction of Travel
6

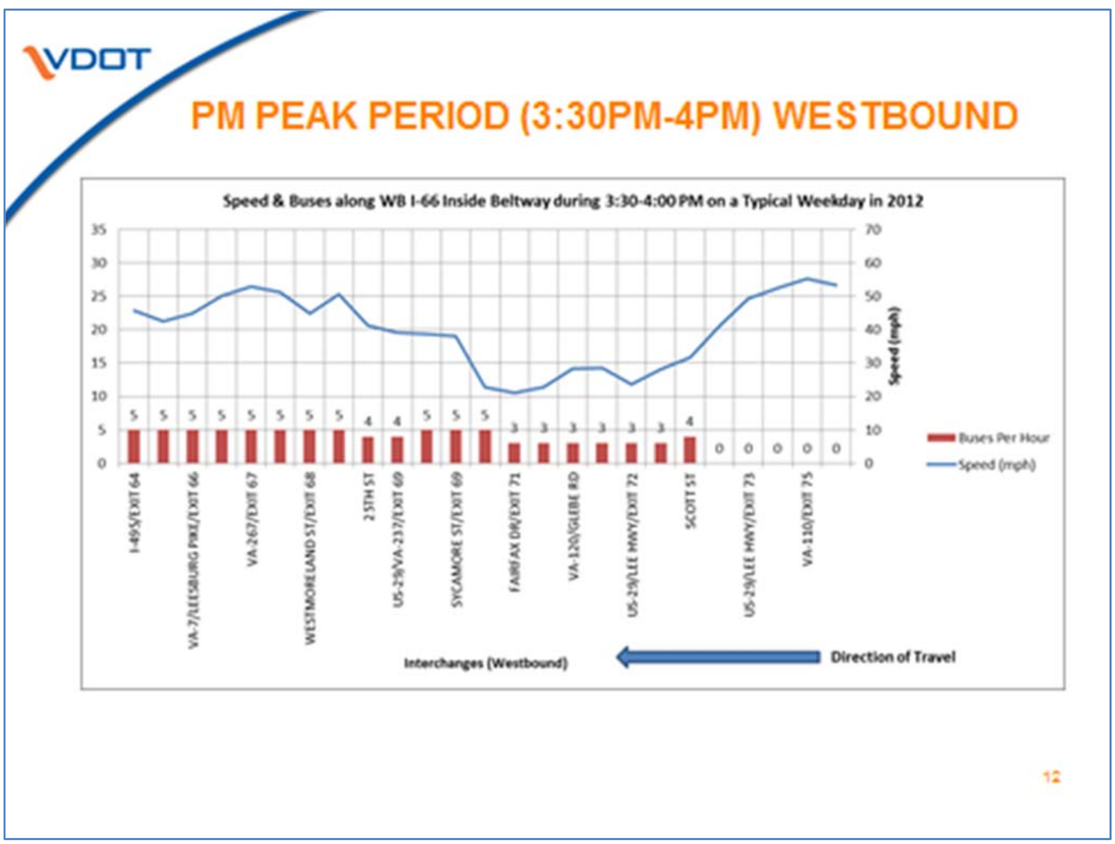

VDOT
AM PEAK PERIOD (9:30AM-10AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 9:30-10:00 AM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
7

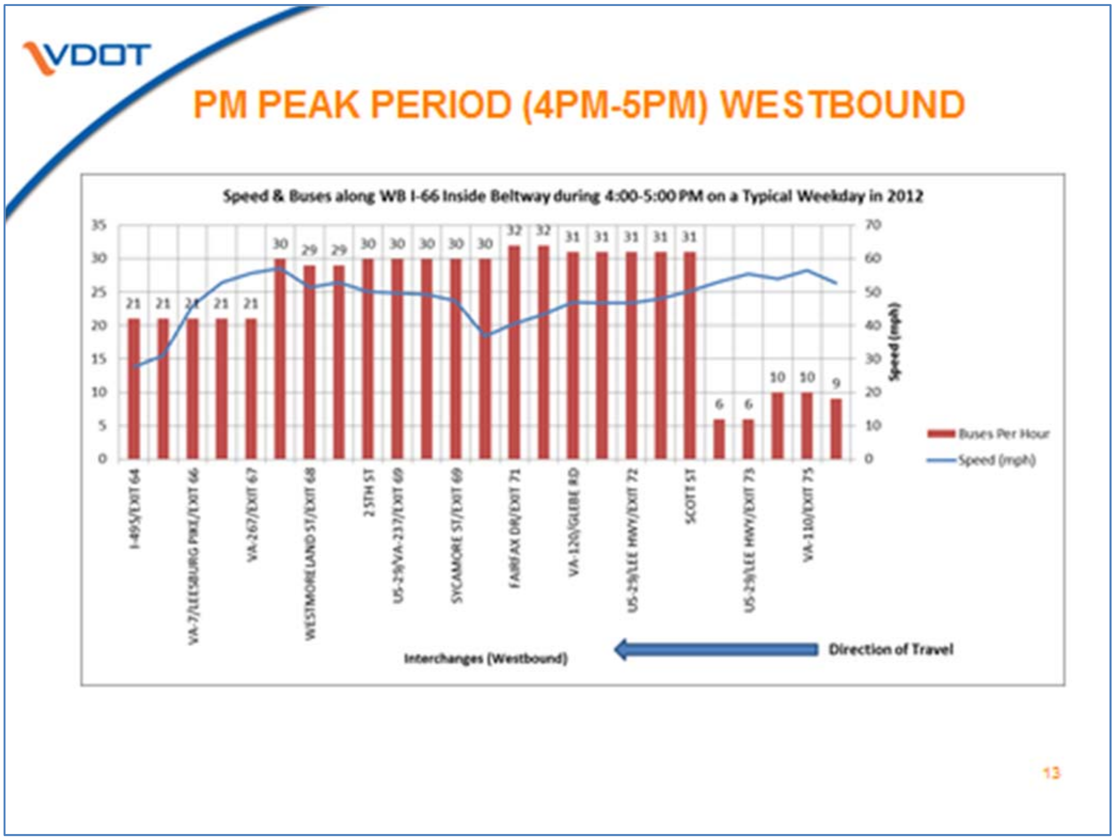

VDOT
AM PEAK PERIOD (10AM-11AM) EASTBOUND
Speed & Buses along EB I-66 Inside Beltway during 10:00-11:00 AM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
8

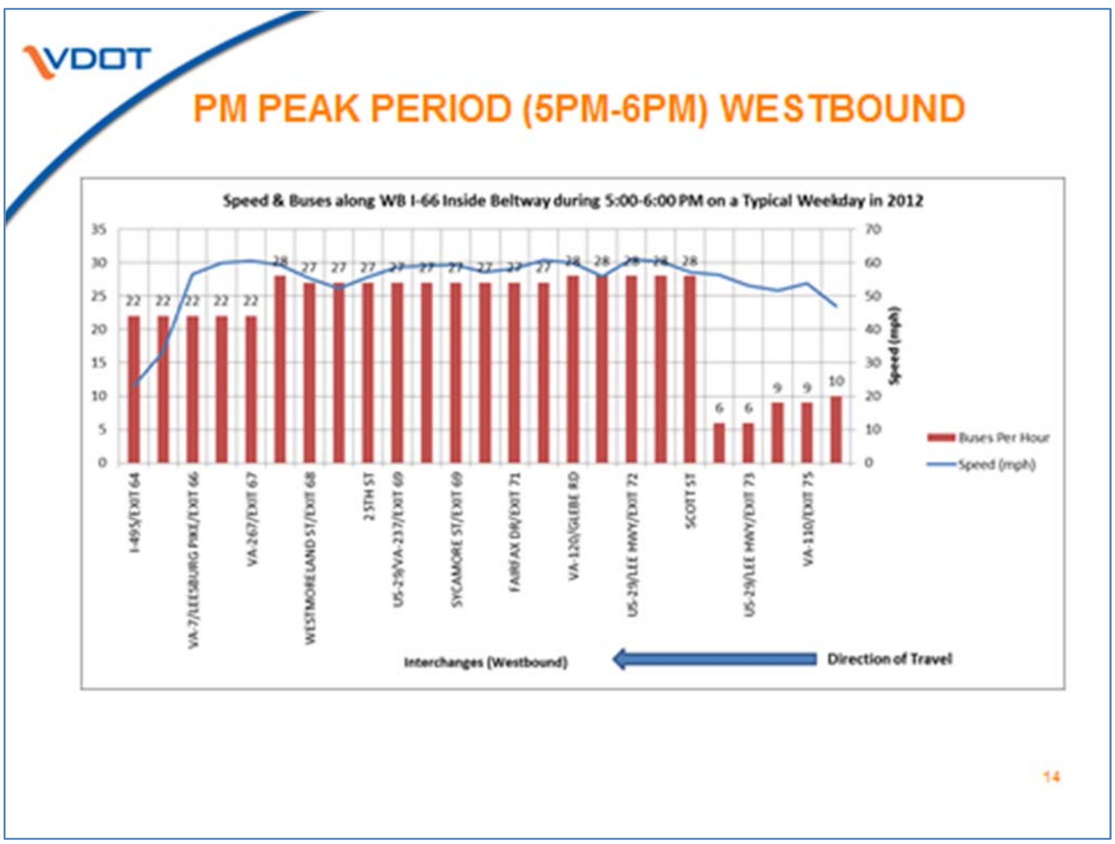

PM PEAK PERIOD (1PM-2PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 1:00-2:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
9

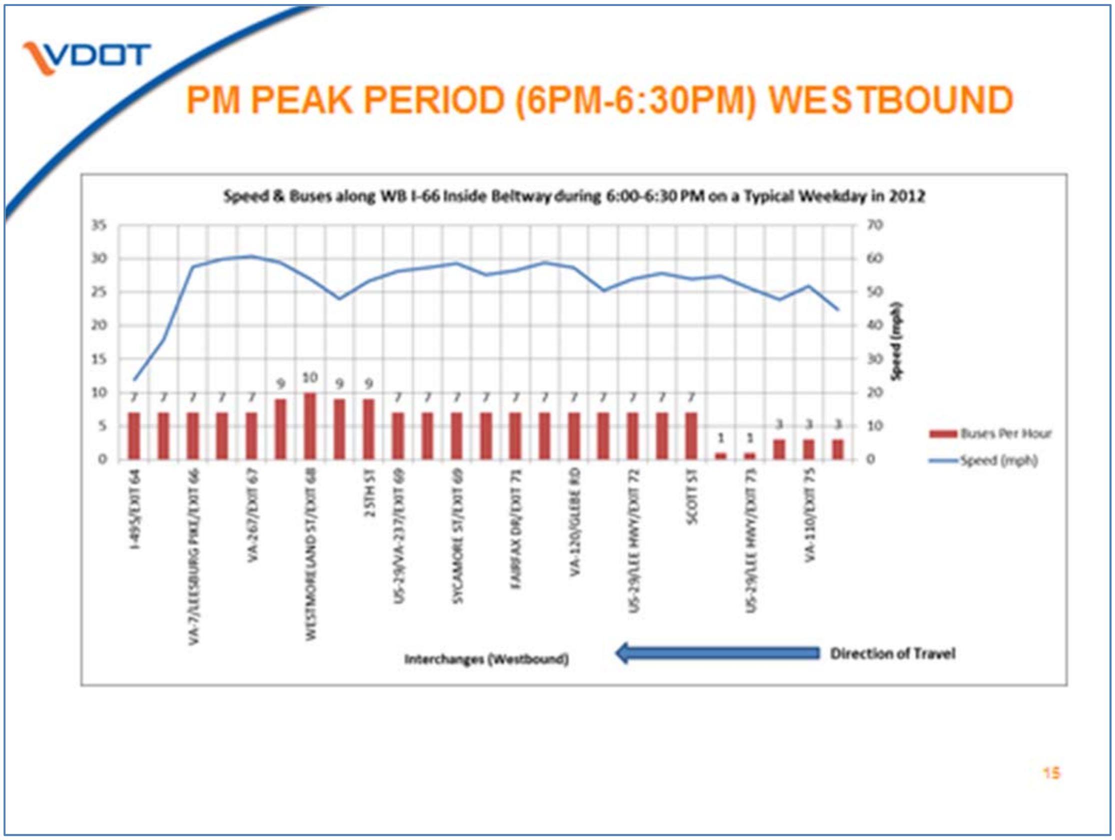

PM PEAK PERIOD (2PM-3PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 2:00-3:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
10

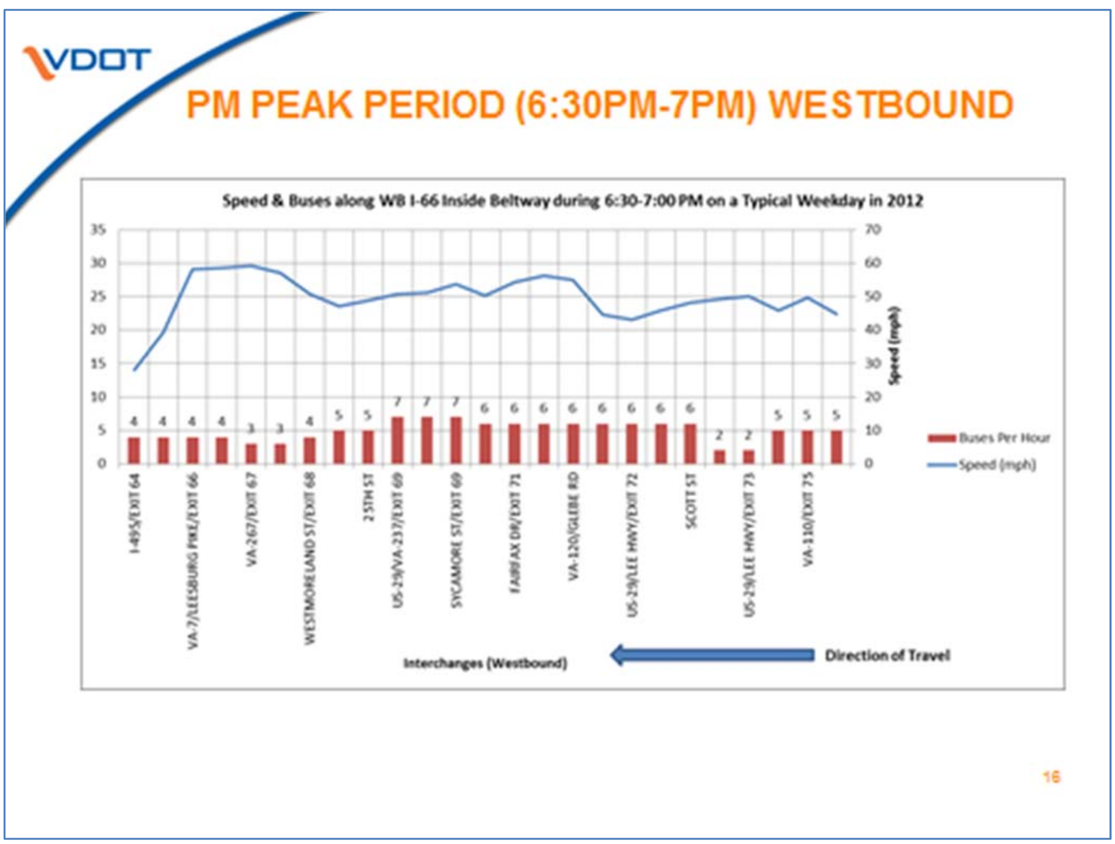

VDOT
PM PEAK PERIOD (3PM-3:30PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 3:00-3:30 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
11

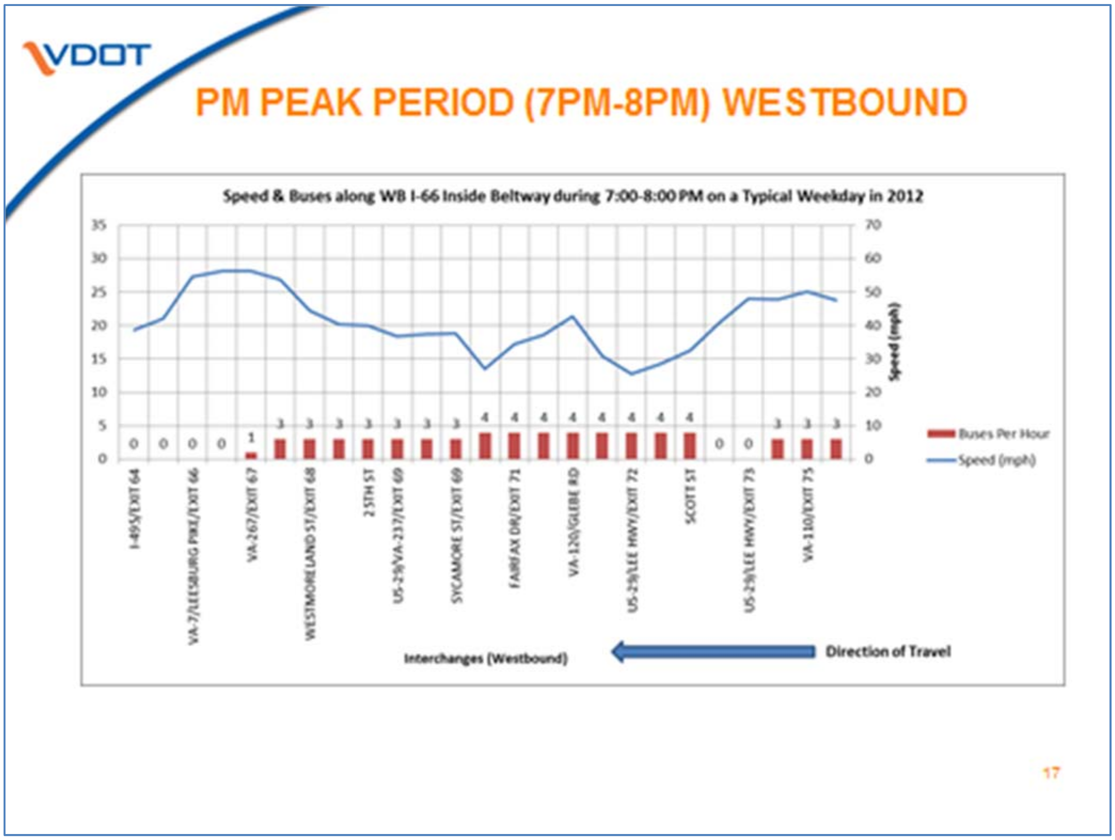

VDOT
PM PEAK PERIOD (3:30PM-4PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 3:30-4:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
12


VDOT
PM PEAK PERIOD (4PM-5PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 4:00-5:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
13

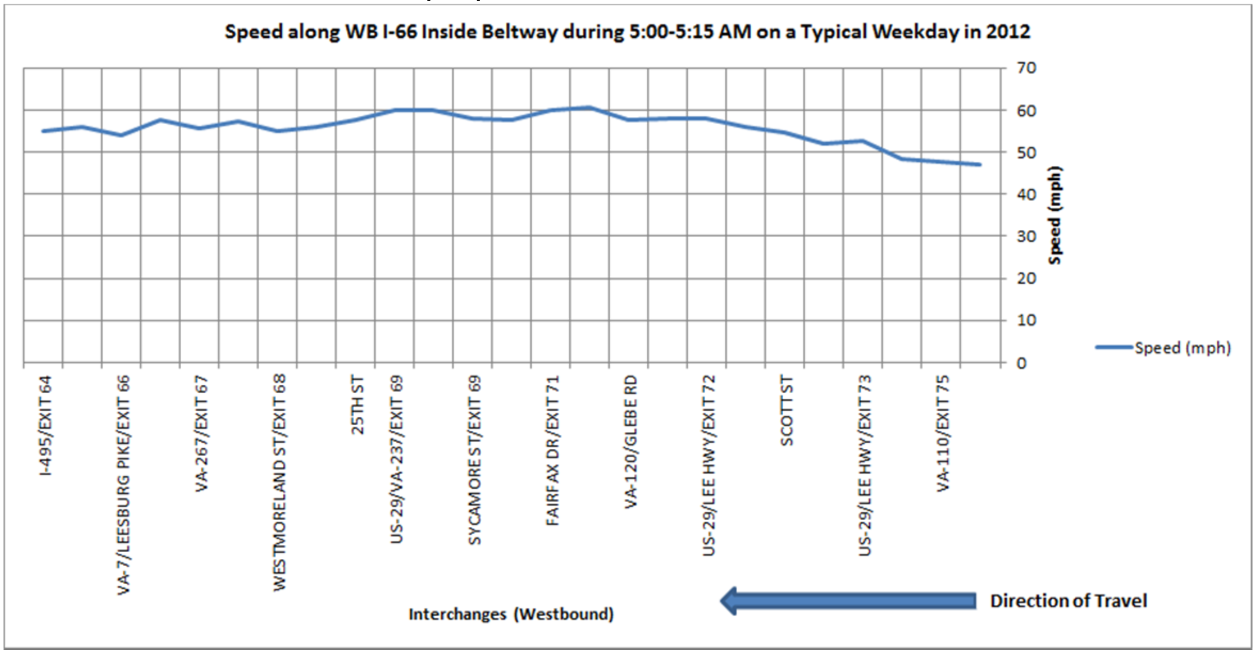

VDOT
PM PEAK PERIOD (5PM-6PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 5:00-6:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
14

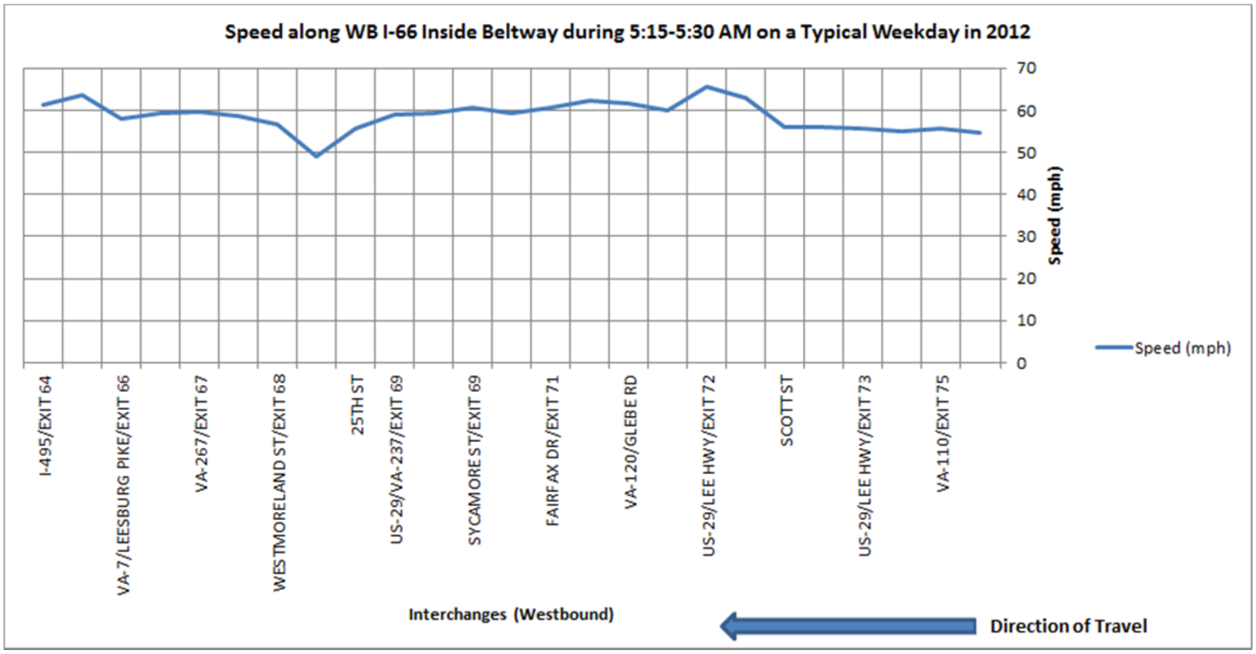

VDOT
PM PEAK PERIOD (6PM-6:30PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 6:00-6:30 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
15

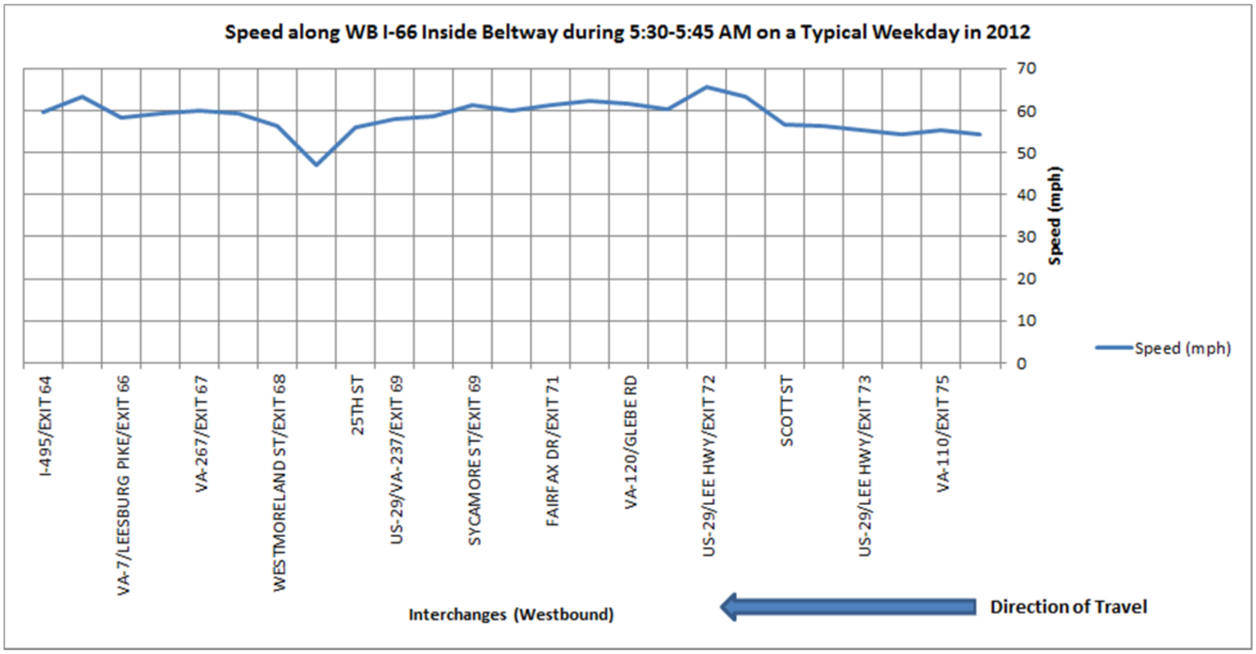

VDOT
PM PEAK PERIOD (6:30PM-7PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 6:30-7:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
16

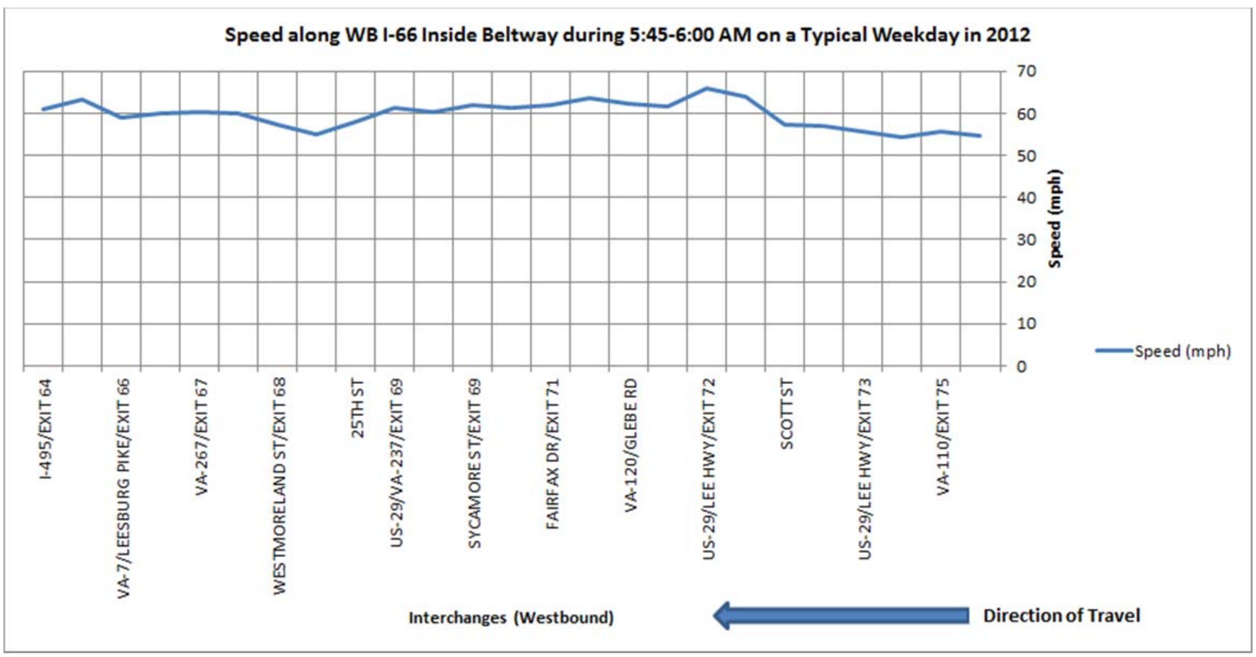

VDOT
PM PEAK PERIOD (7PM-8PM) WESTBOUND
Speed & Buses along WB I-66 Inside Beltway during 7:00-8:00 PM on a Typical Weekday in 2012
Speed (mph)
Buses Per Hour
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel
17

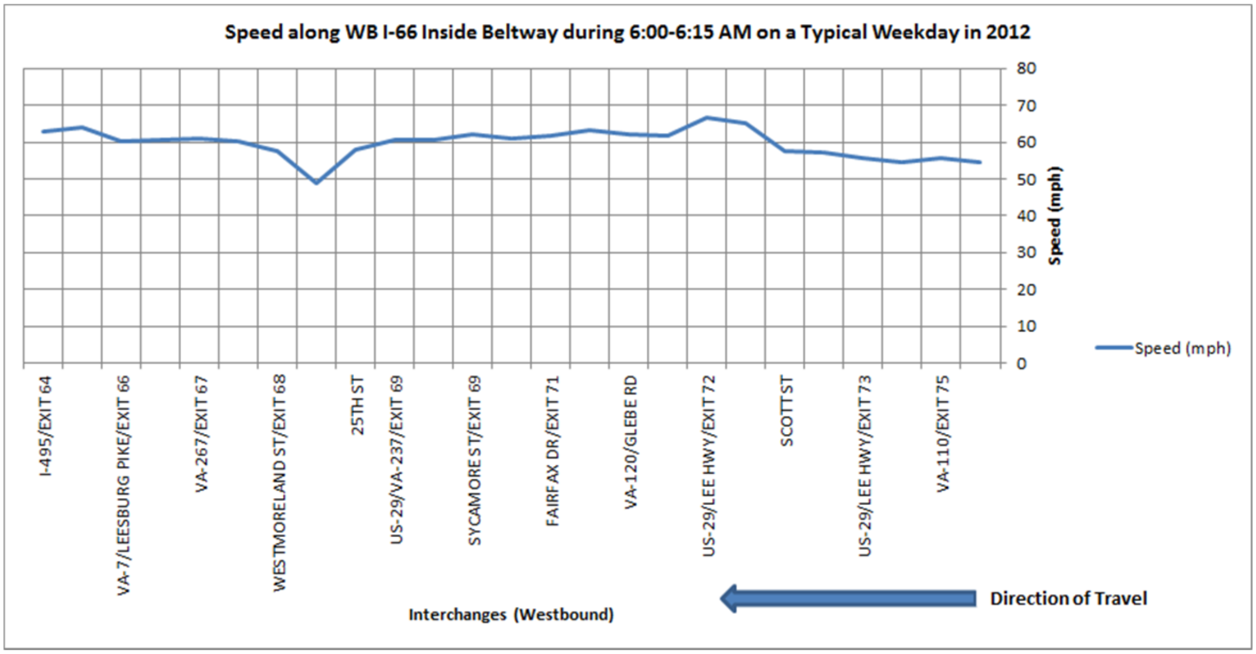
2012, Off-Peak Direction of Travel (AM)

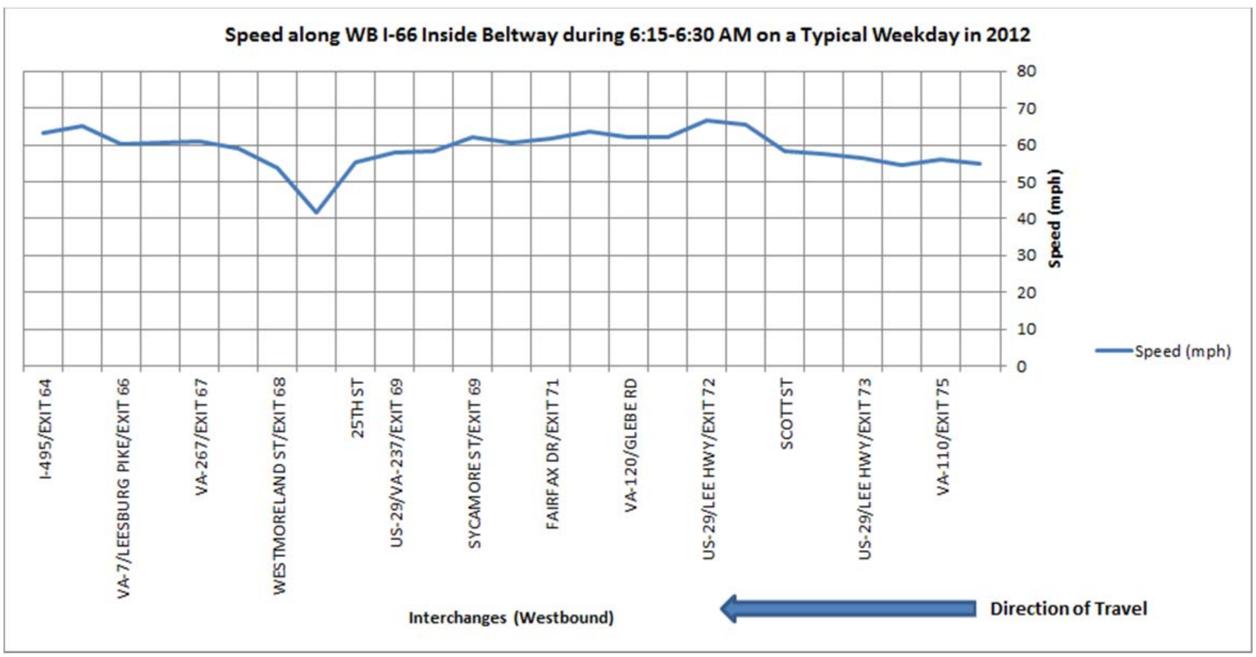


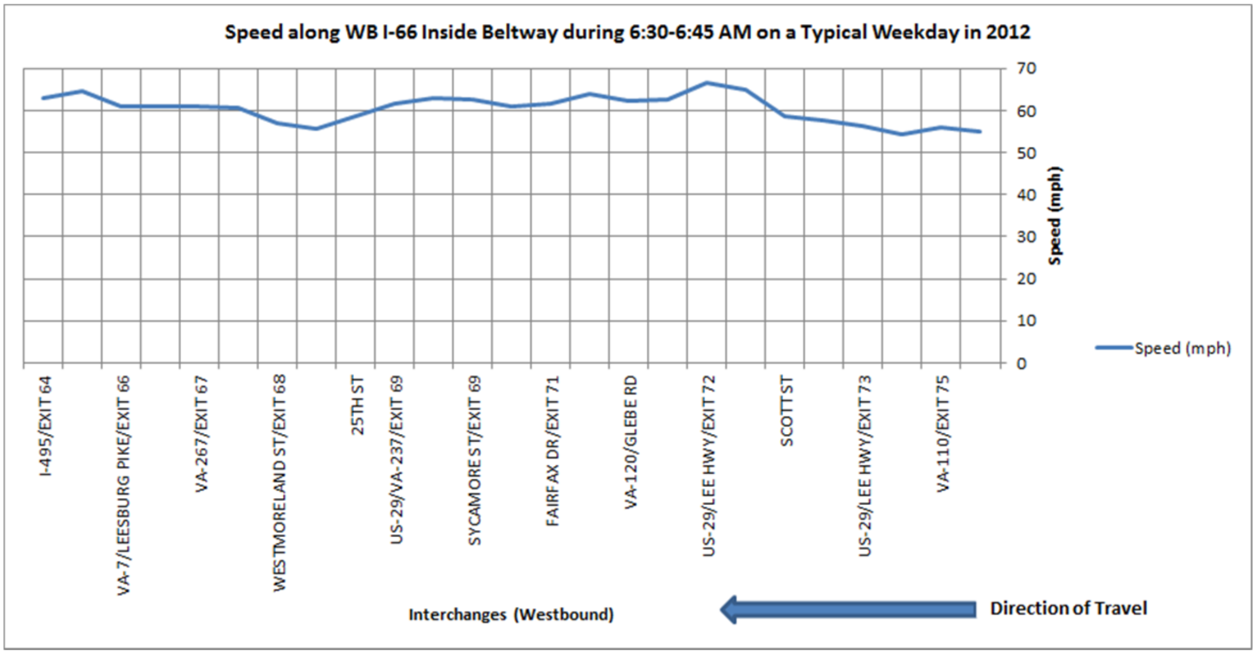


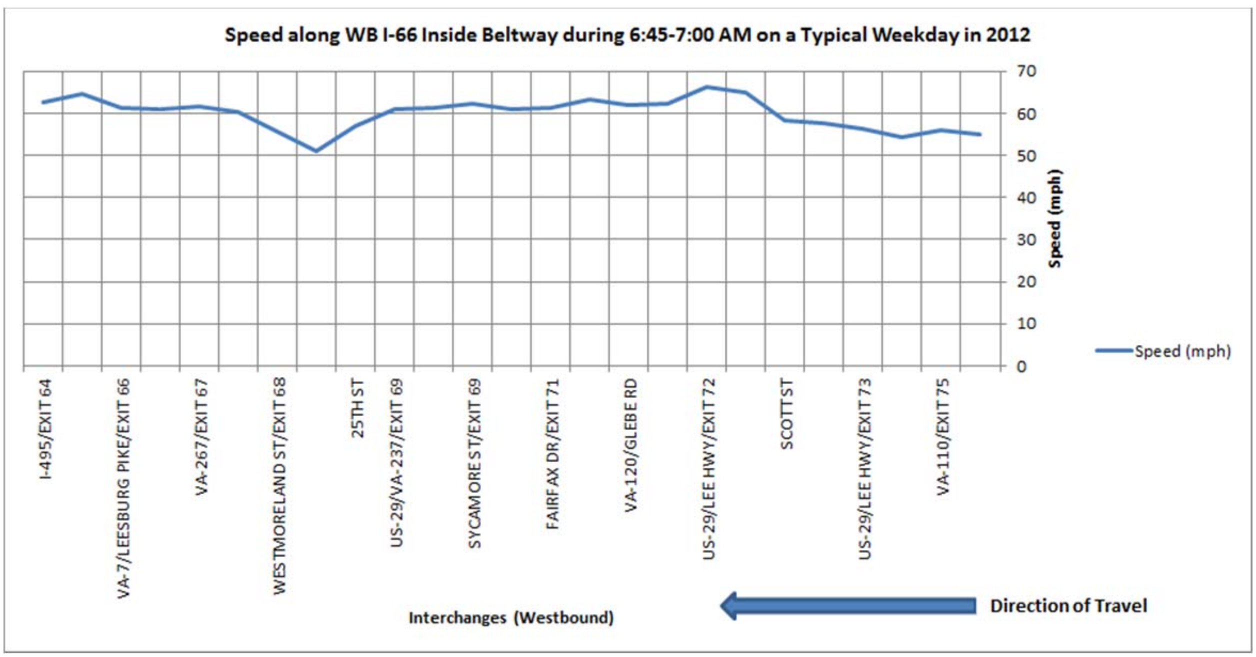

Speed along WB I-66 Inside Beltway during 5:30-5:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

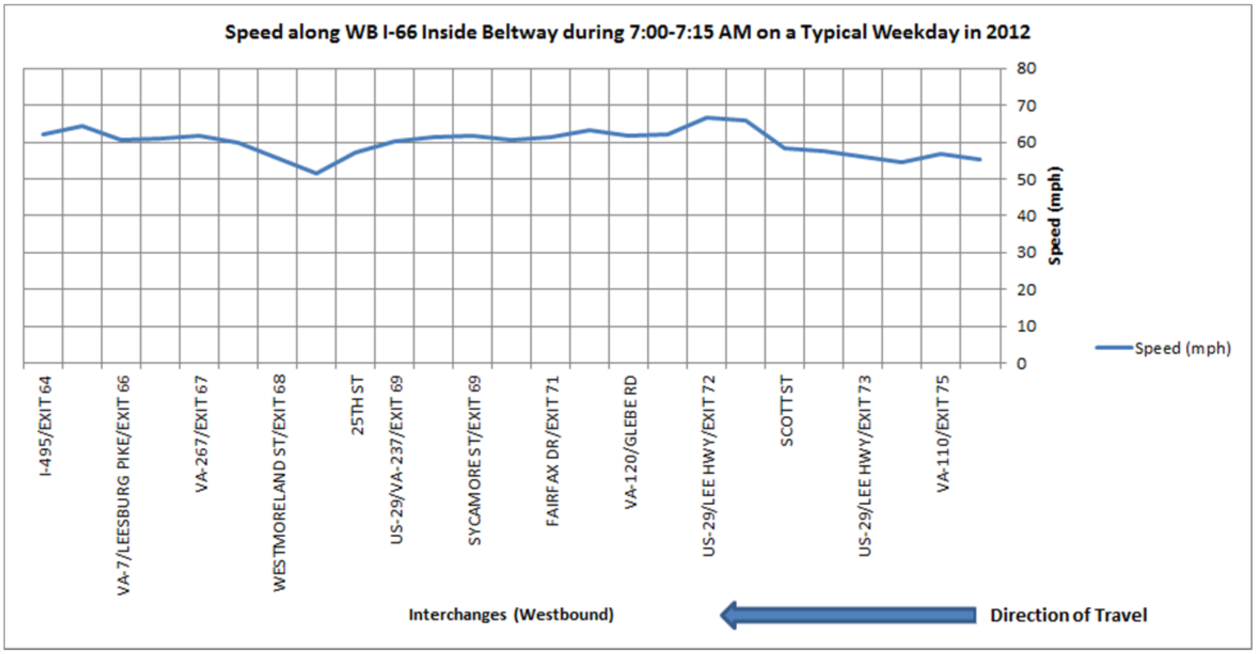

Speed along WB I-66 Inside Beltway during 5:45-6:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

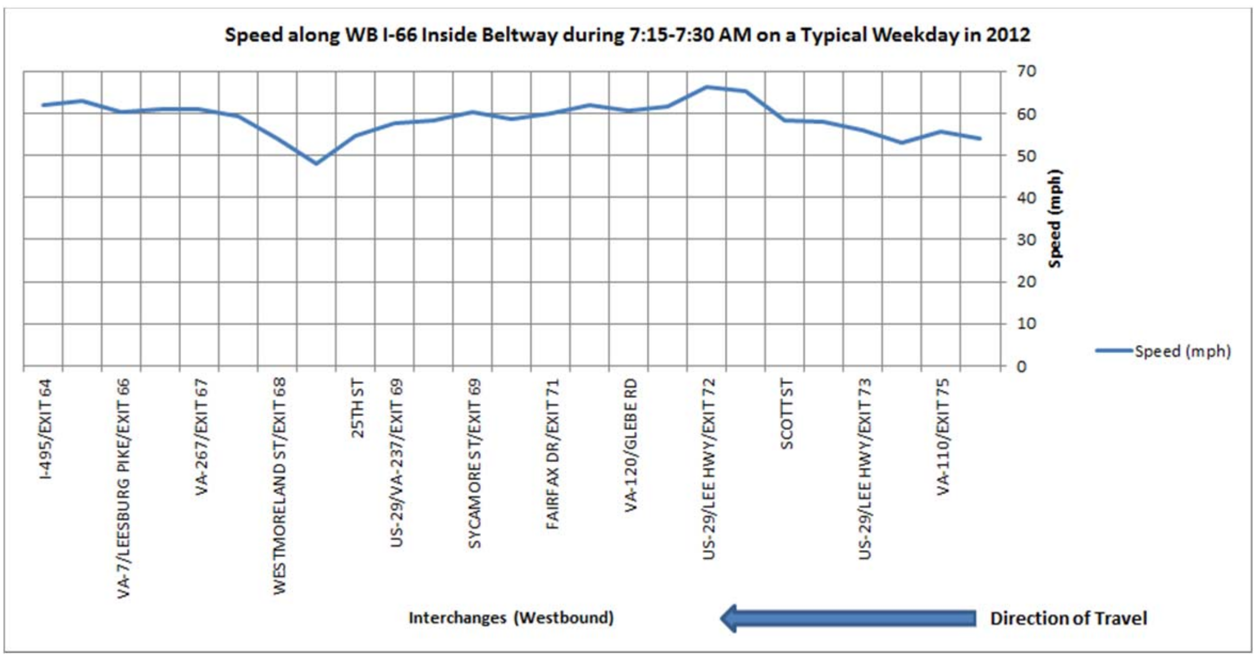

Speed along WB I-66 Inside Beltway during 6:00-6:15 AM on a Typical Weekday in 2012
80
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

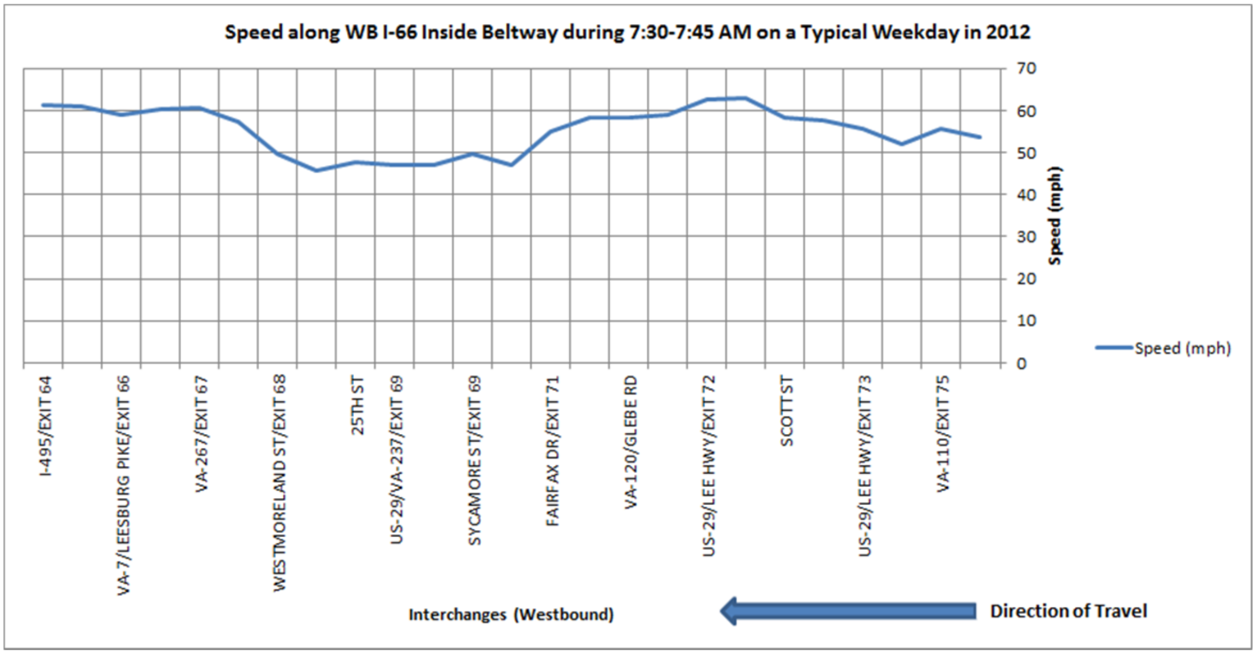

Speed along WB I-66 Inside Beltway during 6:15-6:30 AM on a Typical Weekday in 2012
80
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

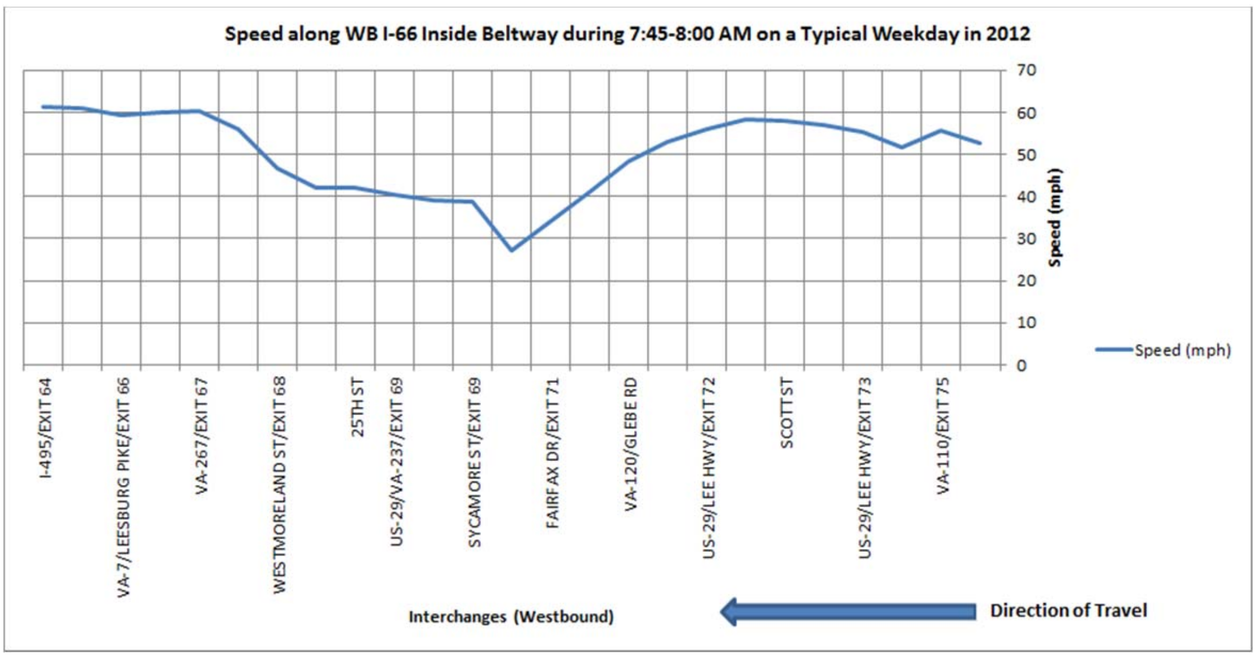

Speed along WB I-66 Inside Beltway during 6:30-6:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

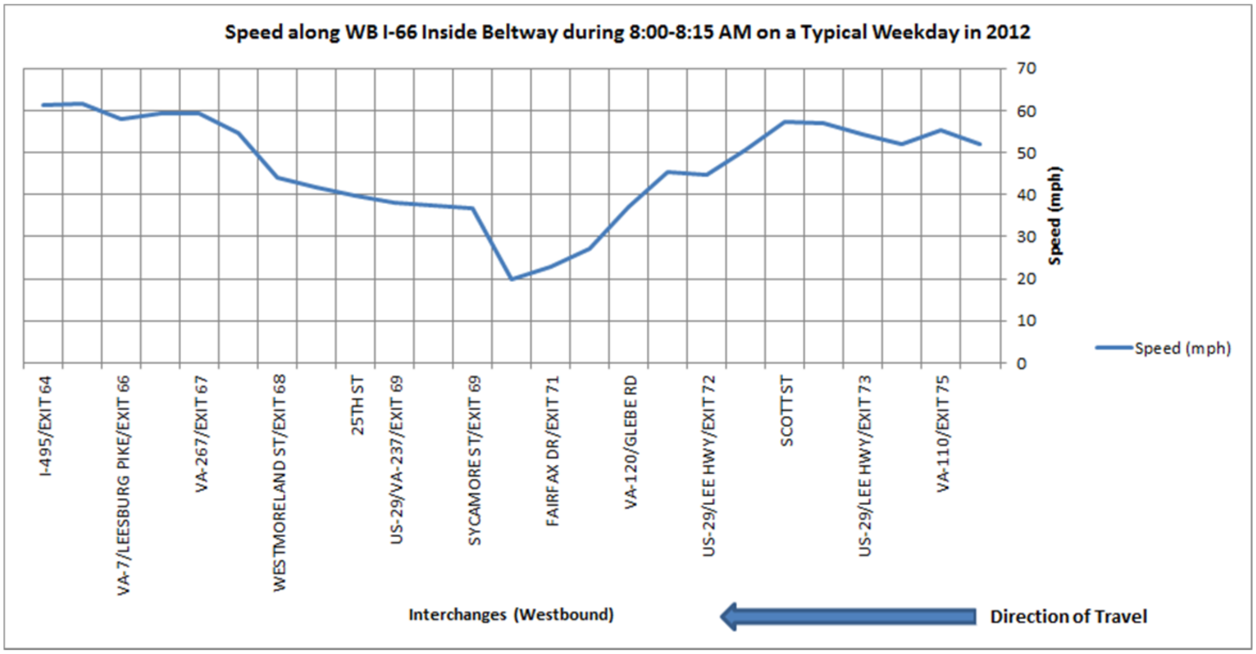

Speed along WB I-66 Inside Beltway during 6:45-7:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

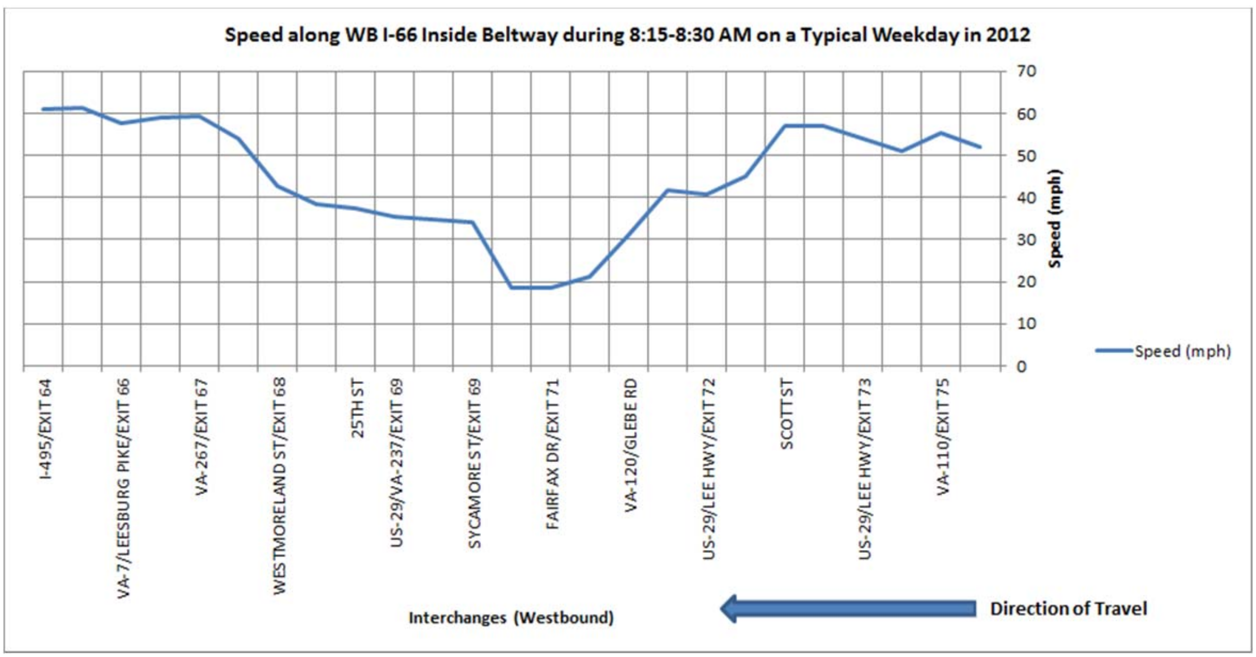

Speed along WB I-66 Inside Beltway during 7:00-7:15 AM on a Typical Weekday in 2012
80
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

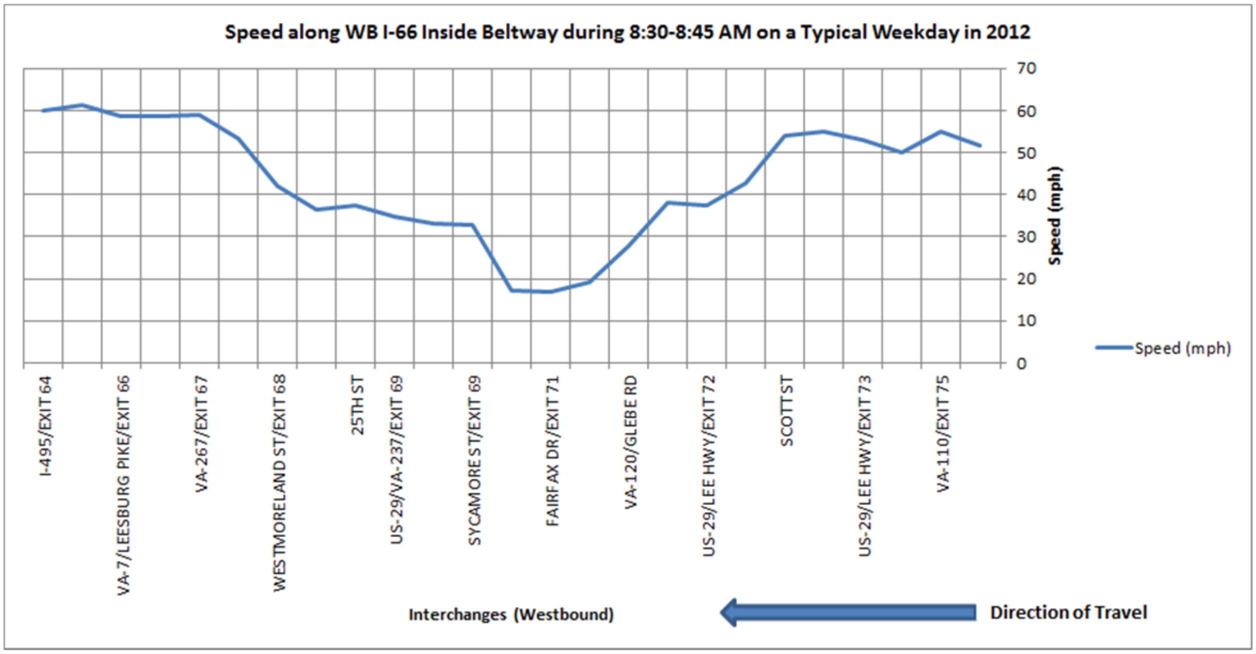

Speed along WB I-66 Inside Beltway during 7:15-7:30 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

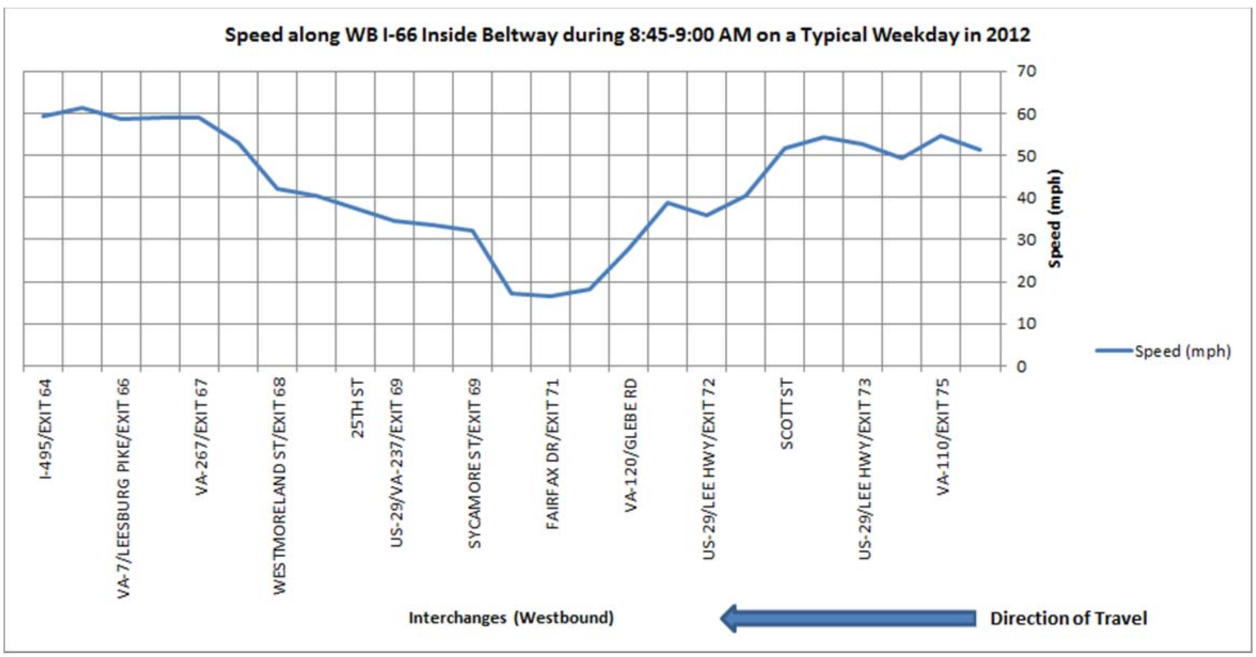

Speed along WB I-66 Inside Beltway during 7:30-7:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

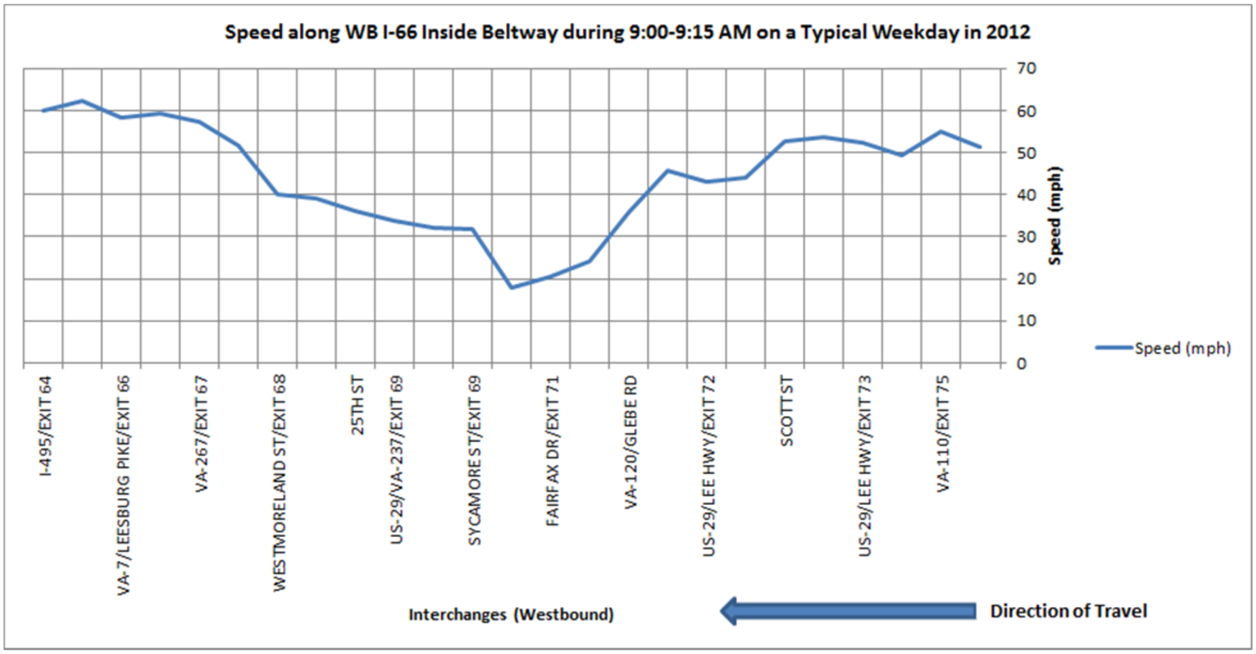

Speed along WB I-66 Inside Beltway during 7:45-8:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

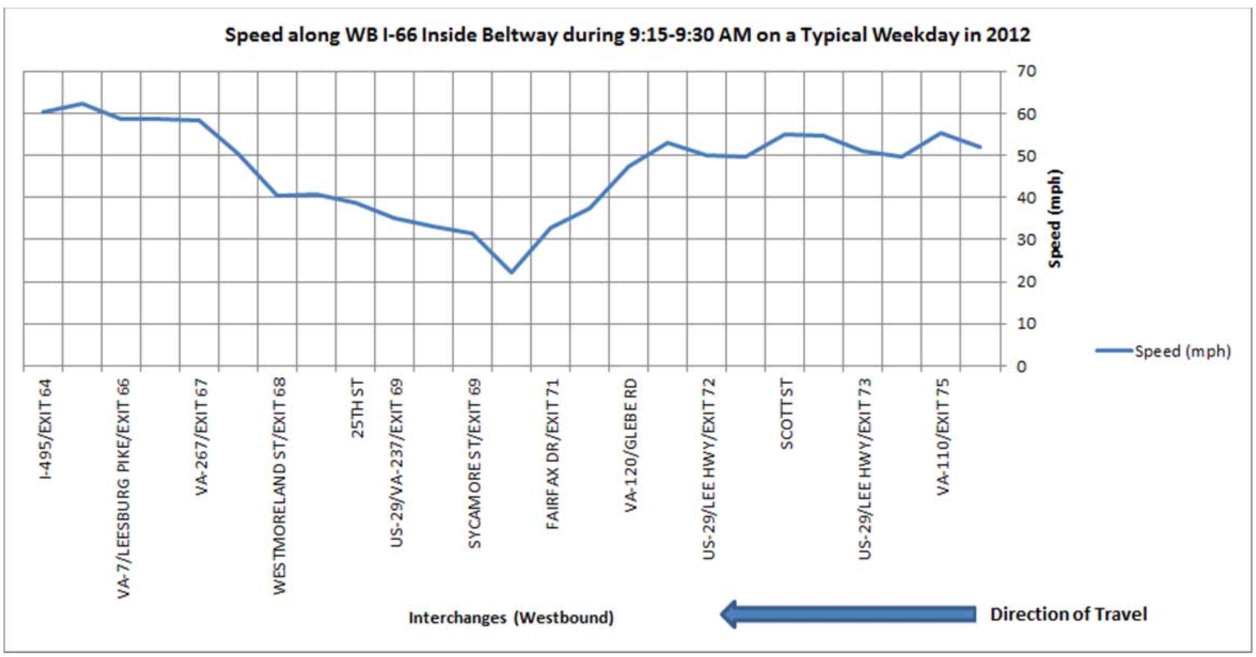

Speed along WB I-66 Inside Beltway during 8:00-8:15 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

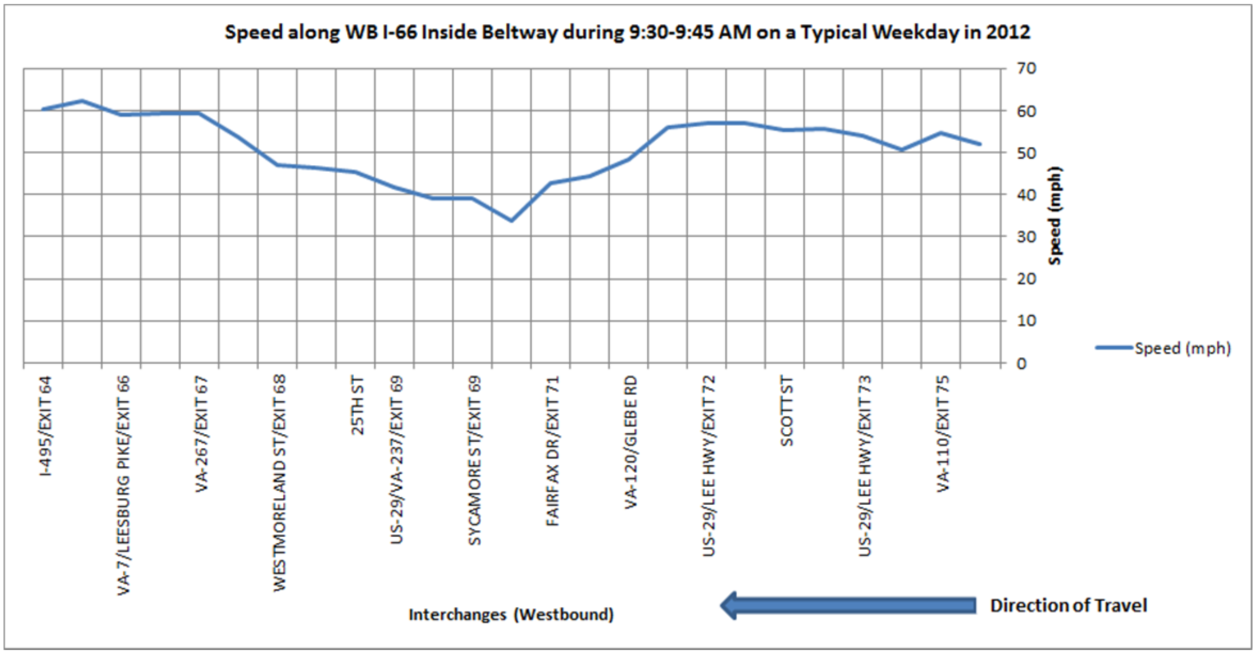

Speed along WB I-66 Inside Beltway during 8:15-8:30 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

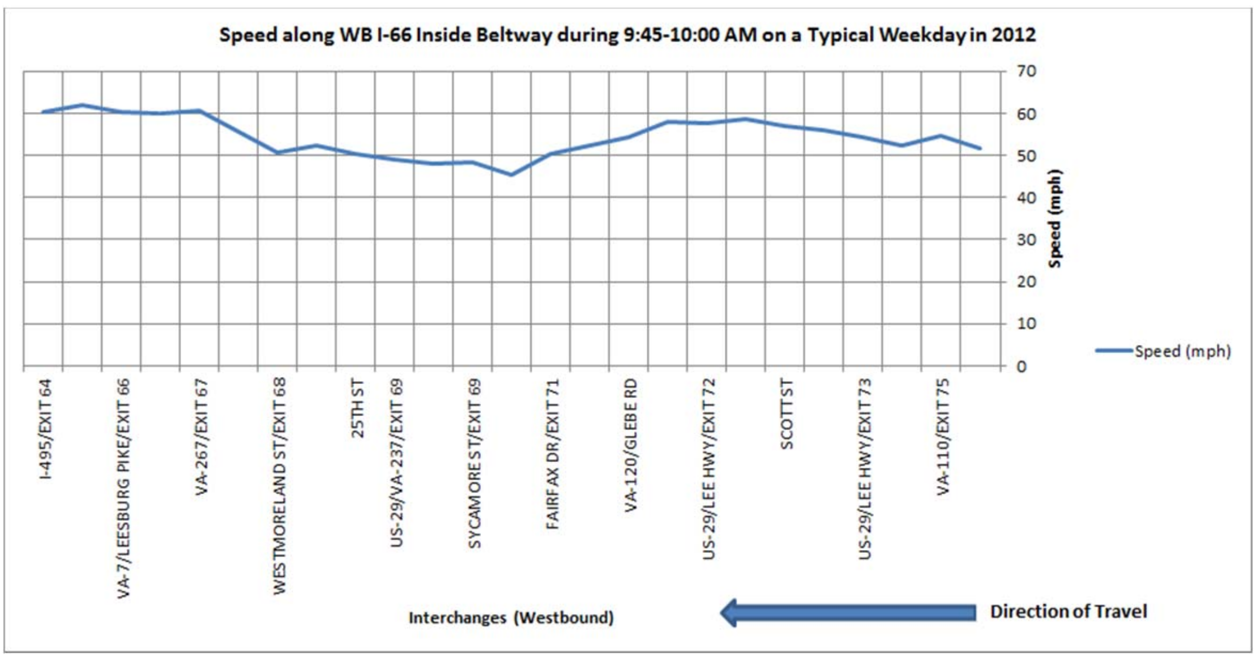

Speed along WB I-66 Inside Beltway during 8:30-8:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

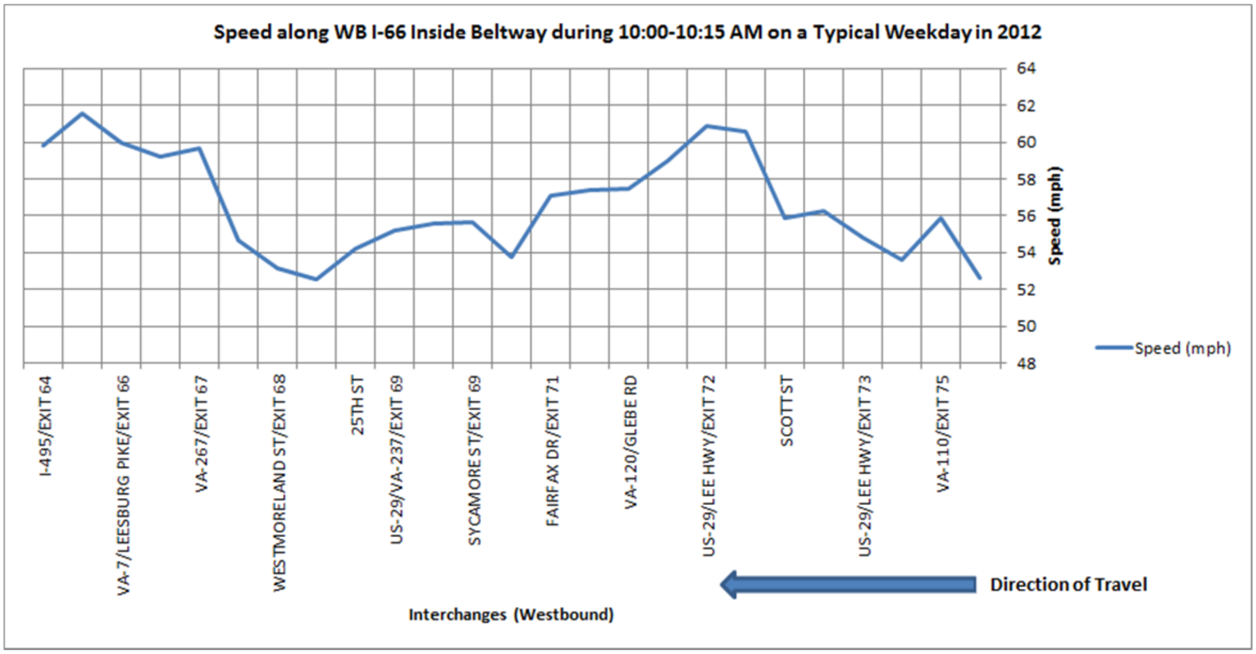

Speed along WB I-66 Inside Beltway during 8:45-9:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

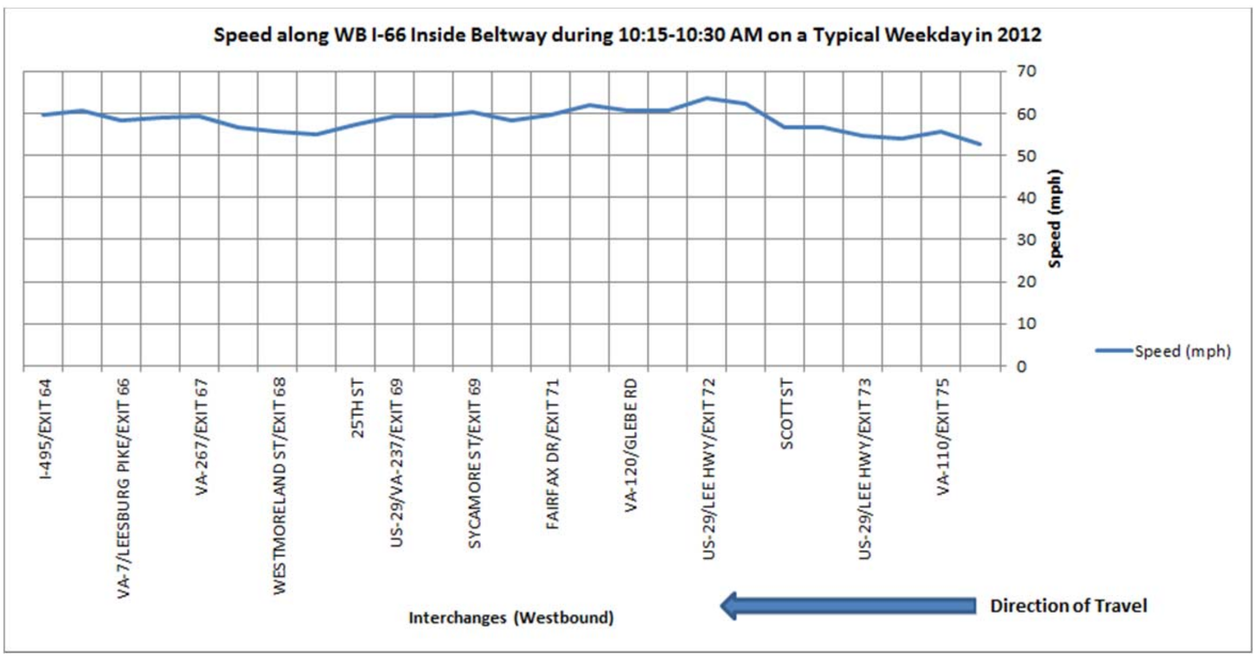

Speed along WB I-66 Inside Beltway during 9:00-9:15 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

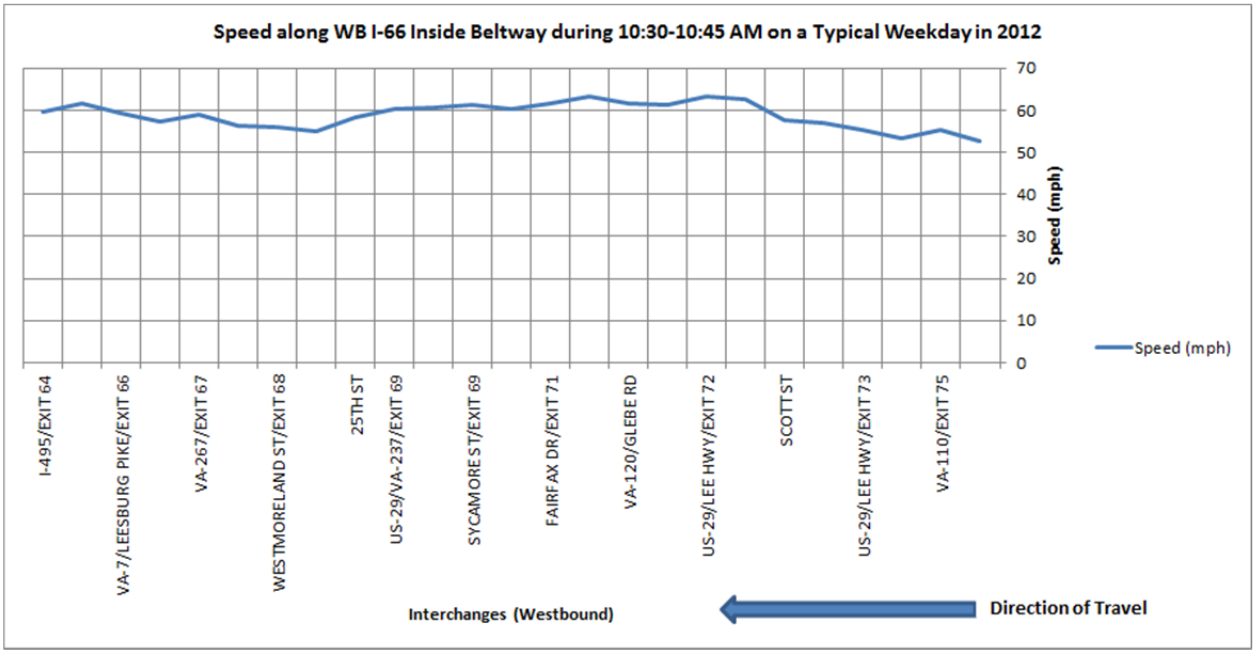

Speed along WB I-66 Inside Beltway during 9:15-9:30 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

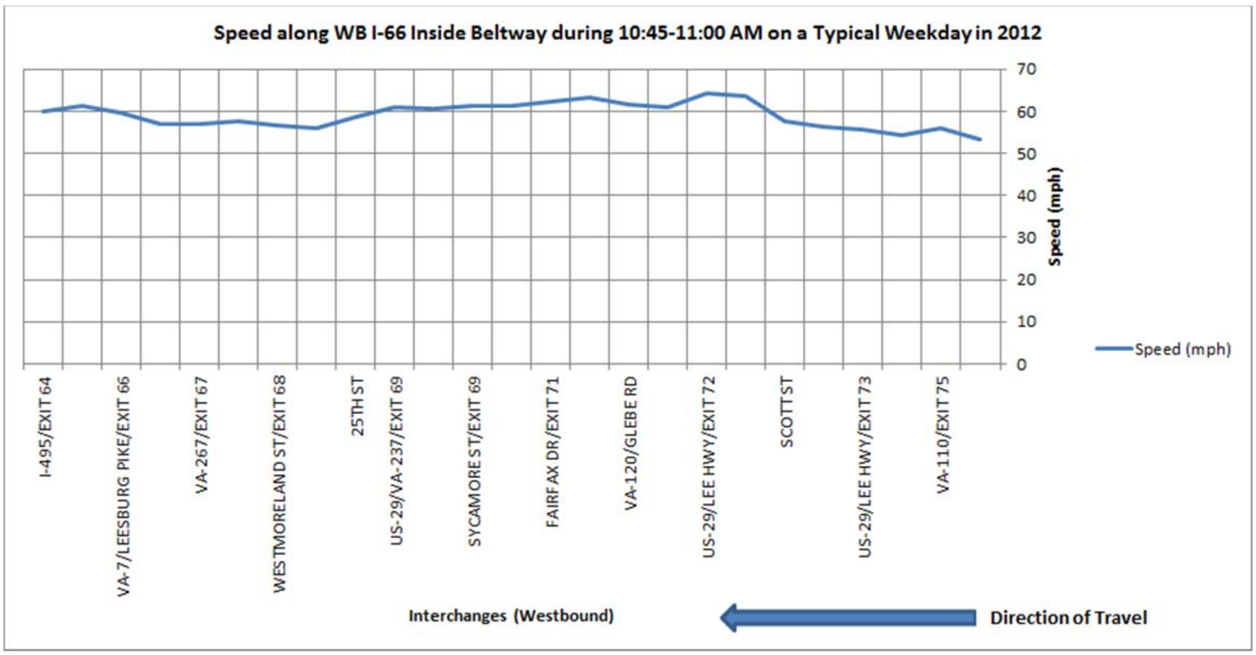

Speed along WB I-66 Inside Beltway during 9:30-9:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel


Speed along WB I-66 Inside Beltway during 9:45-10:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

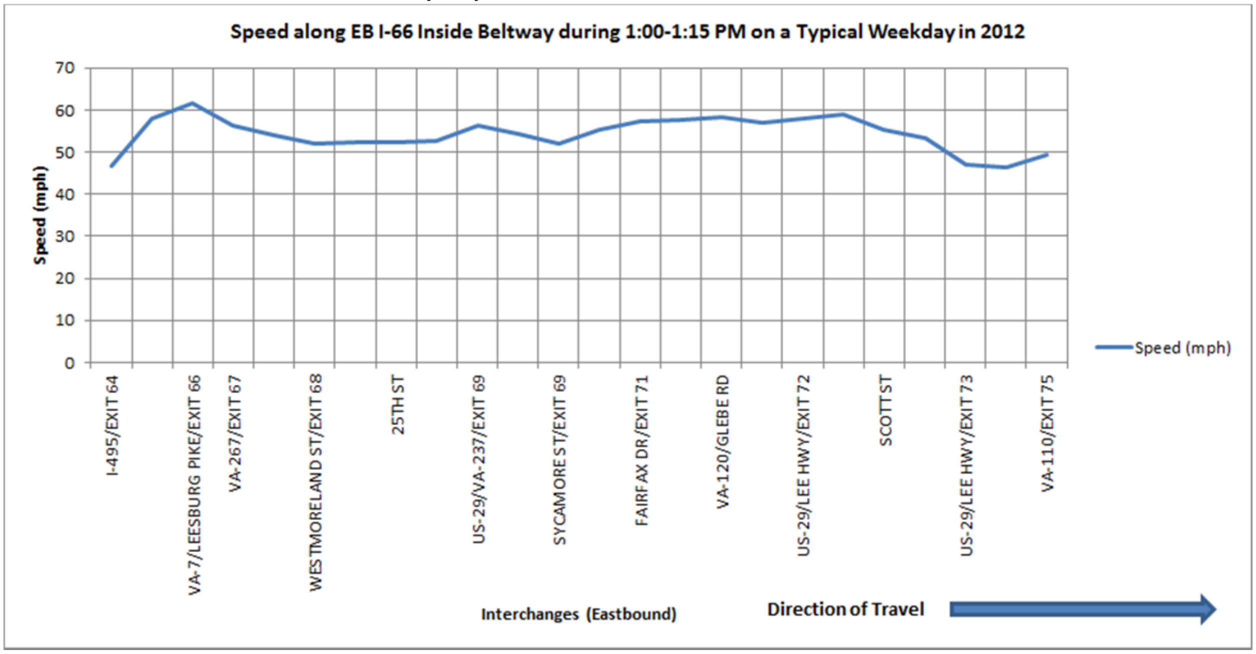

Speed along WB I-66 Inside Beltway during 10:00-10:15 AM on a Typical Weekday in 2012
64
62
60
58
56
54
52
50
48
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Direction of Travel
Interchanges (Westbound)

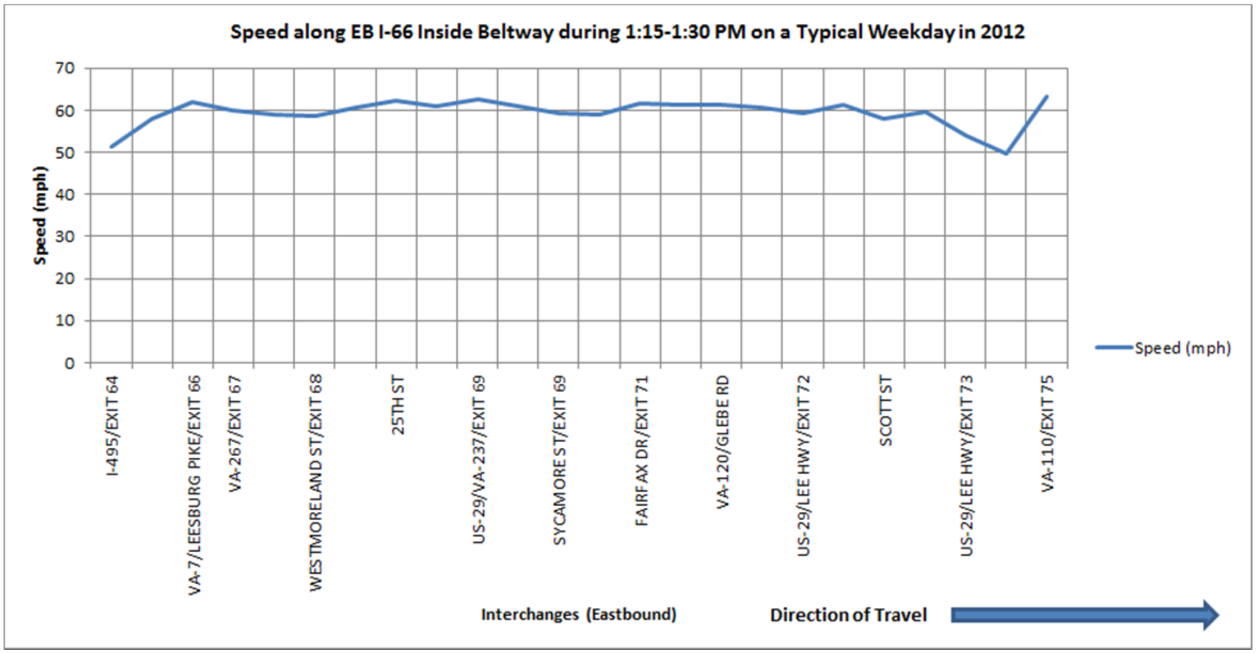

Speed along WB I-66 Inside Beltway during 10:15-10:30 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Direction of Travel
Interchanges (Westbound)

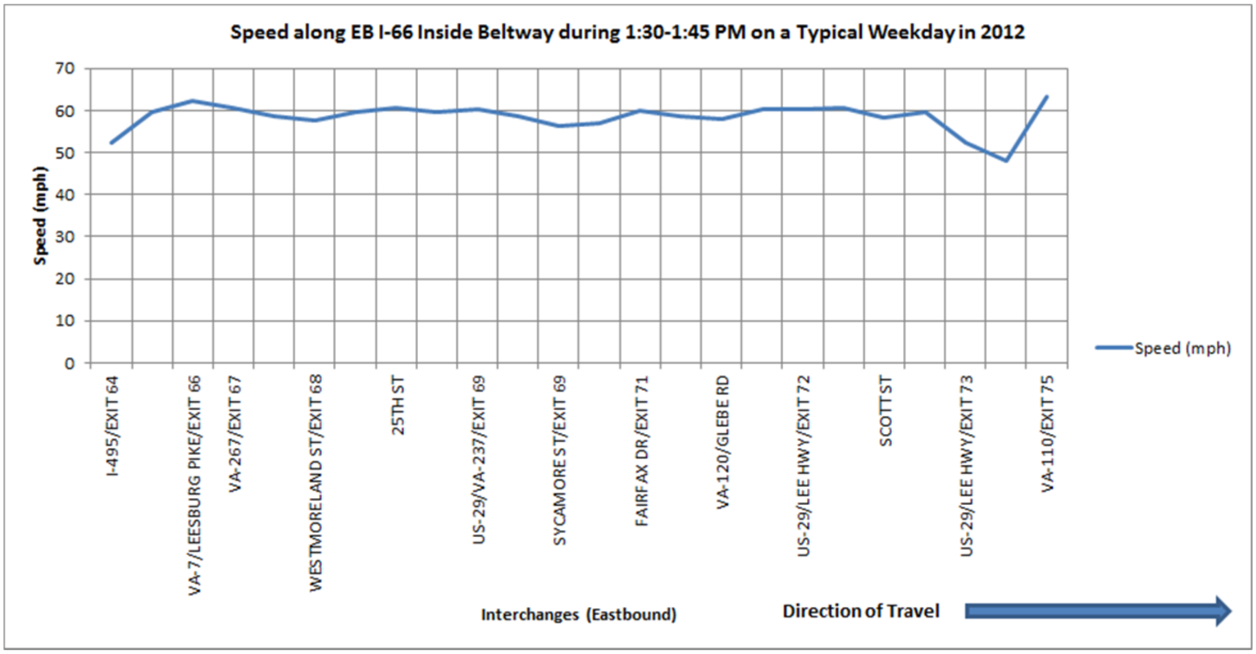

Speed along WB I-66 Inside Beltway during 10:30-10:45 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

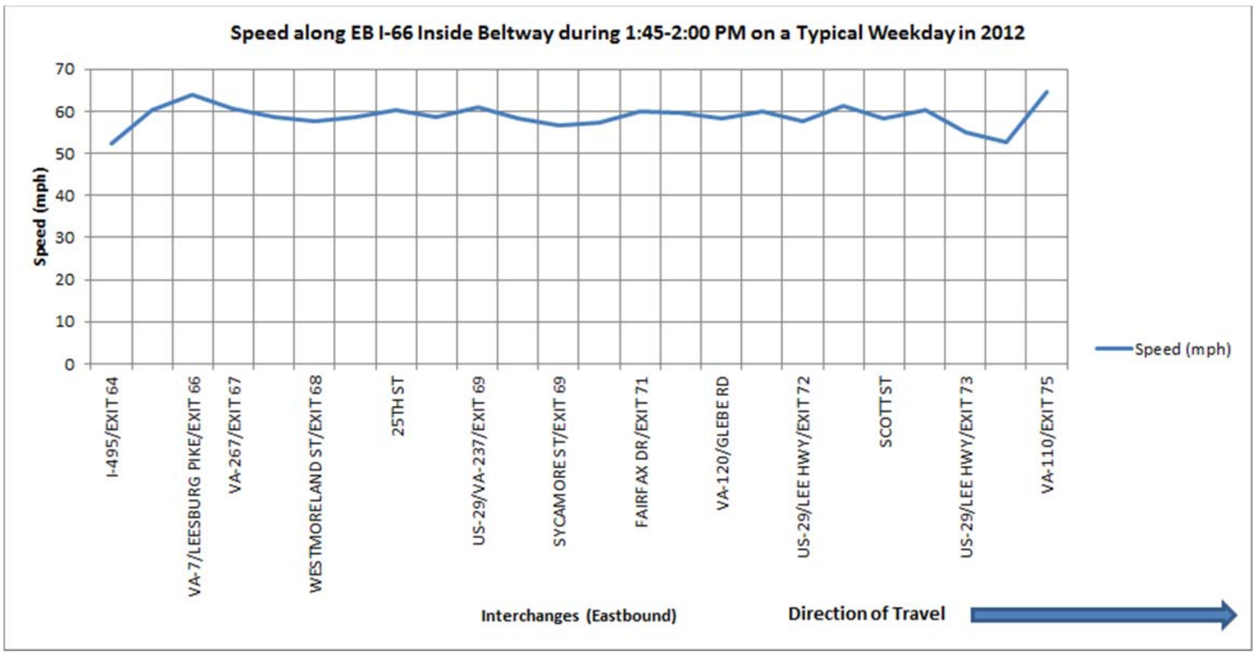

Speed along WB I-66 Inside Beltway during 10:45-11:00 AM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Westbound)
Direction of Travel

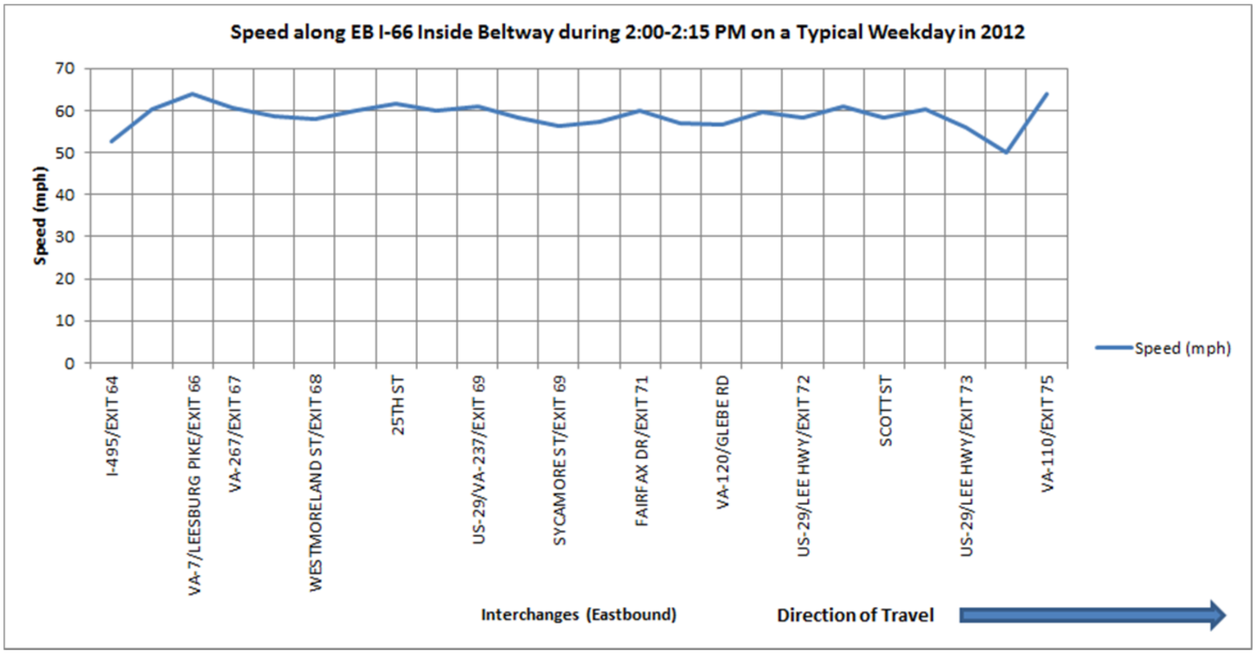
2012, Off-Peak Direction of Travel (PM)

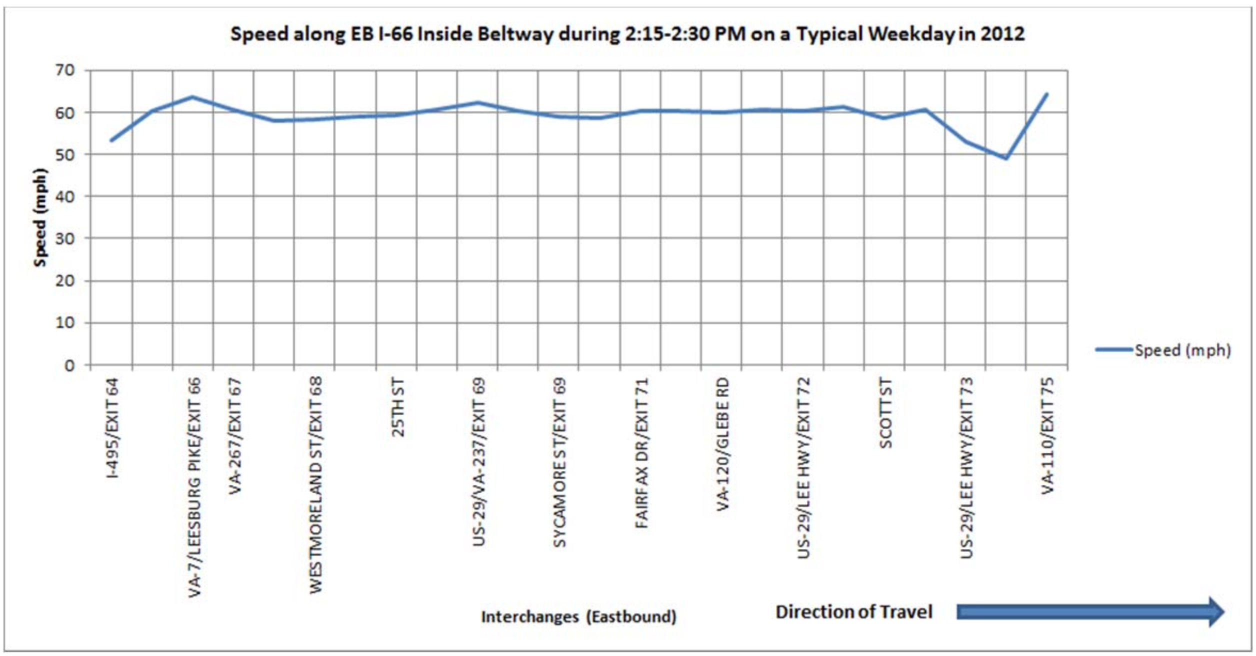


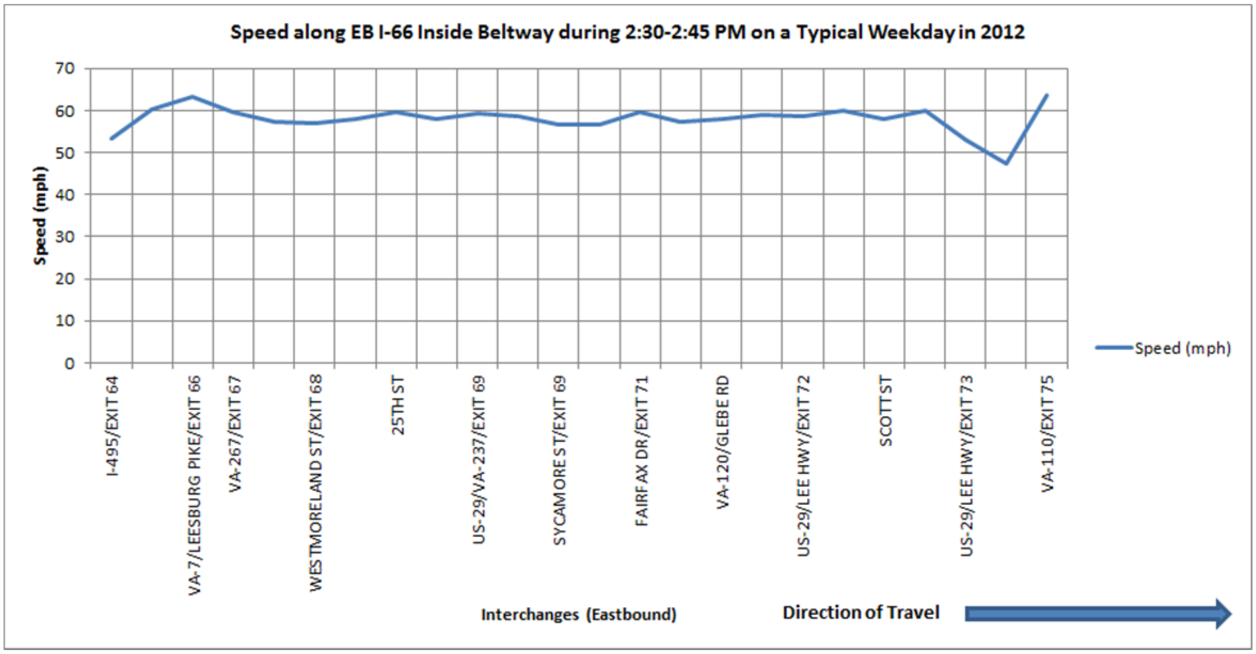


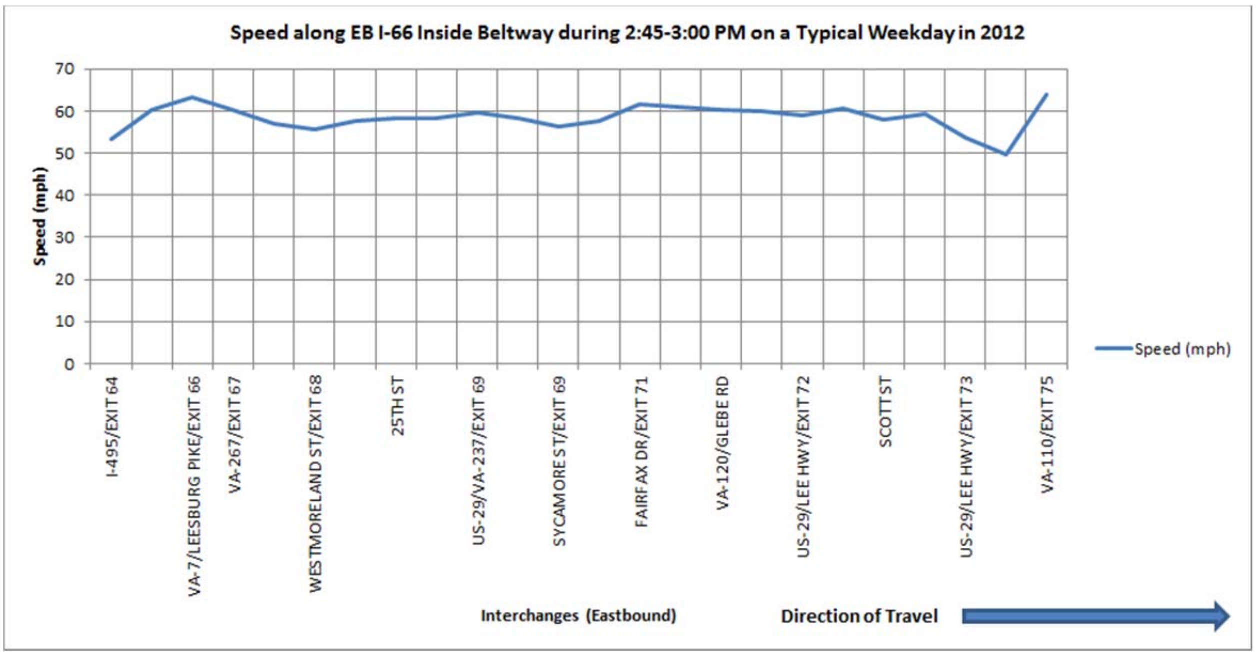

Speed along EB I-66 Inside Beltway during 1:30-1:45 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

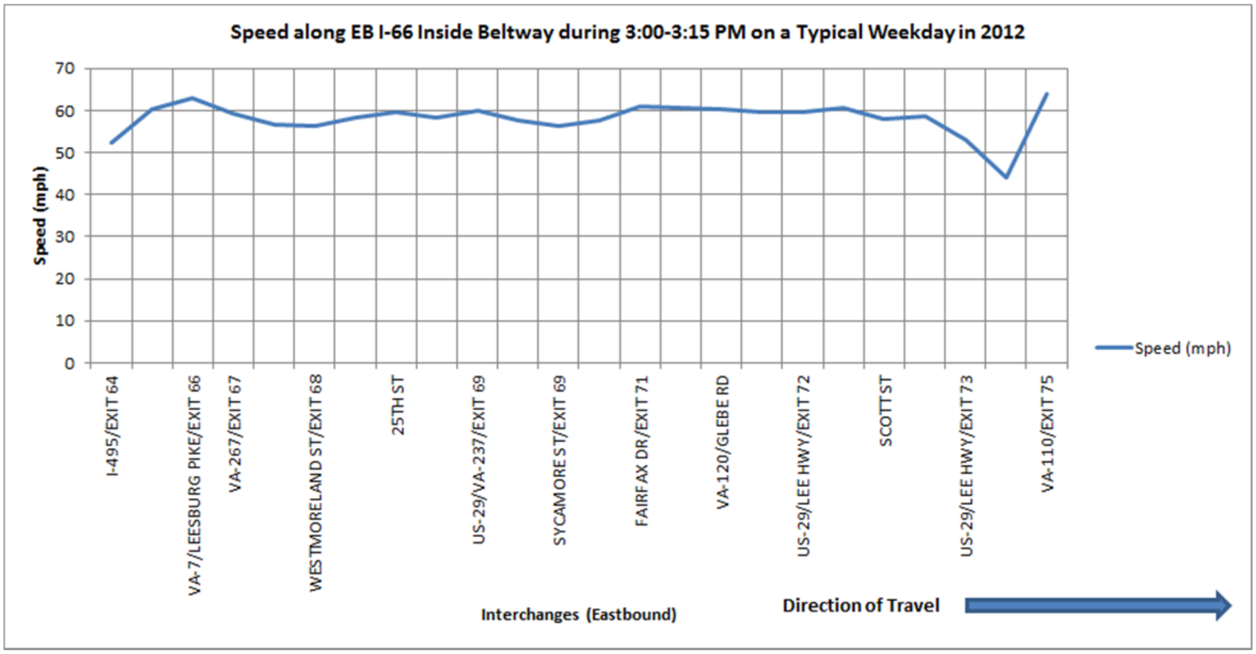

Speed along EB I-66 Inside Beltway during 1:45-2:00 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

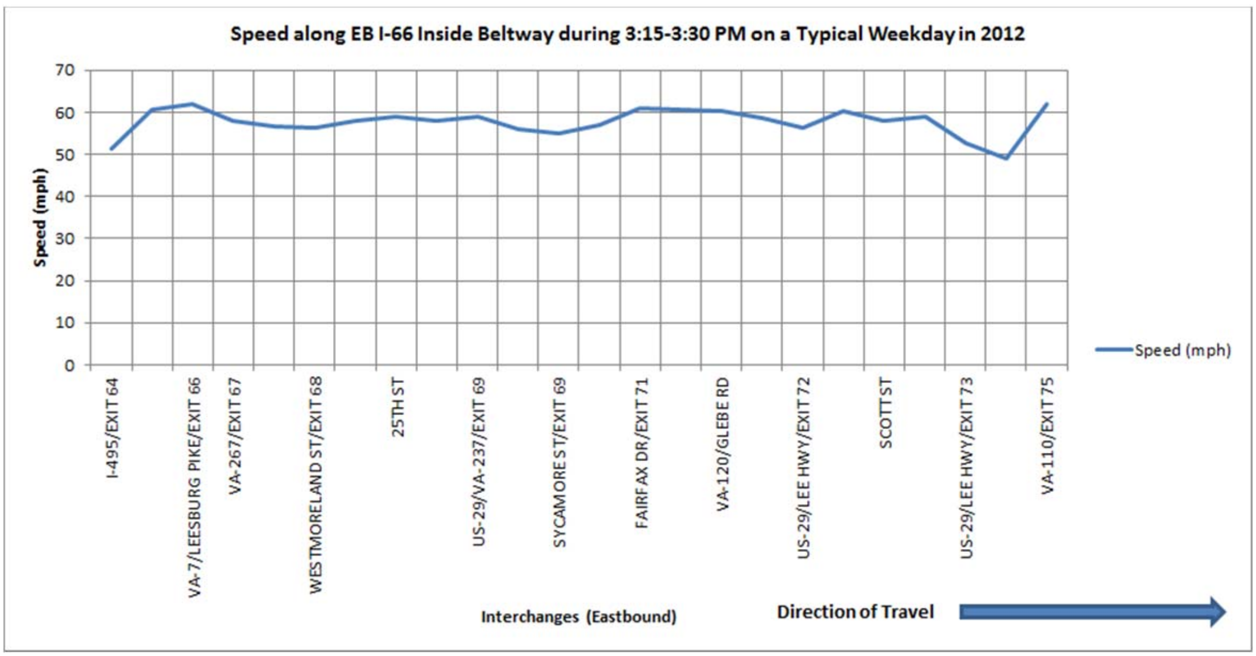

Speed along EB I-66 Inside Beltway during 2:00-2:15 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

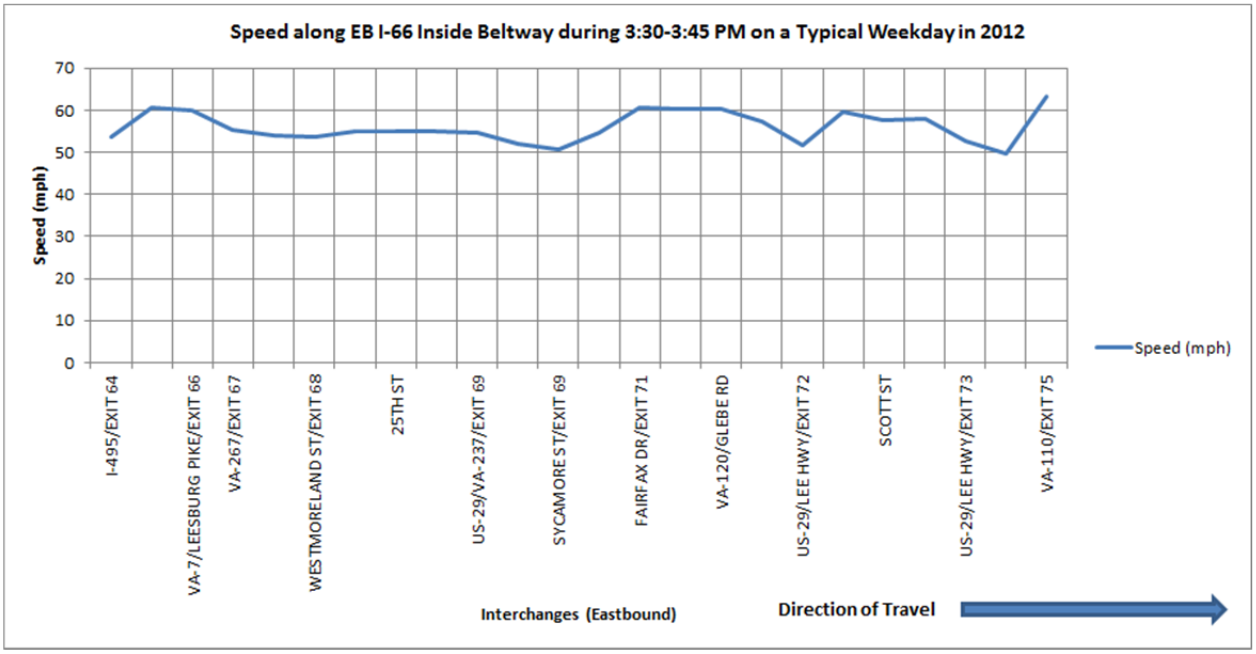

Speed along EB I-66 Inside Beltway during 2:15-2:30 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

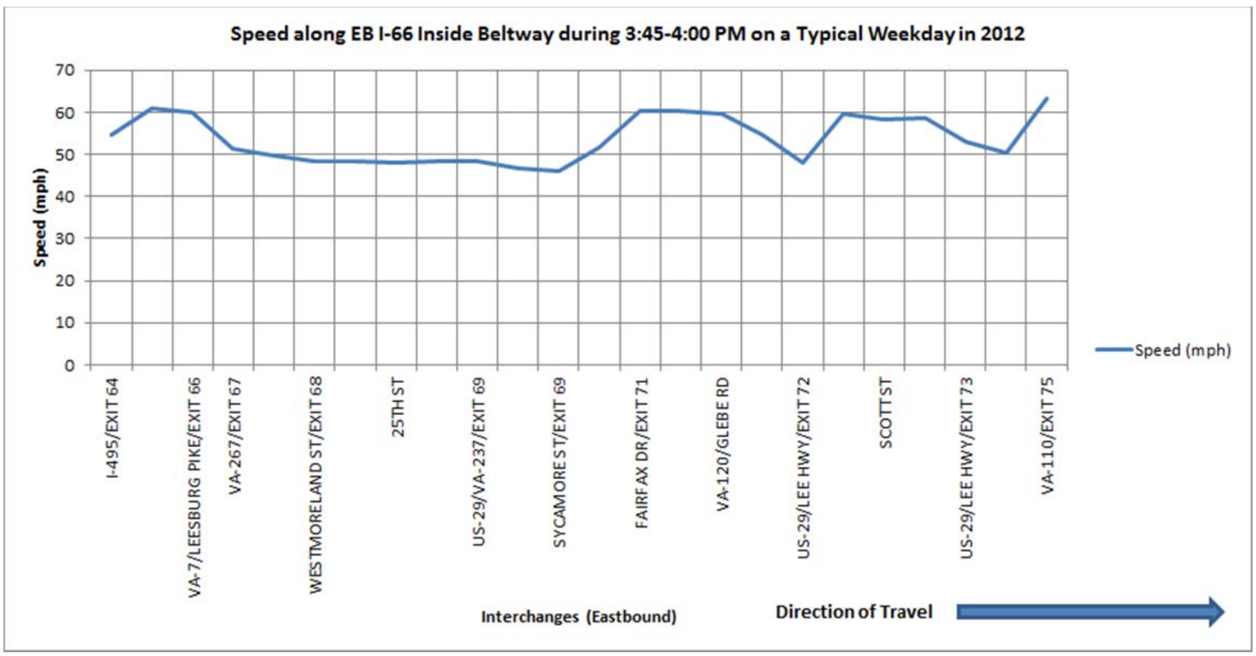

Speed along EB I-66 Inside Beltway during 2:30-2:45 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

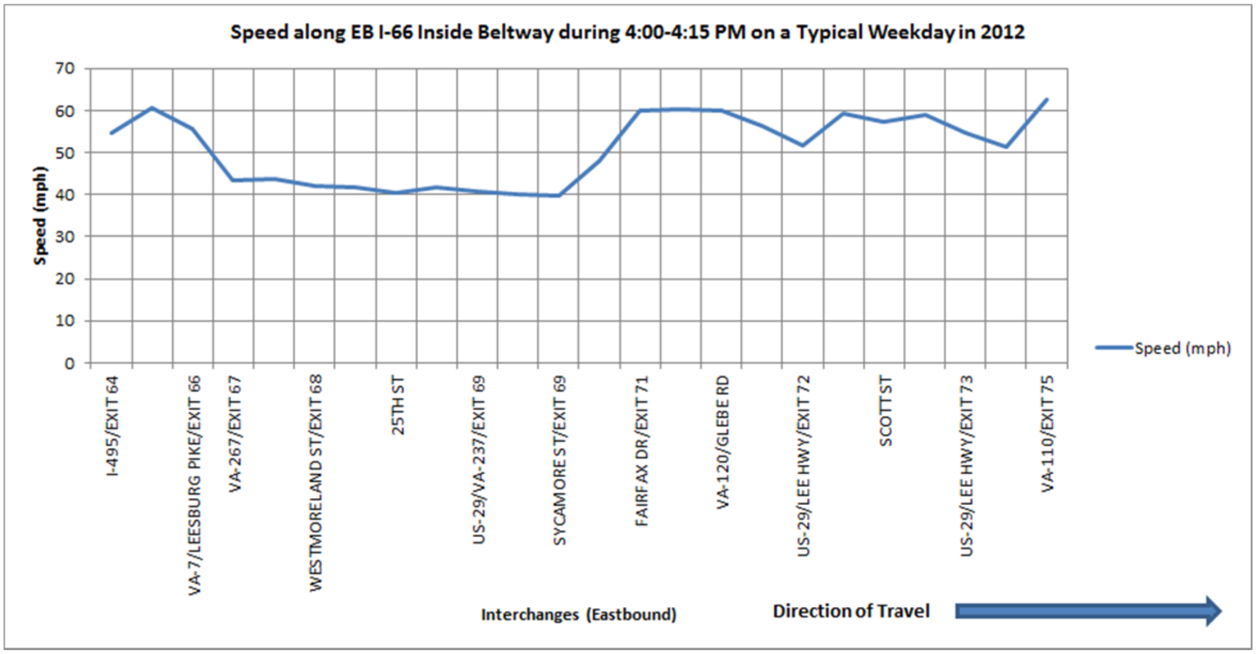

Speed along EB I-66 Inside Beltway during 2:45-3:00 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

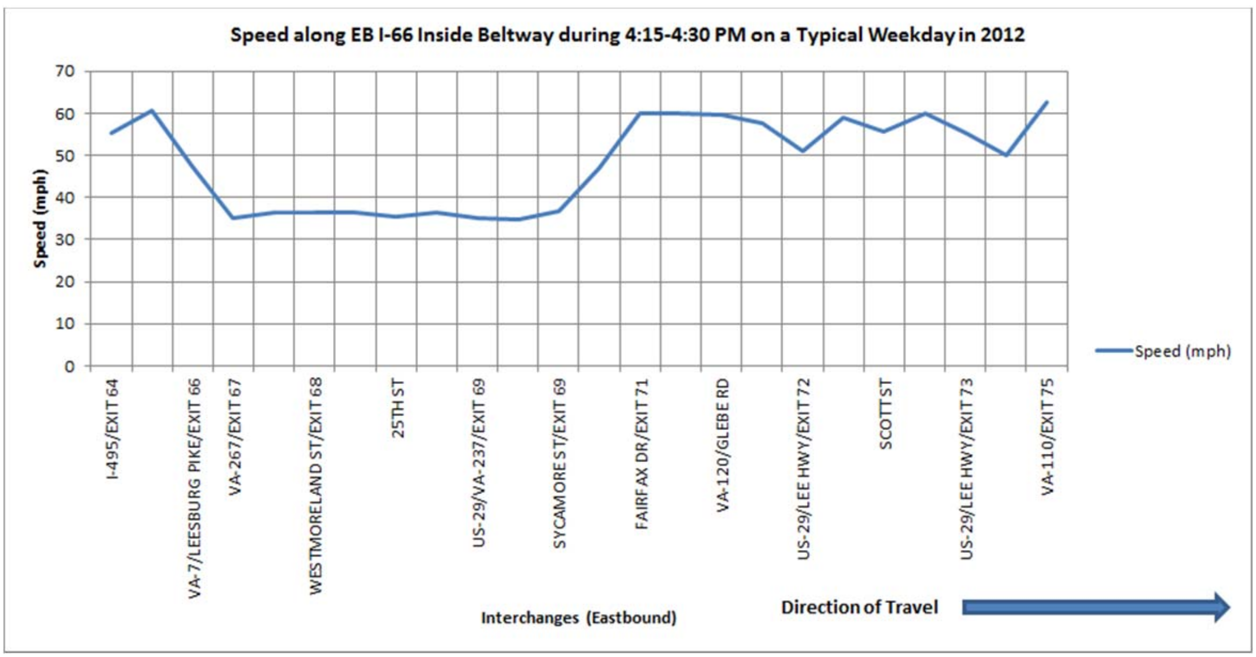

Speed along EB I-66 Inside Beltway during 3:00-3:15 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

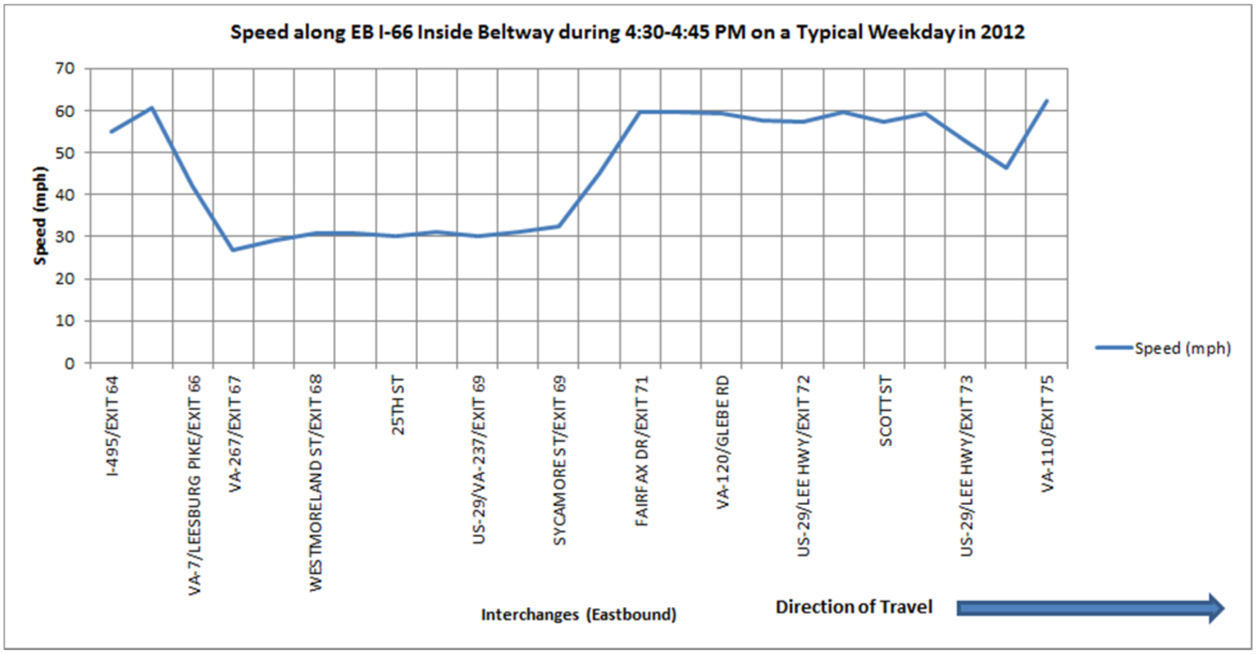

Speed along EB I-66 Inside Beltway during 3:15-3:30 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

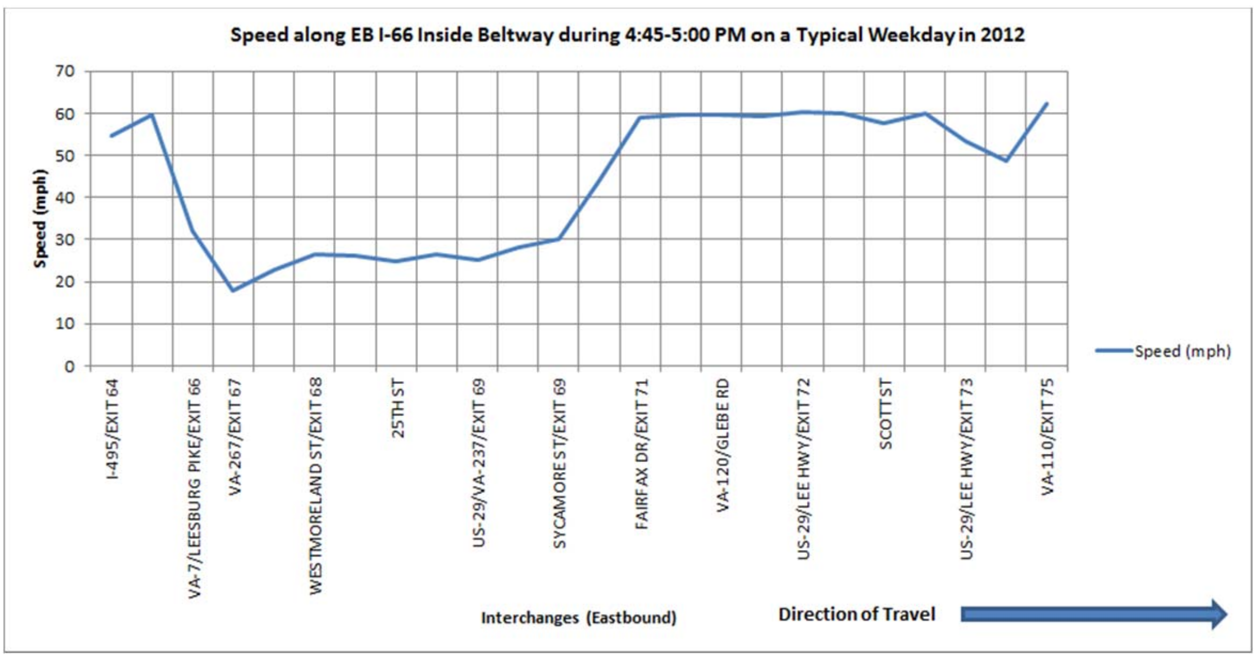

Speed along EB I-66 Inside Beltway during 3:30-3:45 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

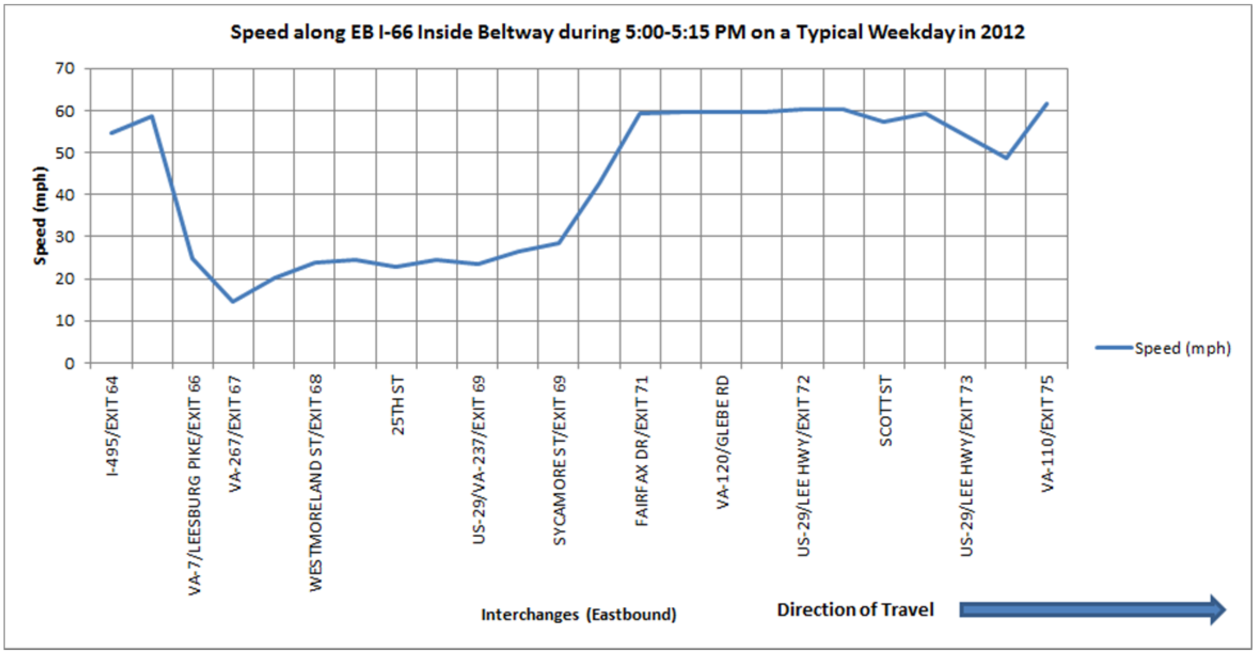

Speed along EB I-66 Inside Beltway during 3:45-4:00 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

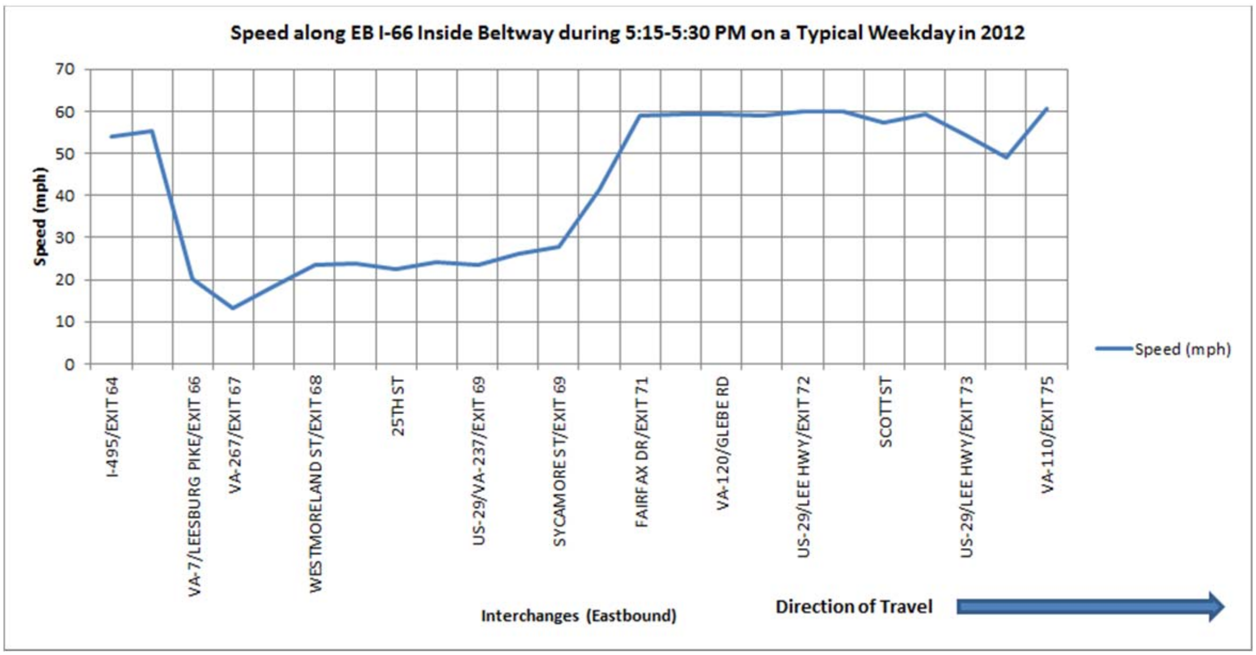

Speed along EB I-66 Inside Beltway during 4:00-4:15 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

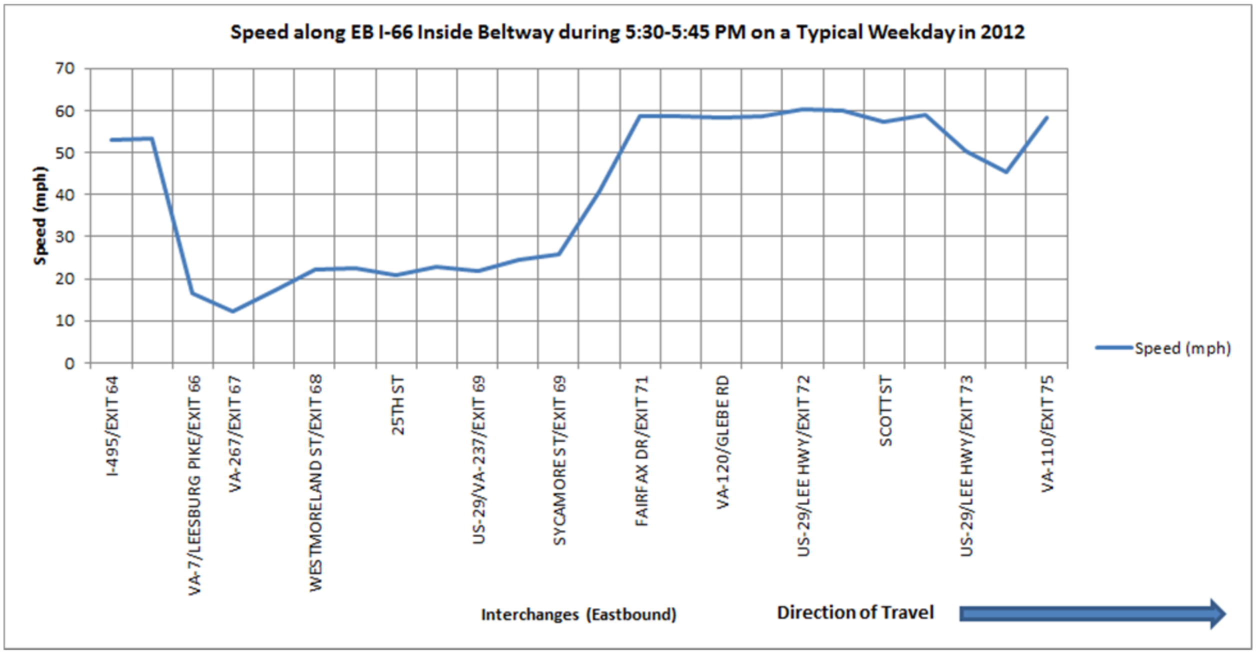

Speed along EB I-66 Inside Beltway during 4:15-4:30 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

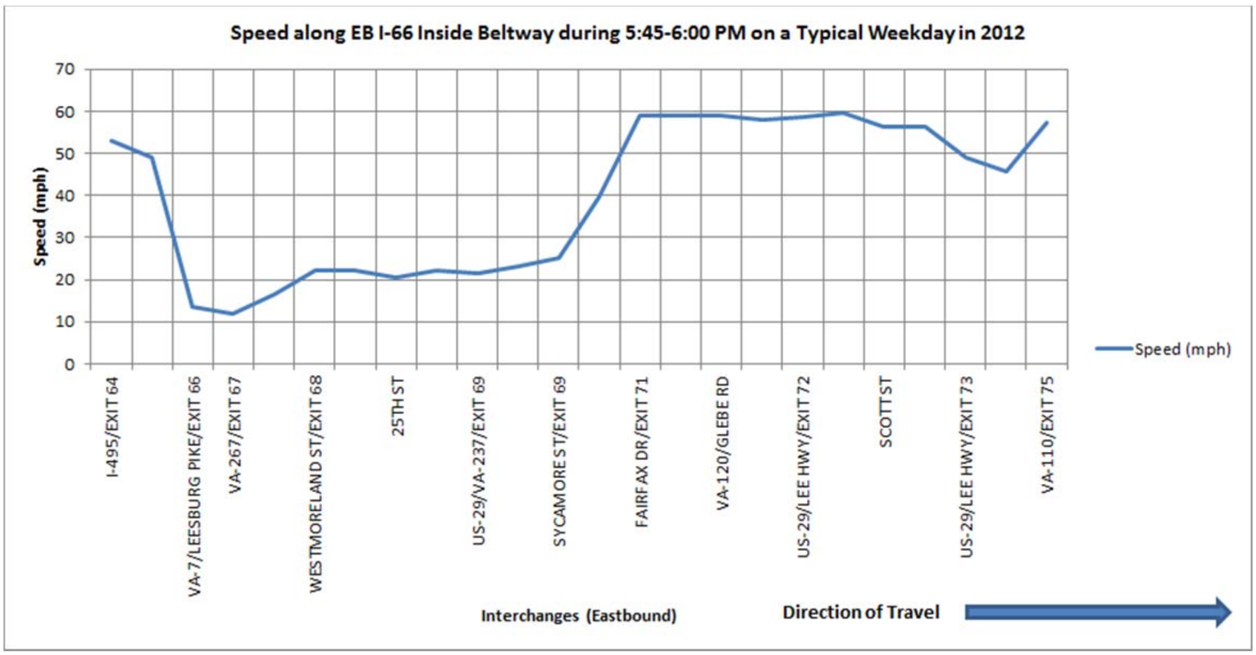

Speed along EB I-66 Inside Beltway during 4:30-4:45 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

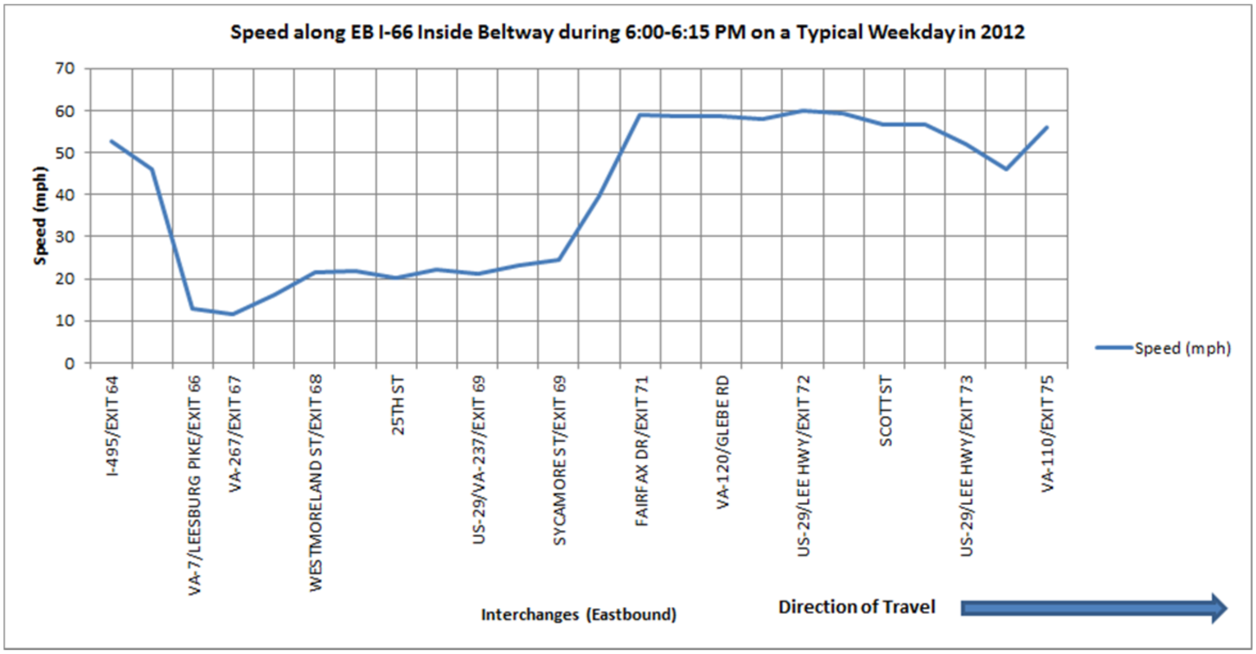

Speed along EB I-66 Inside Beltway during 4:45-5:00 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

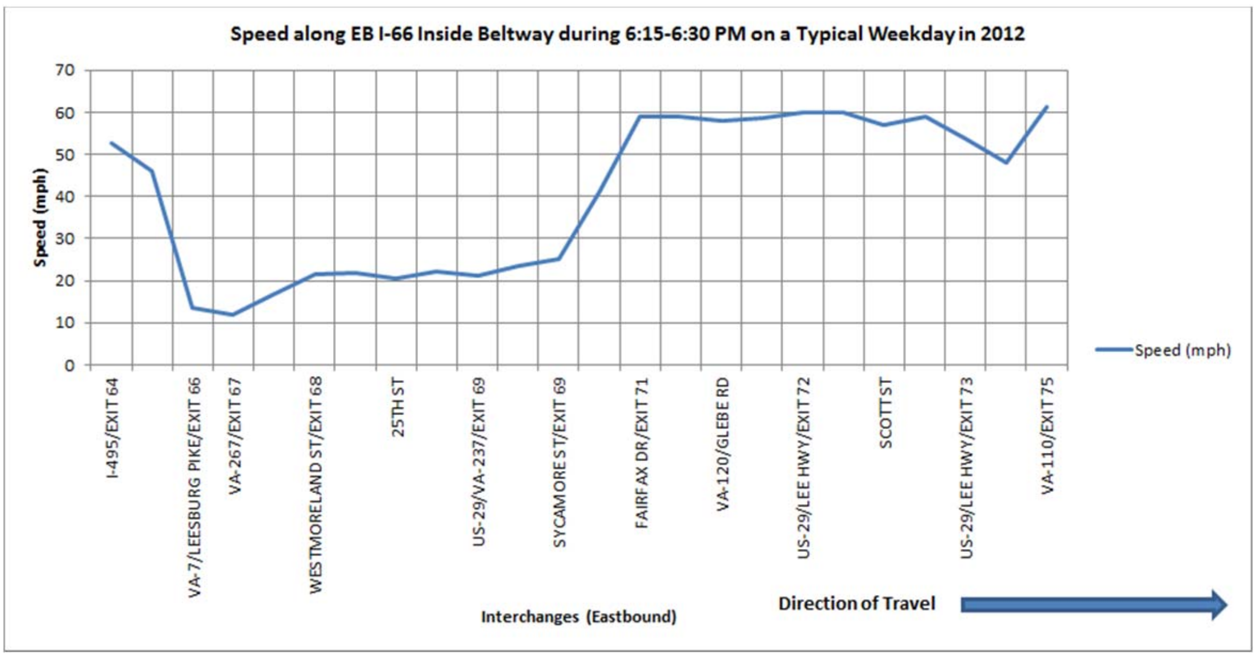

Speed along EB I-66 Inside Beltway during 5:00-5:15 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

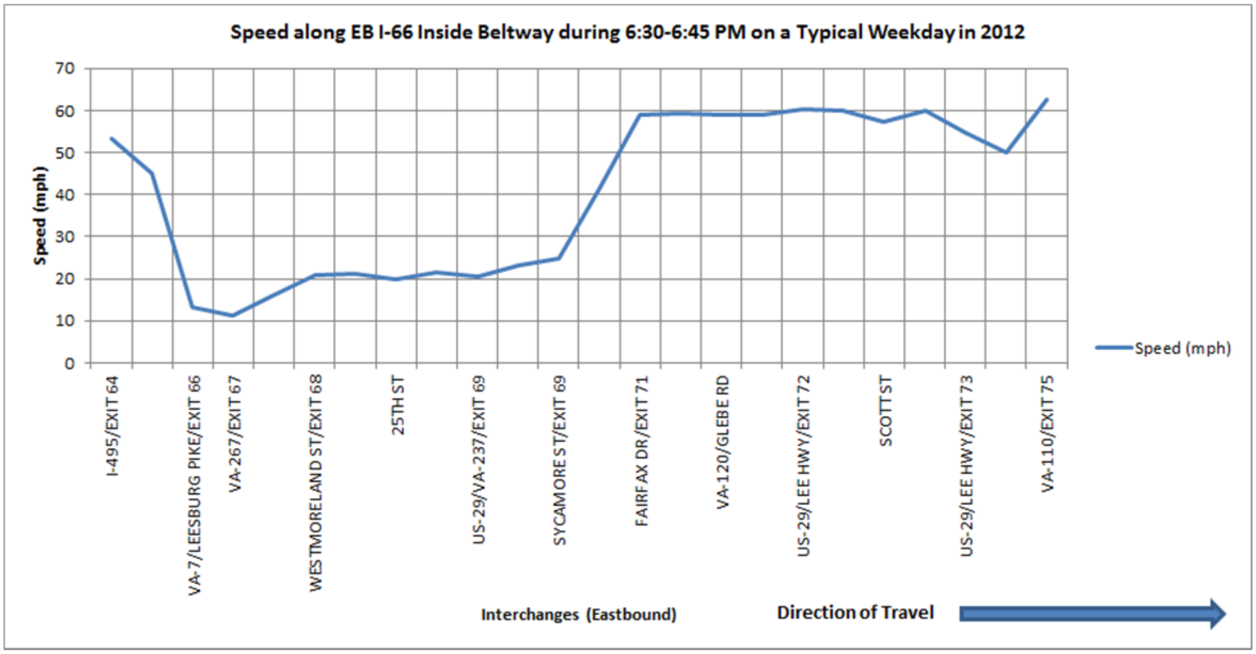

Speed along EB I-66 Inside Beltway during 5:15-5:30 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

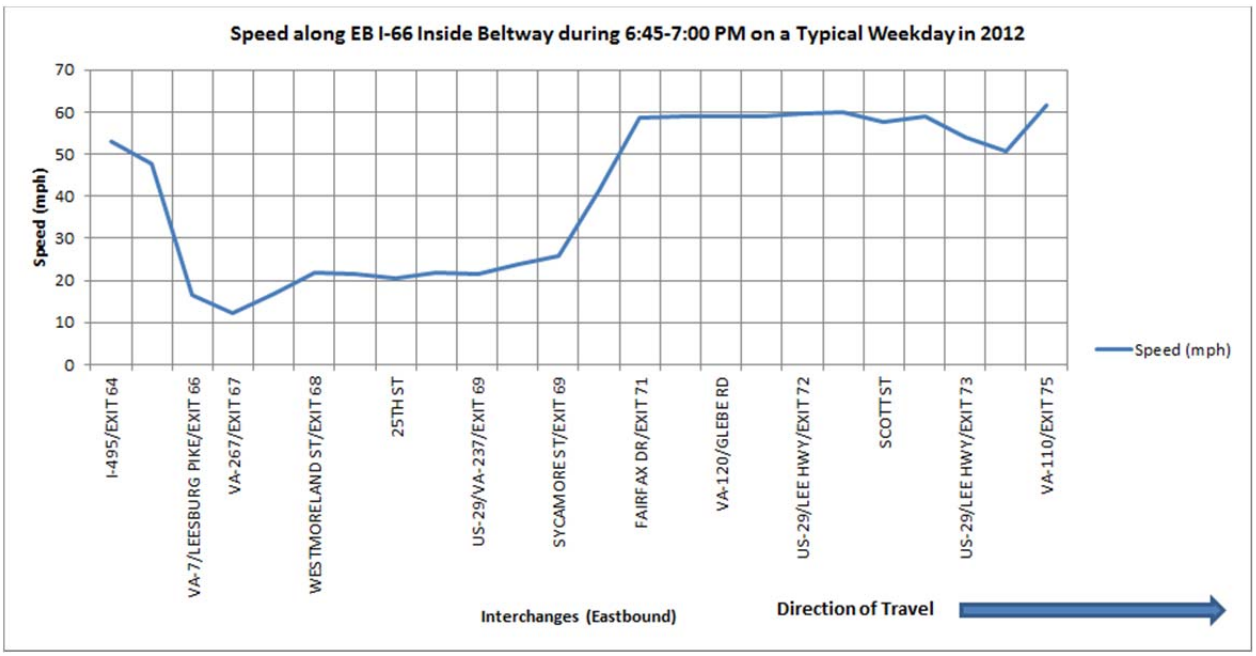

Speed along EB I-66 Inside Beltway during 5:30-5:45 PM on a Typical Weekday in 2012
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

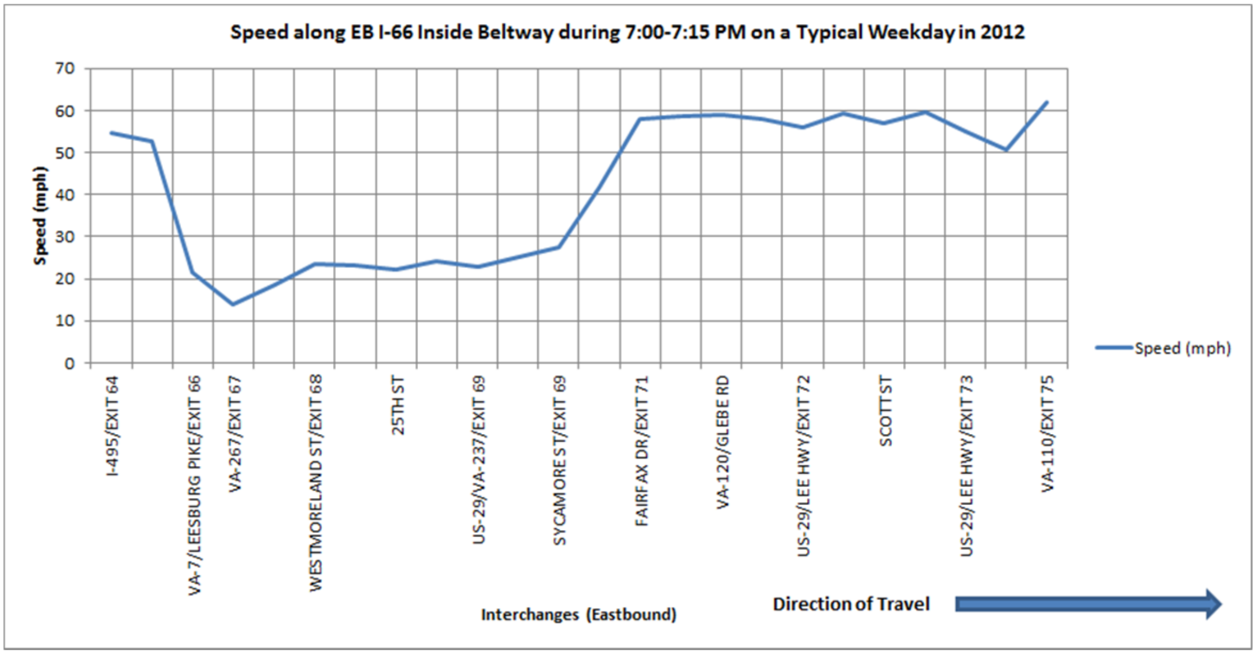

Speed along EB I-66 Inside Beltway during 5:45-6:00 PM on a Typical Weekday in 2012
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

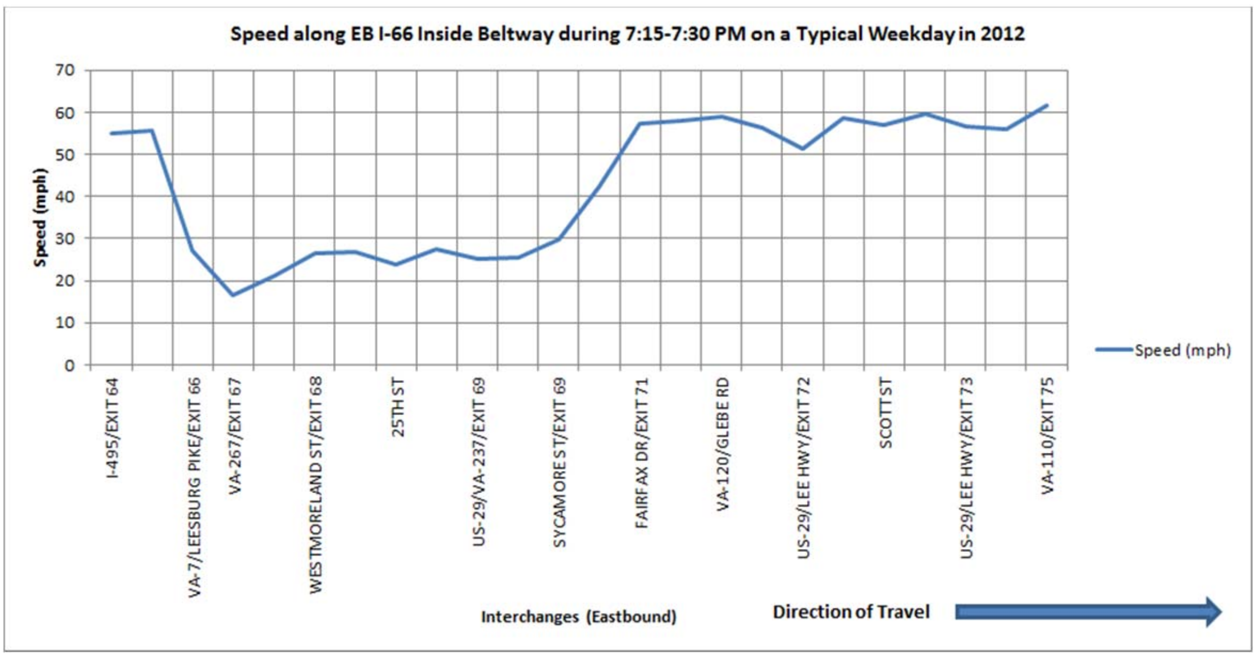

Speed along EB I-66 Inside Beltway during 6:00-6:15 PM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

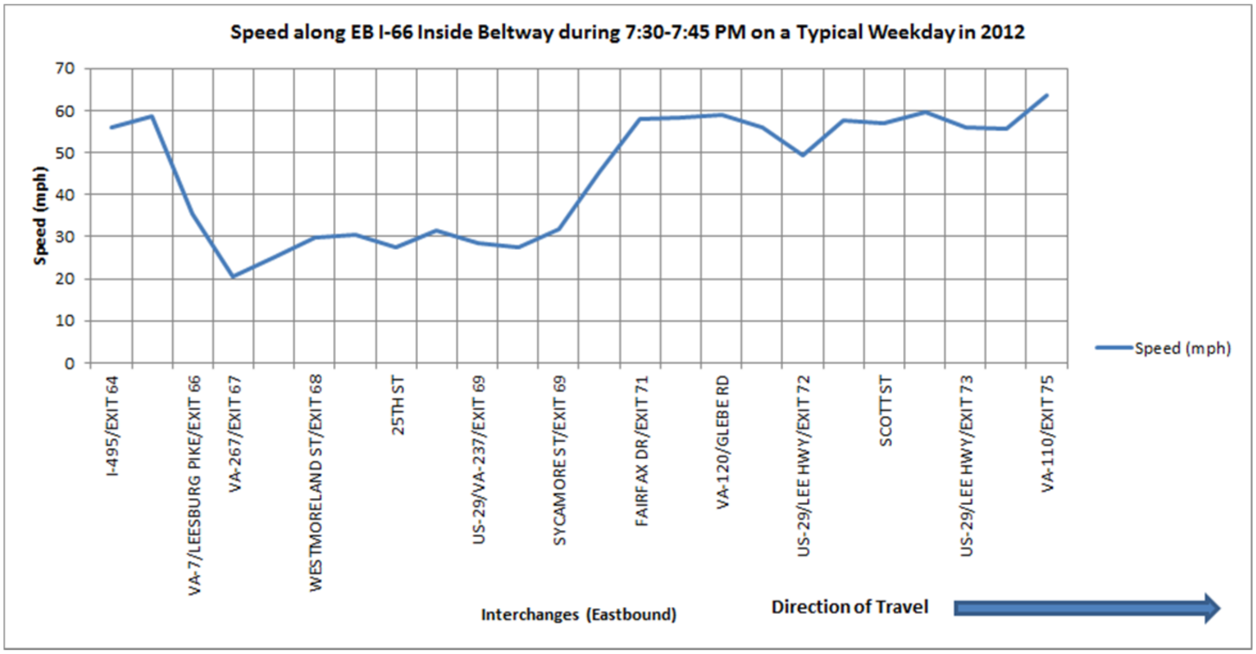

Speed along EB I-66 Inside Beltway during 6:15-6:30 PM on a Typical Weekday in 2012
70
60
50
40
30
20
10
0
Speed (mph)
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)

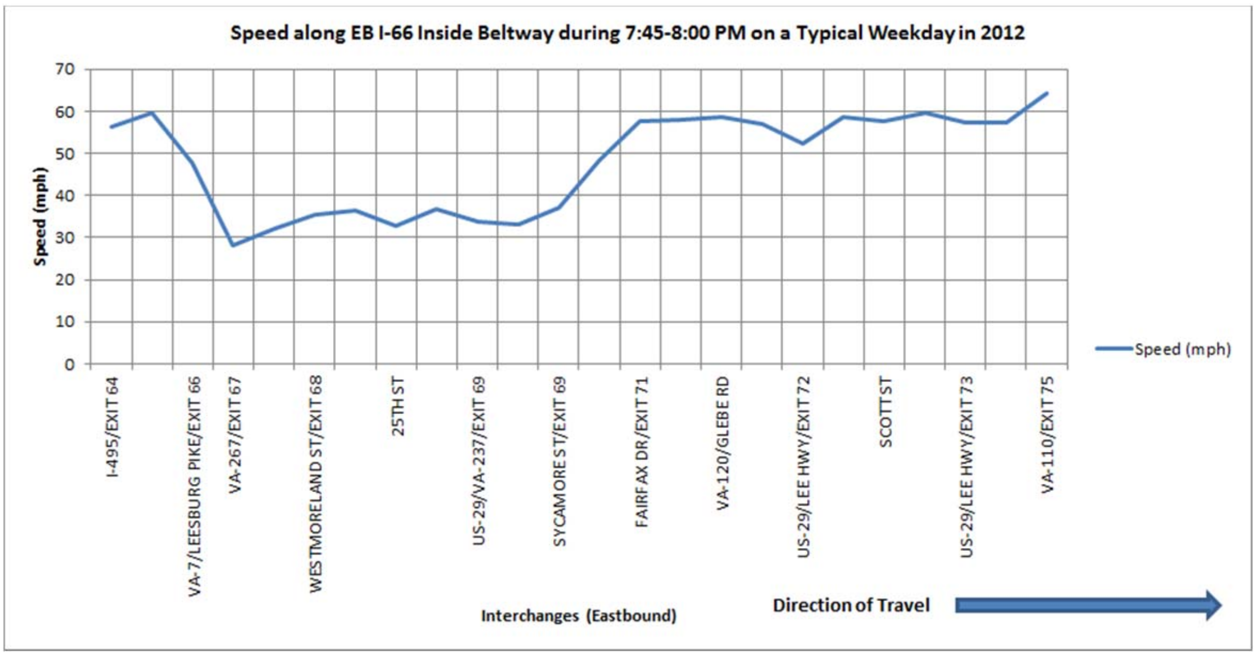

Speed along EB I-66 Inside Beltway during 6:30-6:45 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel


Speed along EB I-66 Inside Beltway during 6:45-7:00 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel


Speed along EB I-66 Inside Beltway during 7:00-7:15 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)


Speed along EB I-66 Inside Beltway during 7:15-7:30 PM on a Typical Weekday in 2012
Speed (mph)
70
60
50
40
30
20
10
0
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Interchanges (Eastbound)
Direction of Travel
Speed (mph)


Speed along EB I-66 Inside Beltway during 7:30-7:45 PM on a Typical Weekday in 2012
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel


Speed along EB I-66 Inside Beltway during 7:45-8:00 PM on a Typical Weekday in 2012
Speed (mph)
0
10
20
30
40
50
60
70
I-495/EXIT 64
VA-7/LEESBURG PIKE/EXIT 66
VA-267/EXIT 67
WESTMORELAND ST/EXIT 68
25TH ST
US-29/VA-237/EXIT 69
SYCAMORE ST/EXIT 69
FAIRFAX DR/EXIT 71
VA-120/GLEBE RD
US-29/LEE HWY/EXIT 72
SCOTT ST
US-29/LEE HWY/EXIT 73
VA-110/EXIT 75
Speed (mph)
Interchanges (Eastbound)
Direction of Travel

Appendix B: Geotechnical Analysis of Shoulders

Appendix C: VDOT Safety Service Patrol Data

I-66 BOS Safety Service Patrol Data
(Working Group Meeting, December 13, 2012)

Safety Service Patrol Data

SSP Assist Incidents from 11/4/2011 to 11/5/2012 for I-66 from Gainesville interchange with Lee Highway (US 29) at MM 43 to TR Bridge / District Line at MM 76.24 (33.24 miles): 6,020

Per mile per year: 181

Length of BOS study corridor: 10.5 miles
Initial estimated incidents per mile per year in corridor: 17

*Assumes equal distribution of incidents along entire NoVA I-66 corridor – incidents likely to have much lower rates in BOS study corridor due to travel conditions (lower speeds, no trucks, urban area, etc.). Nine incidents per mile per year is a reasonable estimate given this factor for the corridor.

Appendix D: Corridor ROW and Shoulder Width Maps

VDOT

Pilot1 EB I-66 : From end of existing BOS on Dulles Connector to I-66

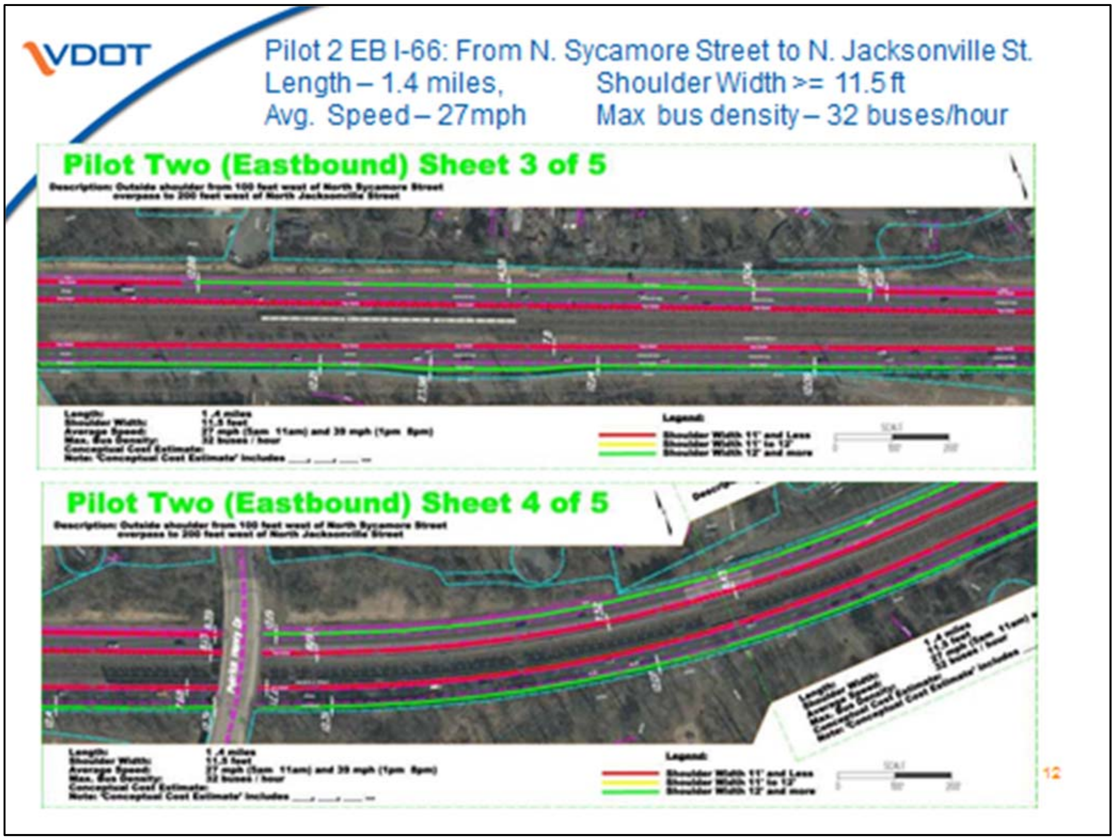
Length – 1.75 miles (including existing shoulder use) Shoulder Width >= 11.5 ft
Avg. Speed – 23 mph Max bus density – 32 buses/hour

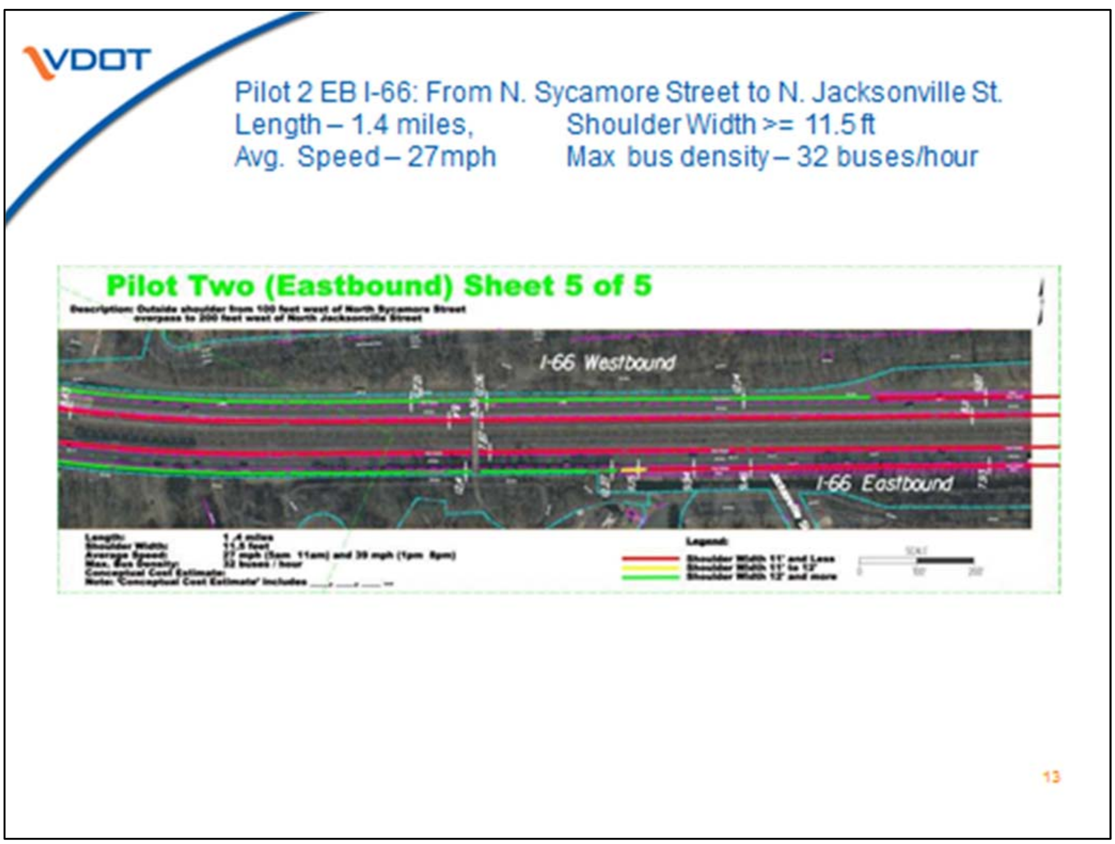
10

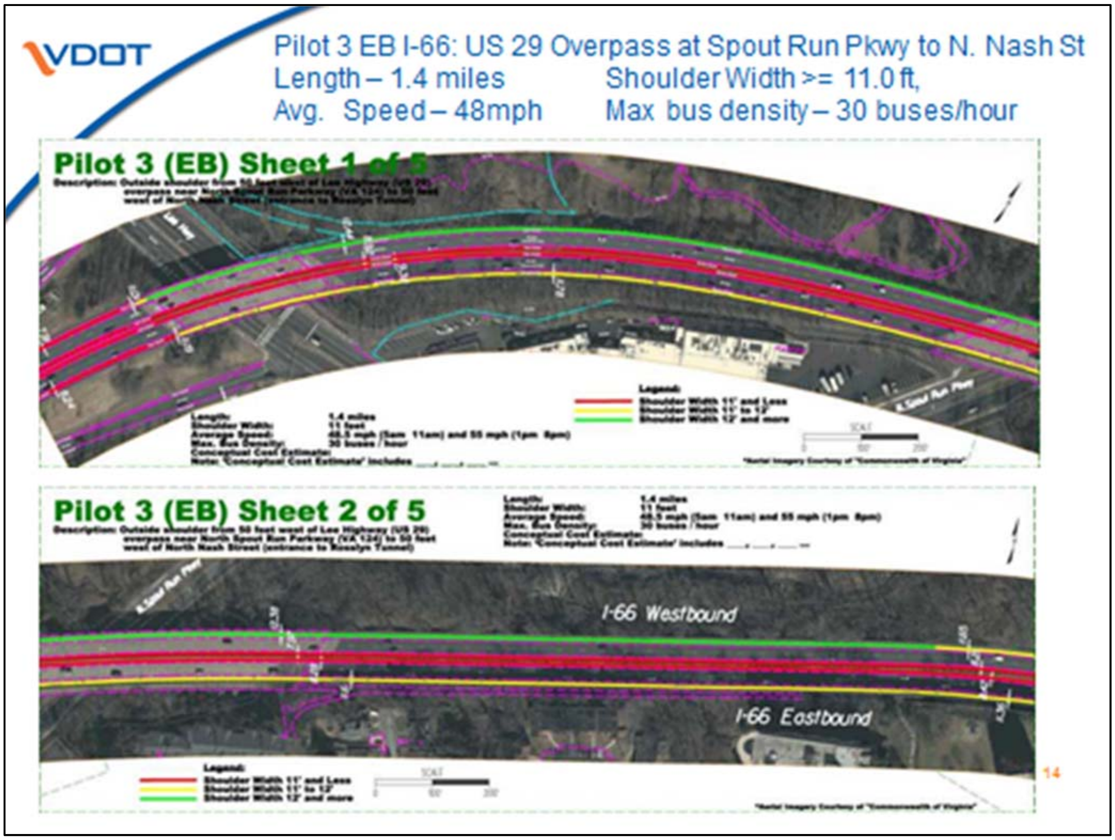
VDOT

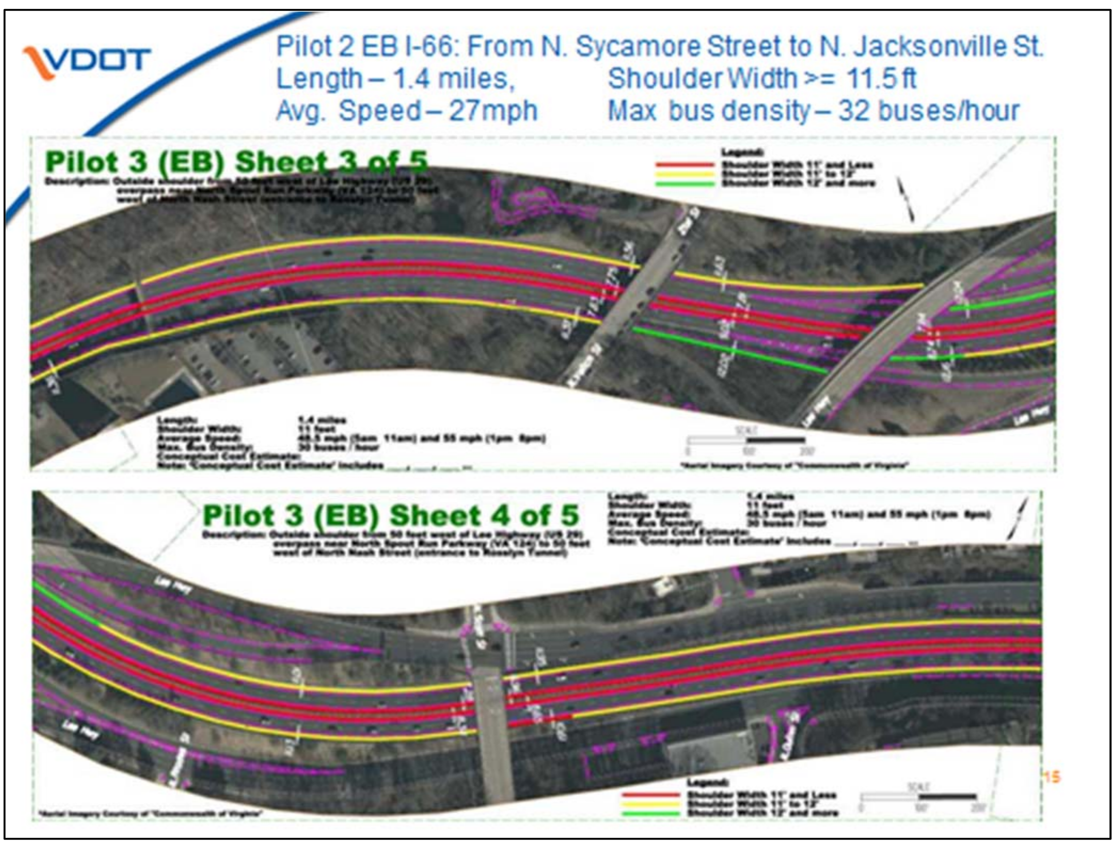
Pilot 2 EB I-66: From N. Sycamore Street to N. Jacksonville St.
Length – 1.4 miles, Shoulder Width >= 11.5 ft
Avg. Speed – 27mph Max bus density – 32 buses/hour

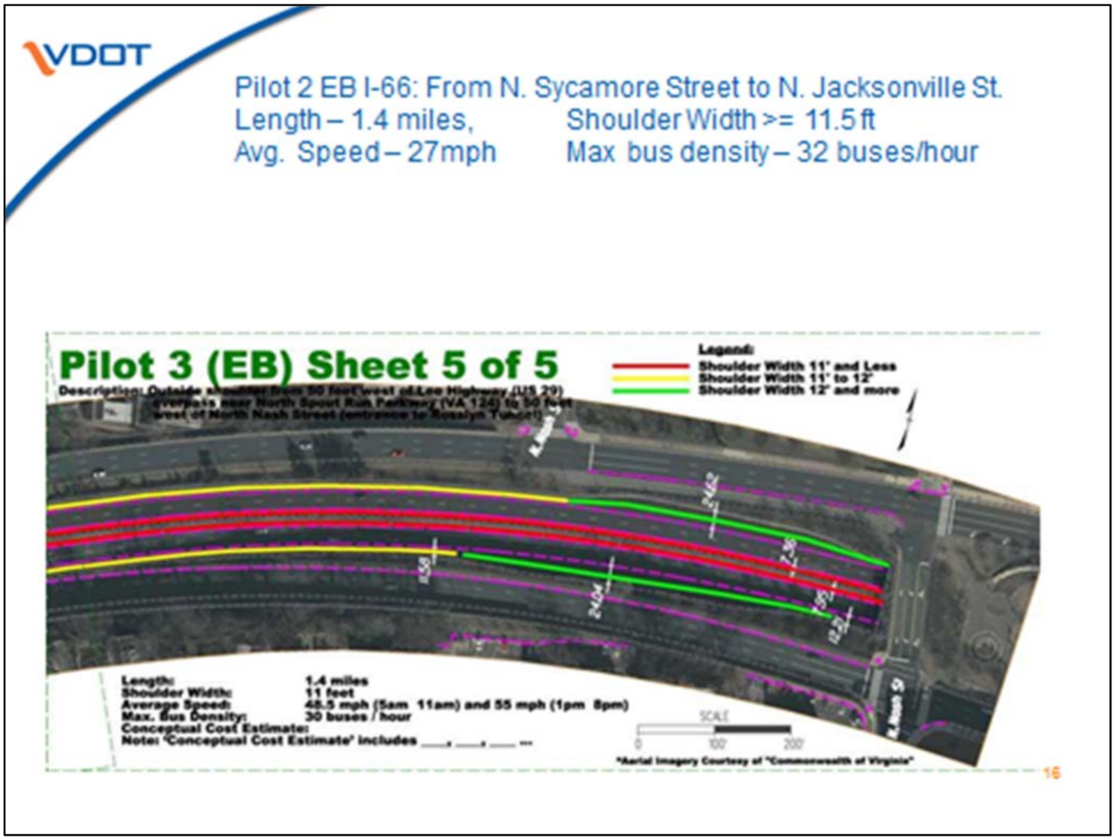
11

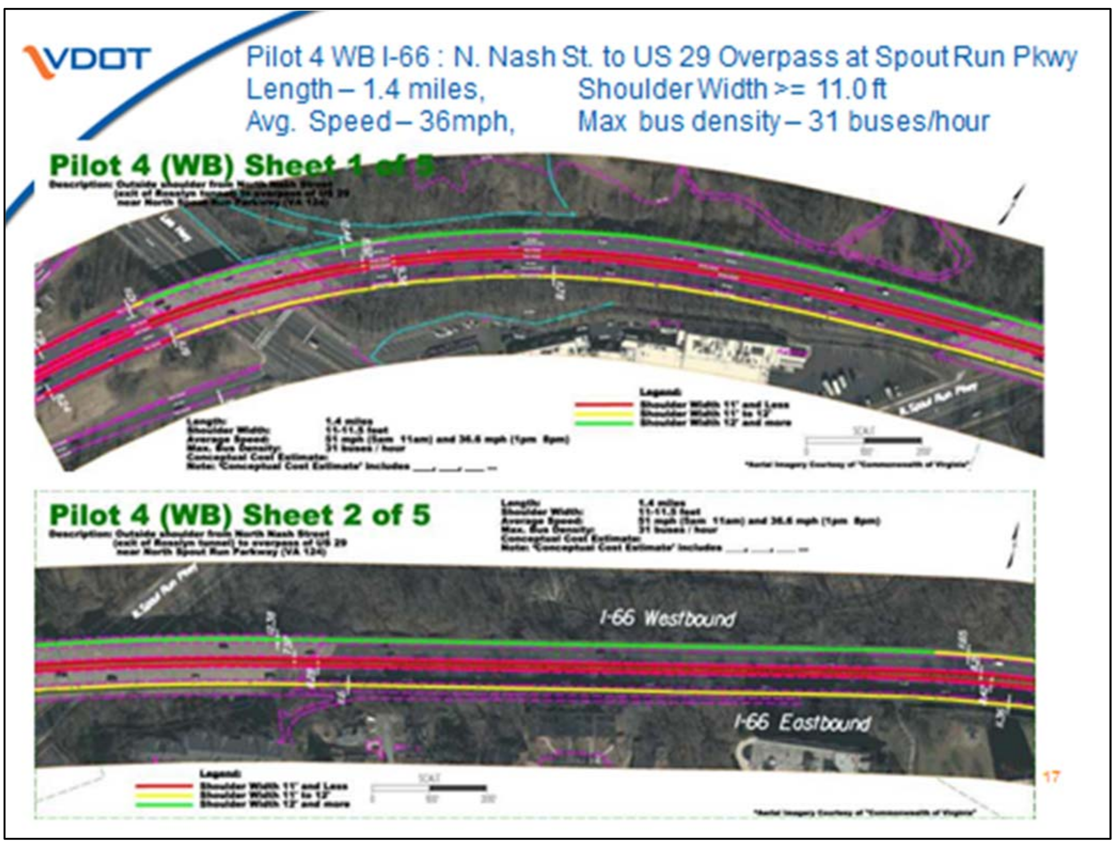

VDOT
Pilot 2 EB I-66: From N. Sycamore Street to N. Jacksonville St.
Length – 1.4 miles,
Shoulder Width >= 11.5 ft
Avg. Speed – 27mph
Max bus density – 32 buses/hour
Pilot Two (Eastbound) Sheet 3 of 5
Pilot Two (Eastbound) Sheet 4 of 5
12

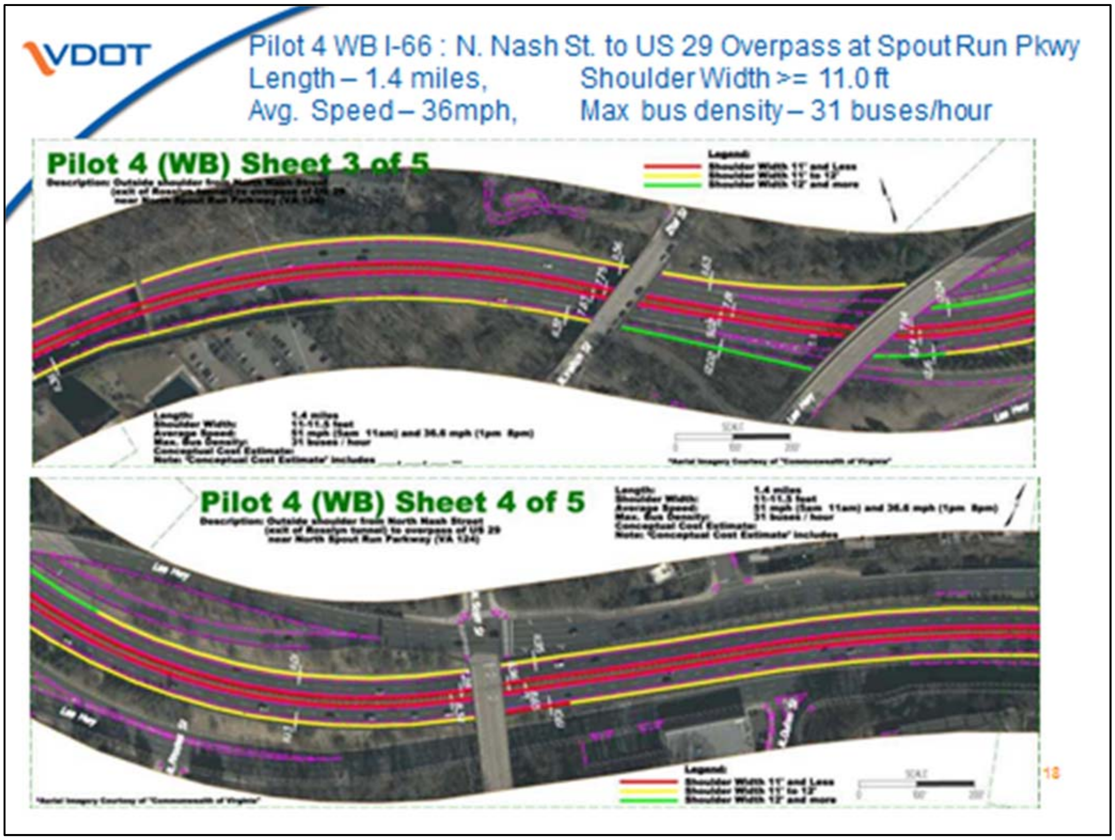

VDOT
Pilot 2 EB I-66: From N. Sycamore Street to N. Jacksonville St.
Length – 1.4 miles,
Shoulder Width >= 11.5 ft
Avg. Speed – 27mph
Max bus density – 32 buses/hour
Pilot Two (Eastbound) Sheet 5 of 5
I-66 Westbound
I-66 Eastbound
13

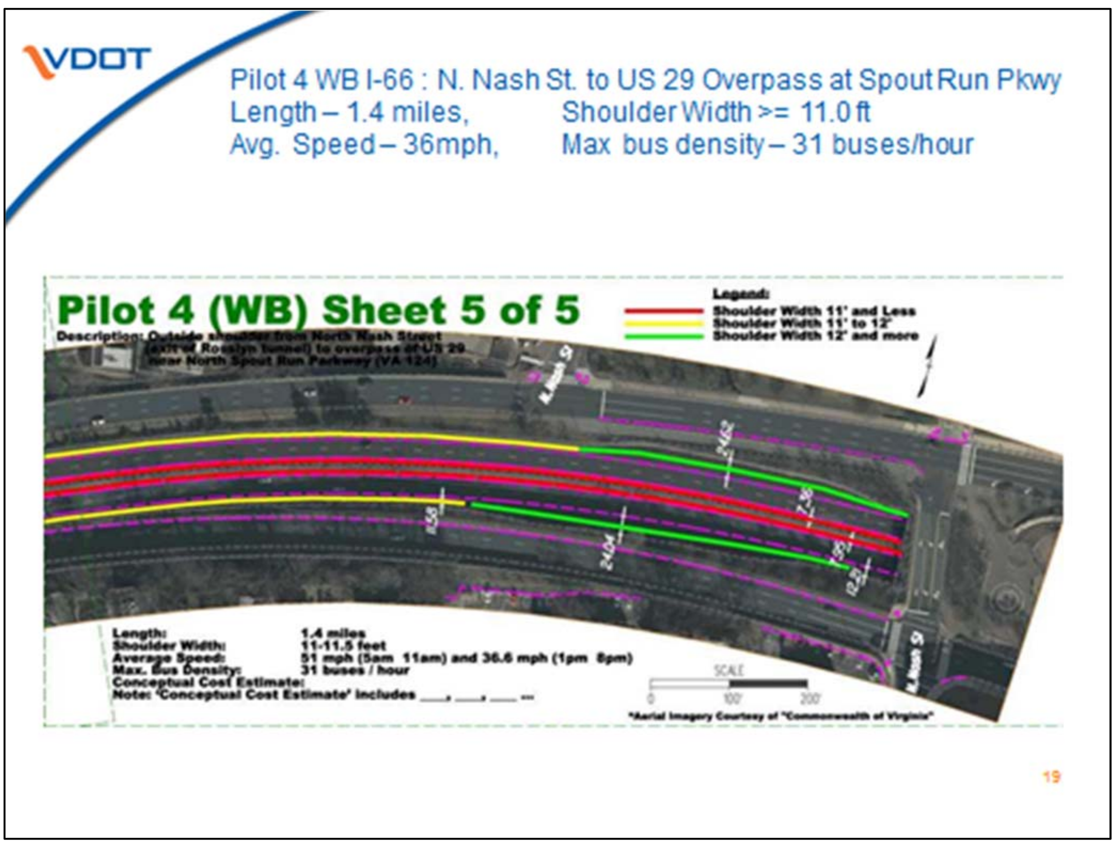

Pilot 3 EB I-66: US 29 Overpass at Spout Run Pkwy to N. Nash St
Length – 1.4 miles
Shoulder Width >= 11.0 ft,
Avg. Speed – 48mph
Max bus density – 30 buses/hour
Pilot 3 (EB) Sheet 1 of 5
Pilot 3 (EB) Sheet 2 of 5
I-66 Westbound
I-66 Eastbound
14

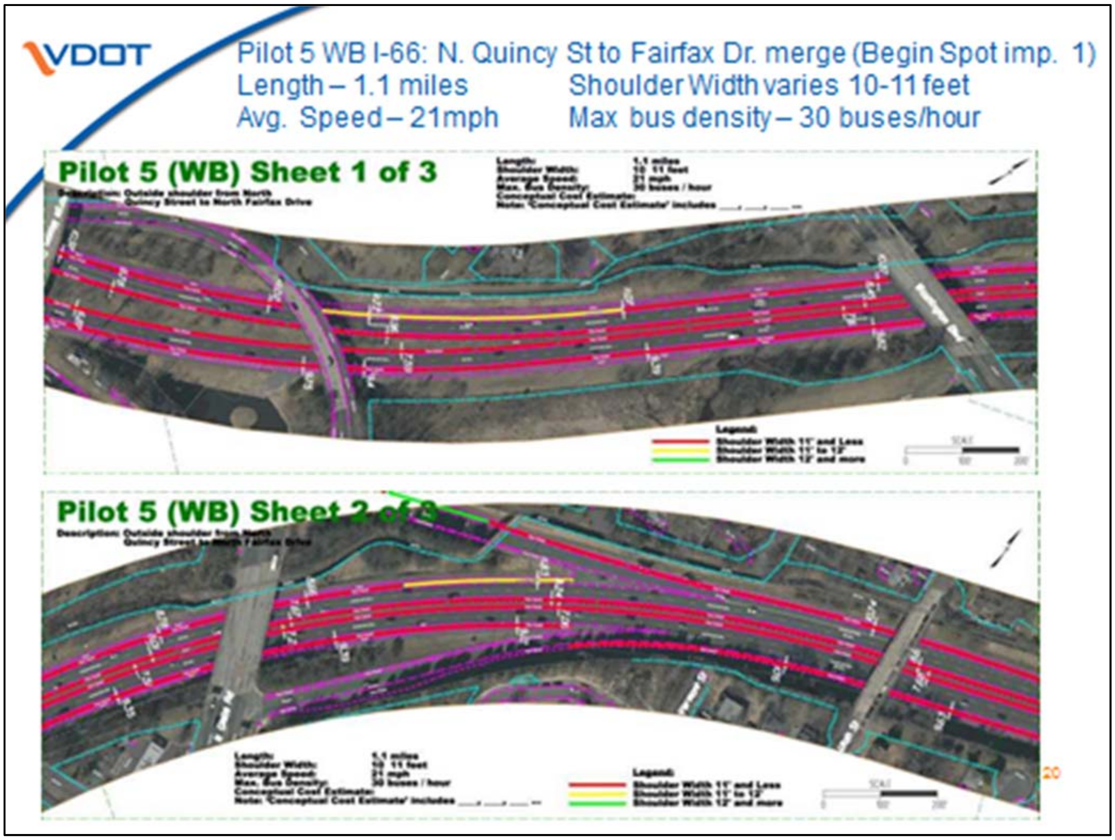

Pilot 2 EB I-66: From N. Sycamore Street to N. Jacksonville St.
Length – 1.4 miles,
Shoulder Width >= 11.5 ft
Avg. Speed – 27mph
Max bus density – 32 buses/hour
Pilot 3 (EB) Sheet 3 of 5
Pilot 3 (EB) Sheet 4 of 5
15

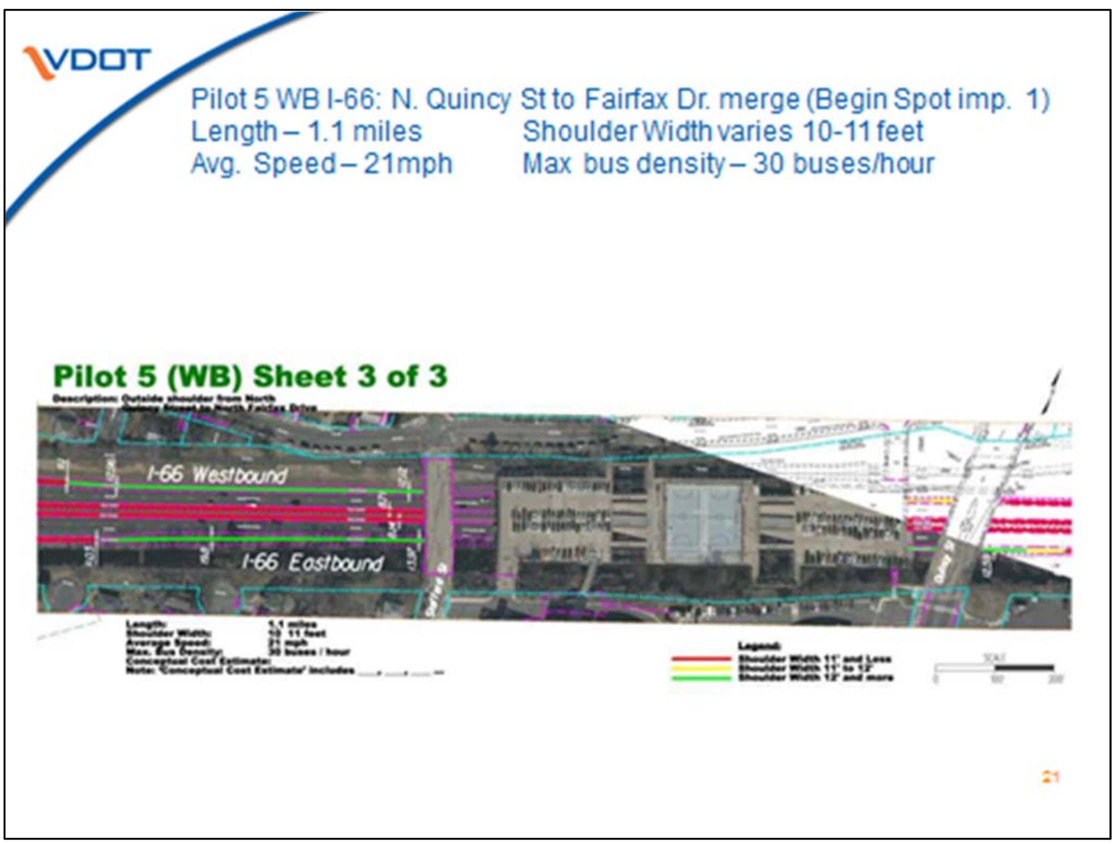

VDOT
Pilot 2 EB I-66: From N. Sycamore Street to N. Jacksonville St.
Length – 1.4 miles,
Shoulder Width >= 11.5 ft
Avg. Speed – 27mph
Max bus density – 32 buses/hour
Pilot 3 (EB) Sheet 5 of 5
Legend:
Shoulder Width 11' and Less
Shoulder Width 11' to 12'
Shoulder Width 12' and more
Length: 1.4 miles
Shoulder Width: 11 feet
Average Speed: 48.5 mph (5am 11am) and 55 mph (1pm 8pm)
Max. Bus Density: 30 buses / hour
Conceptual Cost Estimate:
"Aerial Imagery Courtesy of "Commonwealth of Virginia"
16


VDOT
Pilot 4 WB I-66 : N. Nash St. to US 29 Overpass at Spout Run Pkwy
Length – 1.4 miles,
Shoulder Width >= 11.0 ft
Avg. Speed – 36mph,
Max bus density – 31 buses/hour
Pilot 4 (WB) Sheet 1 of 5
Pilot 4 (WB) Sheet 2 of 5
I-66 Westbound
I-66 Eastbound
Legend:
17


VDOT
Pilot 4 WB I-66 : N. Nash St. to US 29 Overpass at Spout Run Pkwy
Length – 1.4 miles,
Shoulder Width >= 11.0 ft
Avg. Speed – 36mph,
Max bus density – 31 buses/hour
Pilot 4 (WB) Sheet 3 of 5
Pilot 4 (WB) Sheet 4 of 5
18


VDOT
Pilot 4 WB I-66 : N. Nash St. to US 29 Overpass at Spout Run Pkwy
Length – 1.4 miles,
Shoulder Width >= 11.0 ft
Avg. Speed – 36mph,
Max bus density – 31 buses/hour
Pilot 4 (WB) Sheet 5 of 5
Legend:
Shoulder Width 11' and Less
Shoulder Width 11' to 12'
Shoulder Width 12' and more
Length: 1.4 miles
Shoulder Width: 11-11.5 feet
Average Speed: 51 mph (5am 11am) and 36.6 mph (1pm 8pm)
Max. Bus Density: 31 buses / hour
Conceptual Cost Estimate:
Note: 'Conceptual Cost Estimate' includes
SCALE
"Aerial Imagery Courtesy of "Commonwealth of Virginia"
19


VDOT
Pilot 5 WB I-66: N. Quincy St to Fairfax Dr. merge (Begin Spot imp. 1)
Length – 1.1 miles
Shoulder Width varies 10-11 feet
Avg. Speed – 21mph
Max bus density – 30 buses/hour
Pilot 5 (WB) Sheet 1 of 3
Pilot 5 (WB) Sheet 2 of 3
20


VDOT
Pilot 5 WB I-66: N. Quincy St to Fairfax Dr. merge (Begin Spot imp. 1)
Length – 1.1 miles
Shoulder Width varies 10-11 feet
Avg. Speed – 21mph
Max bus density – 30 buses/hour
Pilot 5 (WB) Sheet 3 of 3
I-66 Westbound
I-66 Eastbound
21

Appendix E: Bus Vehicle Characteristics and Deadhead Operations

I-66 BOS – Transit Bus Dimensions and Deadhead and Off-Peak Direction Bus Volumes (Working Group Meeting, December 13, 2012)

Bus Dimensions and Deadhead / Off-Peak Bus Volumes

WMATA

Bus specifications for New Flyer Excelsior XDE40 Transit Buses:

- Width 8.5 feet excluding mirrors
    - o WMATA desires 12 foot minimum shoulder width for BOS operation to account for mirrors and driver inexperience
- Length 41 feet
- Curb weight (approximate) 29,700 lbs
- Gross vehicle weight rating 42,540 lbs

Number of trips using I-66 inside Beltway, 6-9:30 AM westbound and 3-7 PM eastbound weekdays

	Westbound 6-9:30 AM	Eastbound 3-7 PM	**Total**
Deadhead to/from West Ox Garage	15	42	**57**
5A-Dulles service	6	8	**14**
Total	**21**	**50**	**71**

PRTC

- MCI coach bus about 11 feet wide mirror to mirror
- 40,000 lbs empty, up to 50,000 lbs with passengers
- Currently about 20 trips per day that use I-66 inside the Beltway in the off-peak direction
    - o Expected increase in trips following completion of western bus facility in 2016

Loudoun County Transit

- Overall bus width 8.5 feet
- Bus length 45.4 feet
- Gross Vehicle Weight 50,000 lbs

Appendix F: Cost Estimation

Conceptual Cost Estimate Considerations

- Existing pavement strength may be sufficient for short term pilot project of approximately one to two years with low bus volumes per day (less than 150 buses per day) – need to verify with Materials prior to initiating preliminary engineering phase.
- Analysis of existing drainage structures within shoulder is required; local depressions at each inlet must be considered. Bus traffice over inlet grate must also be considered.
- **Pilot 3:** In areas of insufficient shoulder width, assume reduction of through lane width from ~12' to min. 11' via latex slurry seal and restriping.
    - Design Exception required for reduction of thru lane widths on interstate. Per GS-1 standard, 12' lane width required.
    - Assume latex slurry seal is acceptable. However, Materials section must verify. If milling & resurfacing required, would be approximately three times the latex slurry seal cost per lane-mile.
    - Latex double layer (Type B main line only and Type C including shoulders) unit price per lane mile from Interstate Maintenance: $59,215.
    - If latex slurry seal is used rather than milling & resurfacing, pavement markers present difficulties (maintenance issues, bumpy ride, etc)
- Bus will claim the lane in deceleration & acceleration lane areas. It is not clear how this will be striped/signed, and may be undesirable in terms of weaving.
- In areas adjacent to barrier, 11.5' min is preferred, however, there are areas which vary from 11' – 11.5' and were not estimated in the quantity for latex slurry seal/restriping areas.
- Radius of curves will need to be checked, especially in areas where greater breakover between thru lane and shoulder.
- If over 2,500 SF disturbed area (ground disturbing construction activities, i.e. anything greater than milling & resurfacing), stormwater management considerations required.

Pilot One: I-66 BOS EB 1

Pavement Areas

PAVEMENT AREAS	WIDENING LENGTH (ft)	WIDENING WIDTH (ft)	WIDENING AREA (sq yds)	MILLING & RESURFACING LENGTH (ft)	MILLING & RESURFACING WIDTH (ft)	MILLING & RESURFACING AREA (sq yds)
Eastbound 1	1,000	11.5	1,278	0	11	0
TOTALS:	1,000.00		1,277.78	0.00		0.00

Pavement Items

No.	ITEM	AREA	RATE		THICK (in.)	Quantity	Unit	U/P ($)	Total ($)
10636	Asphalt Concrete, Ty I SM-9.5D (Permanent Pavement + Milling/Resurfacing)	1,277.78	180	lb/sy/1.5in	1.5	120	TONS	$ 120.00	$ 14,400
10610	Asphalt Concrete, Ty IM-19.0A	1,277.78	240	lb/sy/2in	2	160	TONS	$ 100.00	$ 16,000
	Aggr. Mat'l No. 21A	1,277.78	165	lb/cf	6	474	TONS	$ 30.00	$ 14,231
10013	Cement Stab. Aggr. Mat'l No. 21A	1,277.78	165	lb/cf	12	949	TONS	$ 30.00	$ 28,463
00270	Select Mat'l Ty I, Min. CBR 30 (Assume 25% Unsuitables - Assume exc 12" below subgrade)	319.44	165	lb/cf	12	237	TONS	$ 35.00	$ 8,302
00355	Geotextile Fabric					319	SY	$ 2.50	$ 799
11070	Saw Cut Pavement (Full Depth)					1,000	LF	$ 15.00	$ 15,000
24410	Demolition of Pavement					1,278	SY	$ 10.00	$ 12,778
10630	Milling					0	SY	$ 10.00	$ -
							CATEGORY SUB TOTAL:	$	97,193.92

Incidental Items

No.	ITEM	Quantity	Unit	U/P ($)	Total ($)
	Modify Junction Box	2	EA	$ 800	$ 1,600
	Modify Existing Inlets	1	EA	$ 2,000	$ 2,000
	Erosion & Sediment Control Miscellaneous	1	LS	$ 5,000	$ 5,000
	Signage	1	LS	$ 2,000	$ 2,000
	Pavement Markings	1000	LF	$ 2	$ 2,000
	Grading	1	LS	$ 30,000	$ 30,000
	Stormwater Management	1	LS	$ 20,000	$ 20,000
			CATEGORY SUB TOTAL:	$	62,600.00

TOTALS

Subtotal 1		$ 159,794
Maintenance of Traffic @ 30% of Subtotal 1		$ 47,938
Construction Surveying @ 2% of Subtotal 1 + MOT		$ 4,155
Subtotal 2		$ 211,887
Mobilization	A) for contracts > $1,000,000: first subtract $1,000,000, multiply Subtotal 2 by 0.05, add $80,000 B) for contracts between $200,000 - $1,000,000: first subtract $200,000, multiply Subtotal 2 by 0.075, add $20,000)	$ 35,892
Subtotal 3		$ 247,778
Contingency / Incidental Construction @ 25% of Subtotal 3		$ 61,945
Subtotal 4		$ 309,723
CEI @ 19% of Subtotal 3		$ 58,847
	TOTAL:	**$ 368,570**

Pilot Two: I-66 BOS EB 2

Pavement Areas

PAVEMENT AREAS	LATEX SLURRY SEAL			MILLING & RESURFACING		
	LENGTH (ft)	LANES (inc. shoulder)	LENGTH (ft)	LENGTH (ft)	WIDTH (ft)	AREA (sq yds)
Eastbound 2	0	3	0	0	11	0
• Number of accel./decel. lane crossings: 1 accel. / 0 decel.						
TOTALS:	0.00		0.00	0.00		0.00

Pavement Items

No.	ITEM	LENGTH	RATE		THICK (in.)	Quantity	Unit	U/P ($)	Total ($)
	Latex Slurry Seal	0				0	LN-MI	60,000	0
	Asphalt Patching					1	LS	30,000	30,000
	Pavement Markers (removal & addition)					0	EA	60	0
10636	Asphalt Concrete, Ty I SM-9.5D (Permanent Pavement + Milling/Resurfacing)	0	180	lb/sy/1.5in	1.5	0	TONS	120	0
10630	Milling	0				0	SY	10	0
						CATEGORY SUB TOTAL:		$	30,000.00

Incidental Items

No.	ITEM	Quantity	Unit	U/P ($)	Total ($)
	Modify Junction Box	25	EA	$ 800	$ 20,000
	Modify Existing Inlets	17	EA	$ 2,000	$ 34,000
	Erosion & Sediment Control Miscellaneous	1	LS	$ 2,000	$ 2,000
	Signage	1	LS	$ 2,000	$ 2,000
	Pavement Markings	0	LF	$ 2	$ -
	Eradication of Existing Pavement Markings	0	LS	$ 2	$ -
	Grading	1	LS	$ -	$ -
	Stormwater Management	1	LS	$ -	$ -
		CATEGORY SUB TOTAL:		$	58,000.00

TOTALS

Subtotal 1		$ 88,000
Maintenance of Traffic @ 30% of Subtotal 1		$ 26,400
Construction Surveying @ 2% of Subtotal 1 + MOT		$ 2,288
Subtotal 2		$ 116,688
Mobilization	A) for contracts > $1,000,000: first subtract $1,000,000, multiply Subtotal 2 by 0.05, add $80,000 B) for contracts between $200,000 - $1,000,000: first subtract $200,000, multiply Subtotal 2 by 0.075, add $20,000)	$ 28,752
Subtotal 3		$ 145,440
Contingency / Incidental Construction @ 25% of Subtotal 3		$ 36,360
Subtotal 4		$ 181,800
CEI @ 19% of Subtotal 3		$ 34,542
	TOTAL:	**$ 216,341**

Pilot Three: I-66 BOS EB 3

Pavement Areas

PAVEMENT AREAS	LATEX SLURRY SEAL			MILLING & RESURFACING		
	LENGTH (ft)	LANES (inc. shoulder)	LENGTH (ft)	LENGTH (ft)	WIDTH (ft)	AREA (sq yds)
Eastbound 3	300	3	900	0	11	0
TOTALS:	300.00		900.00	0.00		0.00

• Assume slurry starts beneath the North Scott St overpass.
• Number of accel./decel. lane crossings: 0 accel. / 1 decel.
• There is a 10.5 ft shoulder just east of North Scott Street for a distance of ≈ 100 feet. Assume latex slurry seal in this area.

Pavement Items

No.	ITEM	LENGTH	RATE		THICK (in.)	Quantity	Unit	U/P ($)		Total ($)	
	Latex Slurry Seal	900				900	LN-MI	$	60,000	$	10,227
	Asphalt Patching					1	LS	$	30,000	$	30,000
	Pavement Markers (removal & addition)					11	EA	$	60	$	675
10636	Asphalt Concrete, Ty I SM-9.5D (Permanent Pavement + Milling/Resurfacing)	0	180	lb/sy/1.5in	1.5	0	TONS	$	120	$	-
10630	Milling	0				0	SY	$	10	$	-
							CATEGORY SUB TOTAL:			$	40,902.27

Incidental Items

No.	ITEM	Quantity	Unit	U/P ($)		Total ($)	
	Modify Junction Box	5	EA	$	800	$	4,000
	Modify Existing Inlets	13	EA	$	2,000	$	26,000
	Erosion & Sediment Control Miscellaneous	1	LS	$	2,000	$	2,000
	Signage	1	LS	$	2,000	$	2,000
	Pavement Markings	900	LF	$	2	$	1,800
	Eradication of Existing Pavement Markings	900	LS	$	2	$	1,350
	Grading	1	LS	$	-	$	-
	Stormwater Management	1	LS	$	-	$	-
		CATEGORY SUB TOTAL:				$	37,150.00

TOTALS

Subtotal 1		$	78,052
Maintenance of Traffic @ 30% of Subtotal 1		$	23,416
Construction Surveying @ 2% of Subtotal 1 + MOT		$	2,029
Subtotal 2		$	103,497
Mobilization	A) for contracts > $1,000,000: first subtract $1,000,000, multiply Subtotal 2 by 0.05, add $80,000 B) for contracts between $200,000 - $1,000,000: first subtract $200,000, multiply Subtotal 2 by 0.075, add $20,000)	$	27,762
Subtotal 3		$	131,260
Contingency / Incidental Construction @ 25% of Subtotal 3		$	32,815
Subtotal 4		$	164,075
CEI @ 19% of Subtotal 3		$	31,174
TOTAL:		**$**	**195,249**

Pilot Four: I-66 BOS WB 1

Pavement Areas

PAVEMENT AREAS	LATEX SLURRY SEAL			MILLING & RESURFACING		
	LENGTH (ft)	LANES (inc. shoulder)	LENGTH (ft)	LENGTH (ft)	WIDTH (ft)	AREA (sq yds)
Westbound 1	0	3	0	0	11.00	0.00
TOTALS:	0.00		0.00	0.00		0.00

• Number of accel./decel. lane crossings: 1 accel. / 0 decel.

Pavement Items

No.	ITEM	LENGTH	RATE		THICK (in.)	Quantity	Unit	U/P ($)	Total ($)
	Latex Slurry Seal	0				0	LN-MI	$ 60,000	$ -
	Asphalt Patching					1	LS	$ 30,000	$ 30,000
	Pavement Markers (removal & addition)					0	EA	$ 60	$ -
10636	Asphalt Concrete, Ty I SM-9.5D (Permanent Pavement + Milling/Resurfacing)	0	180	lb/sy/1.5in	1.5	0	TONS	$ 120	$ -
10630	Milling	0				0	SY	$ 10	$ -
						CATEGORY SUB TOTAL:			$ 30,000.00

Incidental Items

No.	ITEM	Quantity	Unit	U/P ($)	Total ($)
	Modify Junction Box	27	EA	$ 800	$ 21,600
	Modify Existing Inlets	5	EA	$ 2,000	$ 10,000
	Erosion & Sediment Control Miscellaneous	1	LS	$ 2,000	$ 2,000
	Signage	1	LS	$ 2,000	$ 2,000
	Pavement Markings	0	LF	$ 2	$ -
	Eradication of Existing Pavement Markings	0	LS	$ 2	$ -
	Grading	1	LS	$ -	$ -
	Stormwater Management	1	LS	$ -	$ -
		CATEGORY SUB TOTAL:			$ 35,600.00

TOTALS

Subtotal 1		$ 65,600
Maintenance of Traffic @ 30% of Subtotal 1		$ 19,680
Construction Surveying @ 2% of Subtotal 1 + MOT		$ 1,706
Subtotal 2		$ 86,986
Mobilization	A) for contracts > $1,000,000: first subtract $1,000,000, multiply Subtotal 2 by 0.05, add $80,000 B) for contracts between $200,000 - $1,000,000: first subtract $200,000, multiply Subtotal 2 by 0.075, add $20,000)	$ 26,524
Subtotal 3		$ 113,510
Contingency / Incidental Construction @ 25% of Subtotal 3		$ 28,377
Subtotal 4		$ 141,887
CEI @ 19% of Subtotal 3		$ 26,959
TOTAL:		**$ 168,845**

Pilot Five: I-66 BOS WB 2

Pavement Areas

PAVEMENT AREAS	WIDENING			MILLING & RESURFACING		
	LENGTH (ft)	WIDTH (ft)	AREA (sq yds)	LENGTH (ft)	WIDTH (ft)	AREA (sq yds)
Westbound 2	1,500	6.00	1,000.00	0	11.00	0.00
TOTALS:	1,500.00		1,000.00	0.00		0.00

Pavement Items

No.	ITEM	AREA	RATE		THICK (in.)	Quantity	Unit	U/P ($)	Total ($)
10636	Asphalt Concrete, Ty I SM-9.5D (Permanent Pavement + Milling/Resurfacing)	1,000.00	180	lb/sy/1.5in	1.5	90	TONS	$ 120.00	$ 10,800
10610	Asphalt Concrete, Ty IM-19.0A	1,000.00	240	lb/sy/2in	2	120	TONS	$ 100.00	$ 12,000
	Aggr. Mat'l No. 21A	1,000.00	165	lb/cf	6	371	TONS	$ 30.00	$ 11,138
10013	Cement Stab. Aggr. Mat'l No. 21A	1,000.00	165	lb/cf	12	743	TONS	$ 30.00	$ 22,275
00270	Select Mat'l Ty I, Min. CBR 30 (Assume 25% Unsuitables - Assume exc 12" below subgrade)	250.00	165	lb/cf	12	186	TONS	$ 35.00	$ 6,497
00355	Geotextile Fabric					250	SY	$ 2.50	$ 625
11070	Saw Cut Pavement (Full Depth)					1,500	LF	$ 15.00	$ 22,500
24410	Demolition of Pavement					0	SY	$ 10.00	$ -
10630	Milling					0	SY	$ 10.00	$ -
						CATEGORY SUB TOTAL:		$	85,834.38

Incidental Items

No.	ITEM	Quantity	Unit	U/P ($)	Total ($)
	Modify Junction Box	22	EA	$ 800	$ 17,600
	Modify Existing Inlets	6	EA	$ 2,000	$ 12,000
	Erosion & Sediment Control Miscellaneous	1	LS	$ 5,000	$ 5,000
	Signage	1	LS	$ 2,000	$ 2,000
	Pavement Markings	1500	LF	$ 2	$ 3,000
	Grading	1	LS	$ 20,417	$ 20,417
	Stormwater Management	1	LS	$ 20,000	$ 20,000
	CATEGORY SUB TOTAL:			$	80,016.67

TOTALS

Subtotal 1		$ 165,851
Maintenance of Traffic @ 30% of Subtotal 1		$ 49,755
Construction Surveying @ 2% of Subtotal 1 + MOT		$ 4,312
Subtotal 2		$ 219,918
Mobilization	A) for contracts > $1,000,000: first subtract $1,000,000, multiply Subtotal 2 by 0.05, add $80,000 B) for contracts between $200,000 - $1,000,000: first subtract $200,000, multiply Subtotal 2 by 0.075, add $20,000)	$ 90,996
Subtotal 3		$ 310,914
Contingency / Incidental Construction @ 25% of Subtotal 3		$ 77,729
Subtotal 4		$ 388,643
CEI @ 19% of Subtotal 3		$ 73,842
	TOTAL:	**$ 462,485**