Assessment of the Feasibility of Bus On Shoulders (BOS) at Select Locations in the National Capital Region

Draft **Report**

Prepared for the Bus On Shoulders Task Force of the National Capital Region Transportation Planning Board (TPB)

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Section A: Introduction

Bus on Shoulders Task Force - Background

At the July 18, 2012 meeting of the Transportation Planning Board (TPB), it was requested that a task force be established to identify promising locations in the region to operate buses on the shoulders of highways. This task force brought together the stakeholder agencies, including transit operators, departments of transportation, and local jurisdictions, to coordinate an assessment of the experience and potential for Bus on Shoulder (BOS) operations on the region's freeways and major arterials. The task force oversaw a scoping of potential locations for BOS, including a high-level benefit-cost analysis of implementing BOS along select corridors and bus routes.

Outline of Report

The regional assessment of BOS feasibility has been coordinated through a series of meetings, with necessary work assigned through discussion.

Section B – Summary of Local and National Experience with Bus on Shoulders

The National Capital Region already has some local experience with BOS, along a short section (1.3 mi) of the Dulles Airport Access Highway (VA 267) for bus access to the West Falls Church Metrorail Station, and along the shoulders of Columbia Pike (US 29) near Burtonsville, MD. In addition, several other cities across the United States and Canada also have BOS service; of these, the twin cities of Minneapolis and St. Paul have the most-developed network with over 280 miles of BOS corridors.

Section C – Lessons and Challenges for BOS Implementation

There are numerous issues and topics that must be addressed in implementing a Bus on Shoulders project by highway, safety, and bus operating agencies. This section summarizes critical experience with current and previous BOS operations, including safety, roadway engineering, and bus service operations aspects.

Section D – Assessment of the Feasibility of BOS at Specific Locations in the National Capital Region

Potential corridors for BOS operation on the region's highway network were identified, based on 1) current bus service, 2) existing highway congestion locations, and 3) highway shoulder conditions.

Section E – Findings

The findings of the research, survey of current conditions, and discussion at meetings are summarized. In addition, potential next steps for further development of potential BOS locations are suggested.

Section F – References

The primary resources used in researching BOS are identified here, though there are many other sources including media articles, conference and research board presentations, and websites.

Appendices

Appendices with additional detail are provided, including a) the progress of the TPB's BOS task force, b) maps of the corridor segments assessed in the study, and c) a discussion of the development and application of a planning-level benefit-cost analysis model.

Section B: Local and National Experience with BOS

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." (Page 1-1).*
> http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_151.pdf

Current local experience with BOS includes bus operation along a short section (1.3 mi) of the Dulles Airport Access Highway (VA 267[1]) for bus access to the West Falls Church Metrorail Station, and along the shoulders of Columbia Pike (US 29) near Burtonsville, MD. Previously, bus service operated along the Maryland portion of the Capital Beltway (I-495) in the vicinity of the American Legion Bridge; these buses were permitted to operate on the shoulders, however, this service was discontinued in 2003. Looking forward, VDOT has completed a planning feasibility study and has begun preliminary engineering for a pilot project to operate BOS along I-66 inside the Beltway.

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

Local Experience

As introduced above, there are two current examples of BOS in the region, on VA 267 and on US 29 near Burtonsville. An addition, there was BOS operation along the Maryland portion of the Capital Beltway from 1999 to 2003, while BOS is being considered for I-66 inside the Beltway.

Virginia: VA-267 BOS

This corridor for BOS is limited in scope to 1.3 miles along the eastbound shoulder of VA-267 inside the Beltway. The corridor leads directly to a bus-only access ramp to the West Falls Church Metrorail Station, just before the intersection with 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* (pp. 26-28).

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[1] This is the Metropolitan Washington Airports Authority's designation of the untolled section of VA 267 inside the Capital Beltway (I-495). See http://www.metwashairports.com/tollroad/925.htm

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.

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. The outside shoulder on which buses operate is 14 feet wide.

<u>Maryland: Columbia Pike (US 29) BOS</u>

This corridor provides for BOS operation along approximately 4 miles, between MD 198 at the north and Randolph Road / Cherry Hill Road at the south (see Figure 2). 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 MD 200, the Inter-County Connector, 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.

<u>Maryland: Capital Beltway (I-495) BOS</u>

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 or approximately 400 persons per day. 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.

Virginia: Study of I-66 inside the Beltway

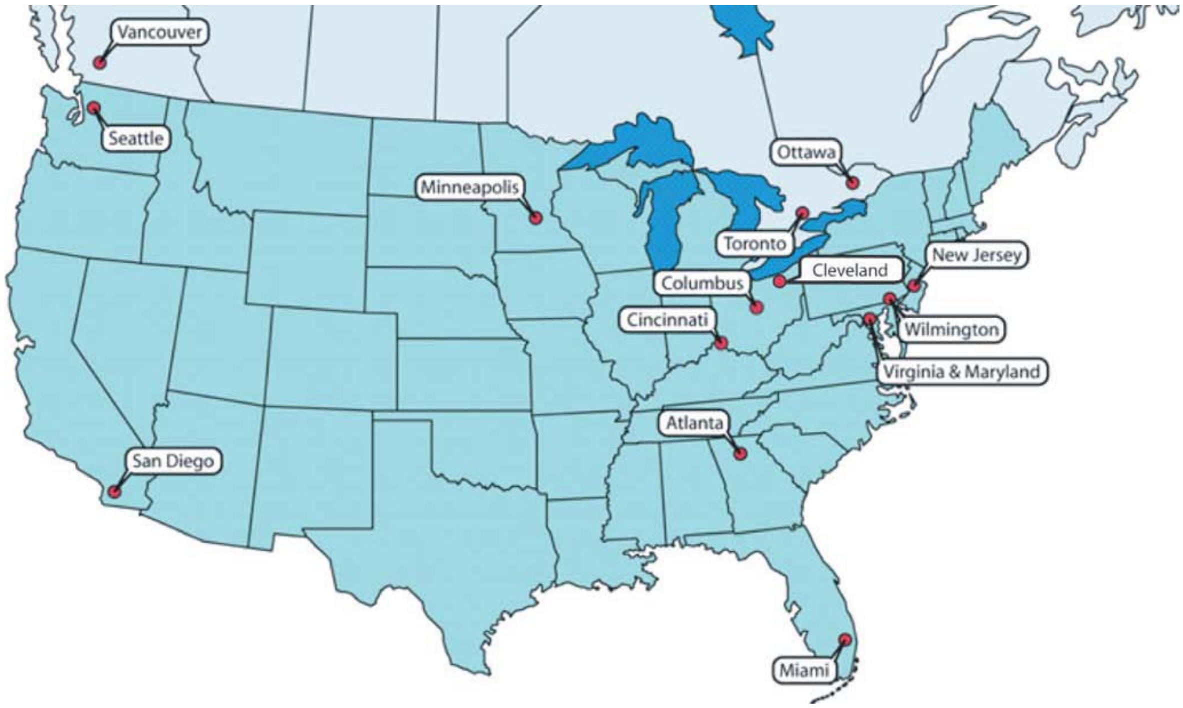
This is a VDOT study in progress on the feasibility of BOS for this corridor, with the goal of establishing a pilot project in 2013. The planning study, which has been completed, identified the best practices related to BOS systems, determined potential locations, and evaluated operational as well as design and safety issues related to a pilot BOS implementation on I-66 inside the Beltway. Five (5) pilot BOS locations were identified in the study, and preliminary engineering has begun for those locations.

As an operational study taking place contemporaneously with the TPB BOS Task Force work, information from the I-66 study was used to better inform the task force's work.

National and Other Experience with BOS

There have been a number of studies of Bus on Shoulders by the Federal Highway Administration (FHWA) and by the TCRP. TCRP Report 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 1.

Figure 1: North American Cities with BOS (TCRP Report 151)



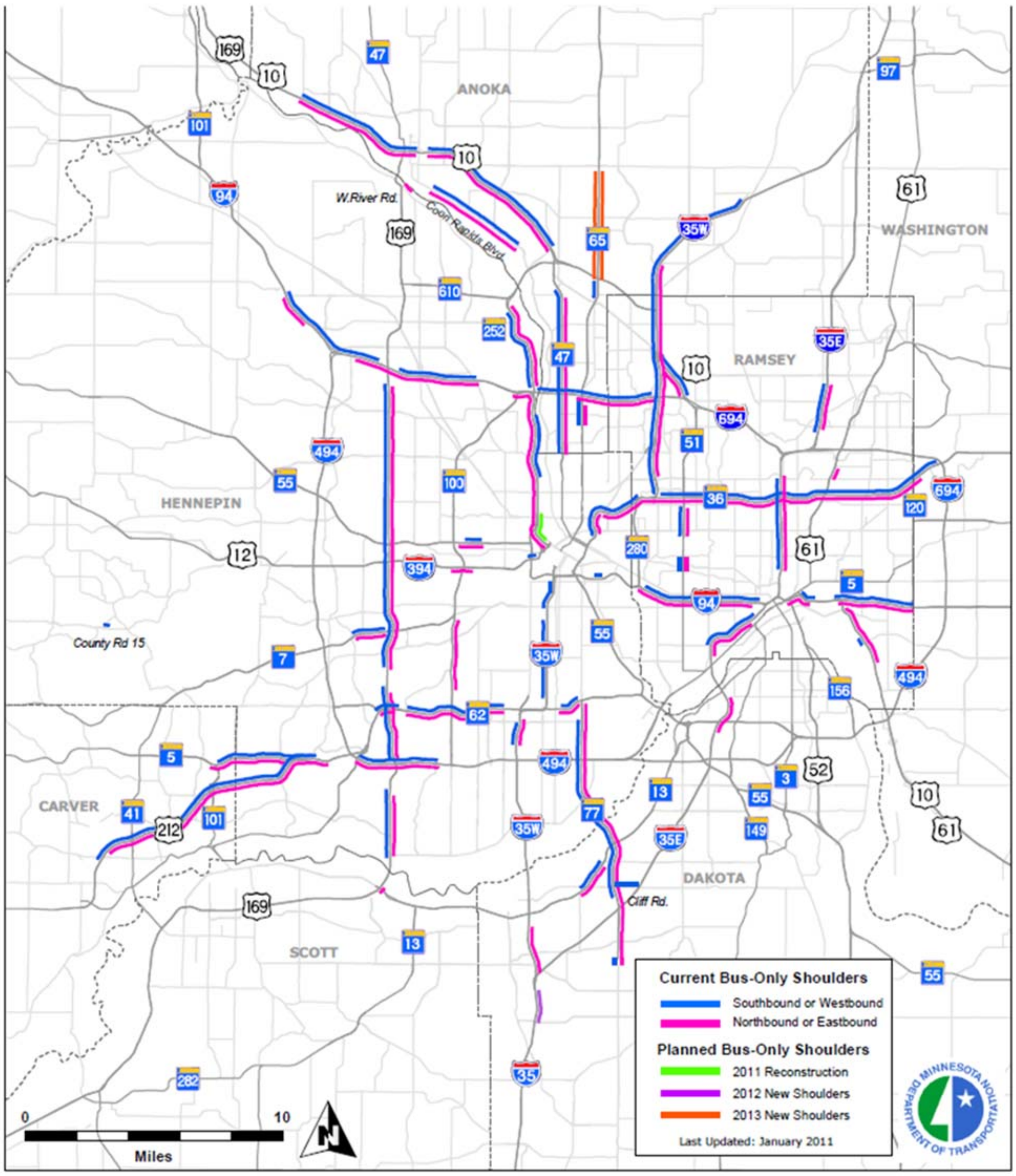
The dominant example of BOS is in the Twin Cities area of Minneapolis and St. Paul. Begun in 1991 in response to floods shutting down several key points on the road network, the quickly implemented measure proved successful, leading to further expansion. The Twin Cities now has a network of over 280 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 State DOT 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.

Policy for BOS implementation, operating requirements, and other elements of the Twin Cities' BOS program are described further in Section C.

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: Map of Twin Cities BOS Network (Minnesota DOT)



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 I-55 corridor in the Chicagoland area. To date, the Chicago experience has proven very successful, with the operating agency Pace now having to add bus trips. From when the BOS pilot project began on 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.

Another recent BOS pilot implementation has taken place in the Triangle area (Raleigh / Durham / Chapel Hill) of North Carolina along I-40. 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. 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.

Section C: Lessons and Challenges for BOS Implementation

There are numerous issues and topics that must be addressed in implementing a Bus on Shoulders project by highway, safety, and bus operating agencies. The TCRP reports and the reports, presentations, and other documentation prepared by federal and state agencies and within the transportation industry review the lessons learned and challenges of BOS implementation in considerable detail. As a supplement to these comprehensive studies, this section of the memorandum notes some of the highlights from these studies and provides some comparisons among BOS projects.

Implementation Considerations

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 is: 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; and 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.

Table 1 – BOS Operational Speeds and Limits (TCRP Report 151)

	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 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 results are presented below in Table 2.

Table 2 – Observed Travel Time and Reliability Data (TCRP Report 151)

	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

Design Elements

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, Minnesota DOT 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 use of these corridors is 100 buses per hour and 60 buses per hour respectively). Seattle also has extra-wide shoulders for BOS operations.

After width, the second most important physical factor is the strength of the shoulder, largely determined by the pavement thickness. **Typical pavement thickness on general travel lanes is a minimum of is 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, they now build all shoulders 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**; Minnesota DOT has moved to a two degree slope standard from the four percent slope of older shoulders. New Jersey required 2.5 degree slopes to replace the previous four degree slopes. 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 arterial BOS project.

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. **Minnesota DOT 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 shoulders of highways. However Cincinnati and Chicago are examples of median shoulder BOS operation for which intersections are typically less of a concern, unless there are left exits and merges are 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

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. **In general, there should be a 1.5 or 2 foot clearance beyond the shoulder width to any barrier or wall, as well as any drainage gratings or culverts.**

Vertical clearance is not typically an issue, unless a facility has bridges that predate modern design clearances, or if repeated resurfacing has raised the road height over time.

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 3: Samples 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, 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. The Washington metropolitan region already employs ITS along I-66 outside the Beltway 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.

Operational Considerations

BOS Safety and Emergency Incidents & 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 make 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 for shoulder debris clearance was increased from once every three weeks to once a week for the BOS segment.

Regulatory and Funding Considerations

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 lanes 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.

In regard to the Washington metropolitan region, it is recommended that signage in the region be either the same or as similar as possible across state lines. There do not appear to be any current BOS operations that continue across state lines, which would require coordination of regulatory and operational factors.

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., non-revenue service) buses to make use of the shoulders; others only allow use when carrying passengers.

However, there are exceptions. Minnesota allows 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. Minnesota also considered allowing vanpools to use shoulders, but this did not pass the state legislature.

Atlanta encountered an unusual exception to eligible vehicles when first implementing 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 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 intersections, accessing and exiting the shoulders, and procedures when the shoulders are blocked or need to be used by first responders. 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.

Funding for Operations and Maintenance

Additional funding is needed for support of BOS operations.   More frequent shoulder clearance of debris, or snowfall, adds to operating costs.   Enforcement costs also increase to patrol the shoulders for traffic offenses and deal more quickly with any breakdowns or vehicle removal. Bus operations for shoulder use will also require some additional funding, as new drivers require training on the protocol for bus operations and familiarization with the shoulders. Some additional supervision costs may also be incurred to ensure more frequent reporting on shoulder use. However, many of these are base costs already being incurred. The additional marginal cost of supporting BOS operations would be difficult to identify.

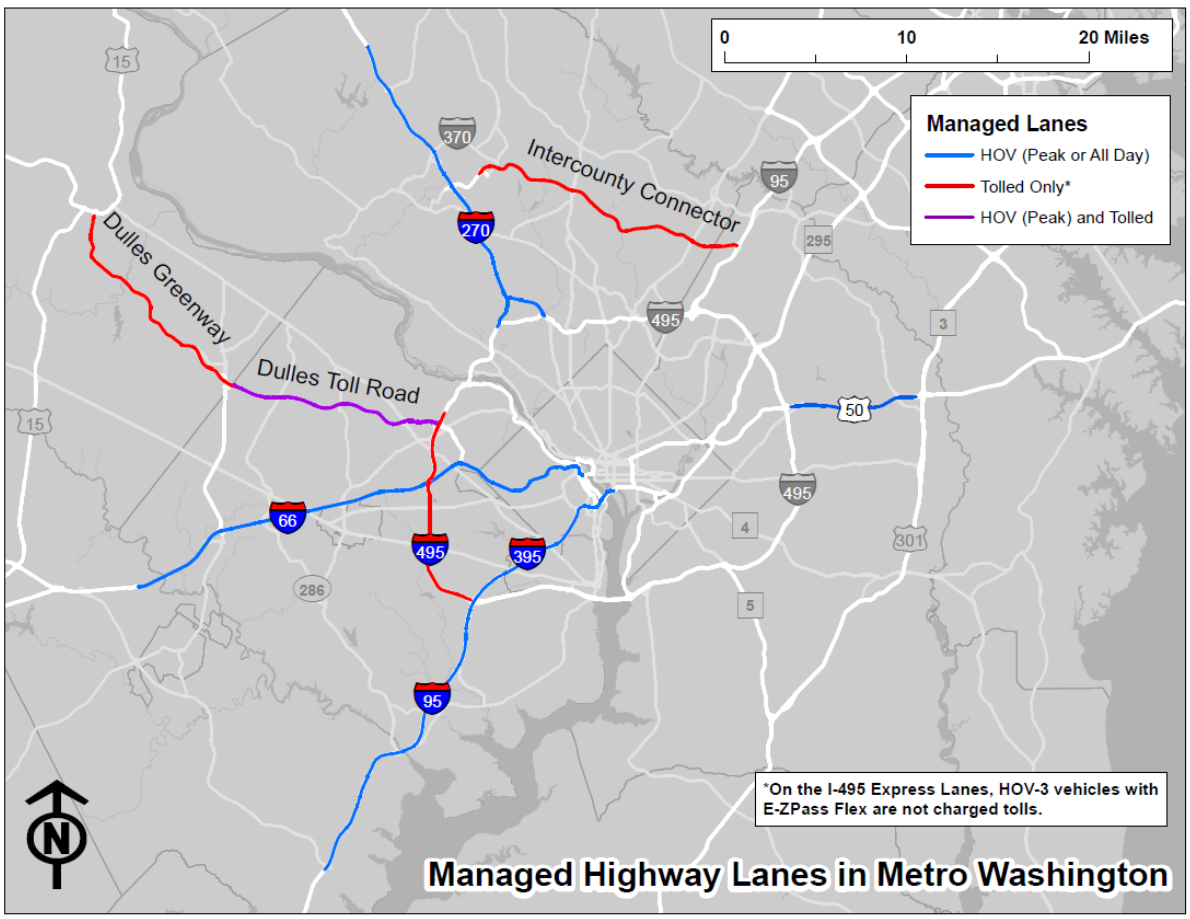
The net financial impact of BOS operations is likely to be indeterminate, or rely on variable traffic conditions. Much bus service using shoulders is implemented in conjunction with shoulder use, so tracking savings from improved travel speeds and schedule reliability is difficult. By and large, practitioners evaluate the bus operating savings as roughly offsetting the costs of driver training and supervision by the transit agencies as well as the enforcement costs for the police and increased road maintenance costs for the highway agencies.

Section D: Assessment of the Feasibility of BOS at Specific Locations in the National Capital Region

In order to assess the feasibility of BOS at specific locations in the metropolitan region, three data elements were identified as being critical: bus service, congestion, and shoulder conditions. The study methodology therefore consisted of reviewing available data for each element or identifying what data is needed. This methodology was then applied to specific locations proposed by regional stakeholders to identify those locations which offered the most potential for feasibility analysis.

Several key highways in Virginia have HOV or restricted access that should enable relatively congestion-free travel by bus, as shown in Figure 5, including: I-66 outside the Beltway, VA-267 (Dulles Access Road), I-495 Express Lanes, and the I-95 HOV Lanes (to be converted to HOT Lanes).

Figure 4: Managed Lanes on Principal Highways in the Washington Metropolitan Region



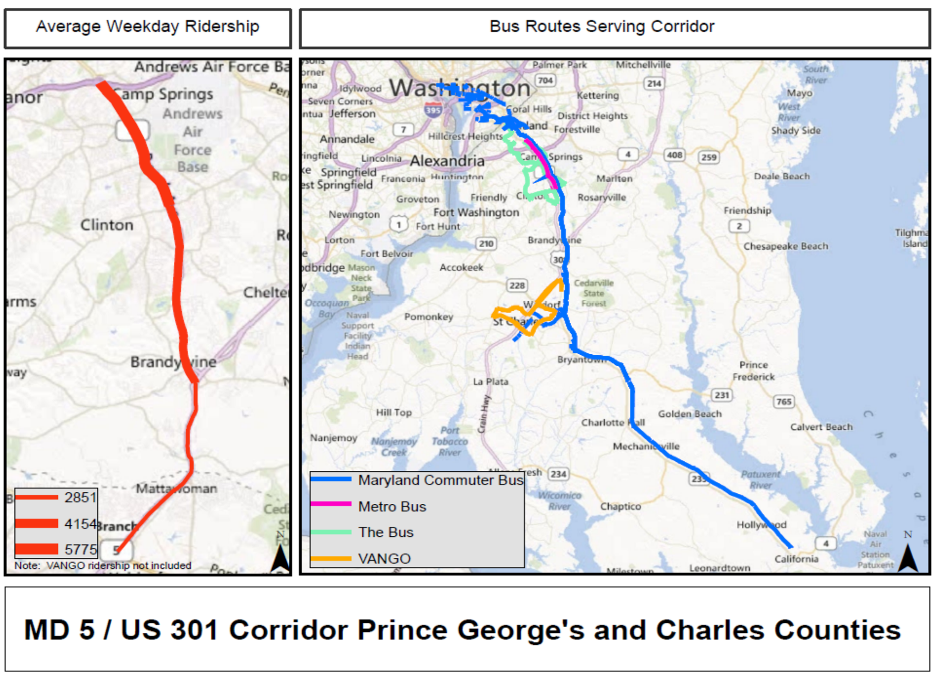
Methodology

Three data elements were evaluated to determine their application to assessing BOS feasibility.

Bus Service

Bus ridership was selected as the most relevant data item for the element of bus service. The TPB's Regional Transit Data Clearinghouse (RTDC) provides GIS functions and data support that enables selecting and combining data from geographically co-located bus routes. The primary data factor available is average weekday ridership over the past fiscal year. Combining the data for all transit routes along a corridor produces a total of daily ridership, all-day and in both directions, that could benefit from improved travel times and reliability.

Figure 5: Transit Ridership Map from the RTDC

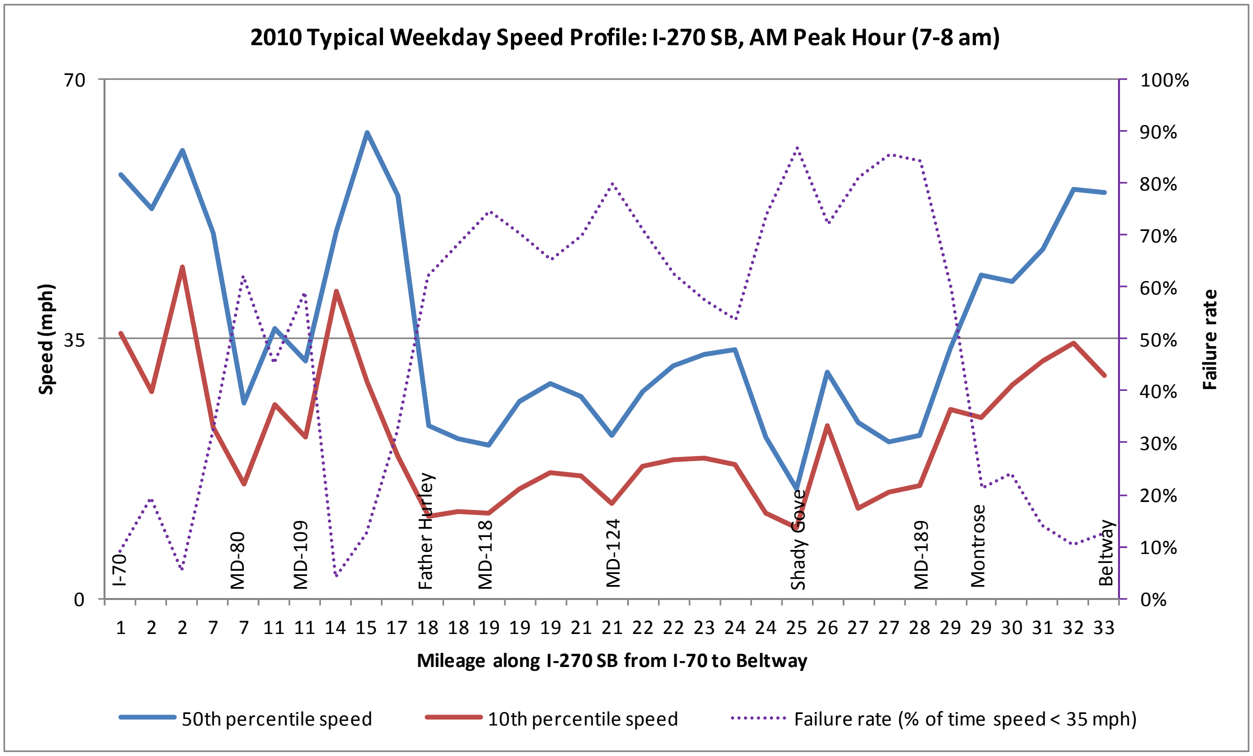


Other bus service data items for a potential BOS corridor that could be considered include the number of bus trips, the on-time performance of bus routes, the scheduled and/or actual running times of bus routes, and more detailed analysis by time period and direction. A full-fledged analysis would consider these elements in a more detailed BOS study.

Traffic Congestion

The specific data items of interest in evaluating traffic congestion are general traffic speeds during the peak hours (and direction of travel) and the percentage of time average speed falls below 35 mph. The 35 mph general traffic speed figure is the most commonly accepted policy threshold below which BOS operations are typically authorized. These data elements are available from INRIX data, to which the TPB has access as an affiliate member of the I-95 Corridor Coalition. Generally, data are collated from Tuesdays, Wednesdays, and Thursdays throughout a calendar year, thereby avoiding many holidays and the less typical traffic of Fridays.

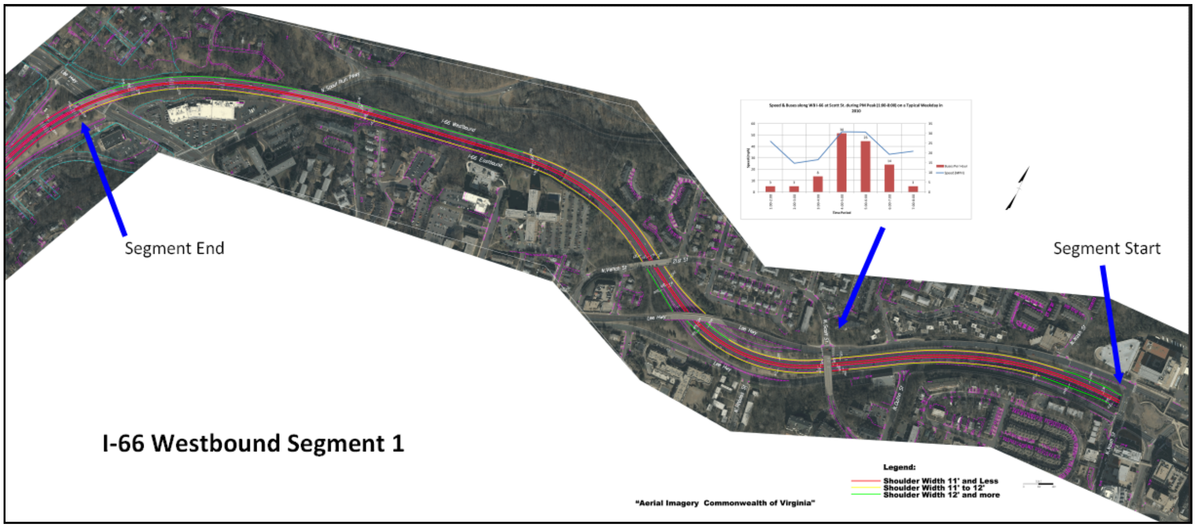
Figure 6: Traffic Congestion Data from INRIX



Shoulder Conditions

The most uncertain data element is the conditions of the shoulders along Interstate and arterial highways. Data on shoulder width, pavement thickness, grade or slope, and obstructions is not generally measured or collected by road agencies. While design standards or contract specifications should ideally determine shoulder conditions, in some cases these may date back forty or more years. Subsequent repaving work or reconstruction of interchanges may have significantly altered original conditions. In only a relatively few cases do road agencies have more detailed shoulder condition data available; VDOT has it for I-66 inside the Beltway because the agency performed a special survey of the roadway as part of project planning work.

Figure 7: Virginia DOT Aerial Map of a segment of I-66 inside the Beltway



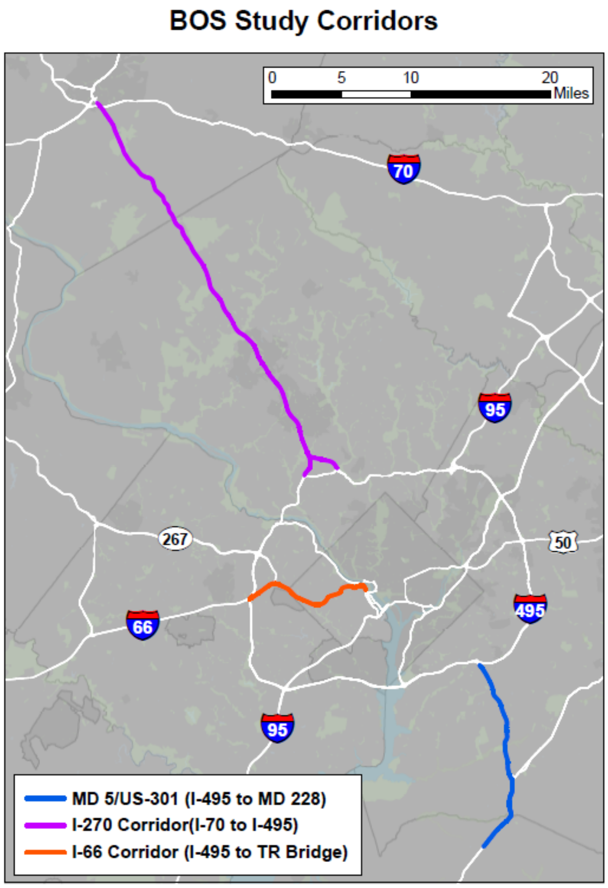
More commonly, general shoulder condition data is available when specific corridors or locations have been the focus of engineering studies preliminary to planned rehabilitation work or to support multimodal analysis studies. Potential sources of general shoulder condition data include aerial surveys, planimetrics using Computer Assisted Design (CAD) drawings, field samples with measurements and shoulder thickness sampling, and other surveys.

Study Locations

Based on the above methodology, the study corridors were further narrowed to three locations.

- MD 5/US 301 Corridor in Prince George's and Charles Counties.
    - Segment 1 – MD 5 from Beltway south to MD 223 (Clinton)
    - Segment 2 – MD 5 from MD 223 to US 301 split (northern end)
    - Segment 3 – US 301 from MD 5 split to MD 228 (Waldorf)
- I-270 Corridor from City of Frederick to the Capital Beltway.
    - Segment 1 – I-270 from I-70 interchange (Frederick) to MD 121 (Clarksburg)
    - Segment 2 – I-270 from MD 121 to MD 124 (Gaithersburg)
    - Segment 3 – I-270 from MD 124 to MD 28 (Rockville)
    - Segment 4 – I-270 from MD 28 to Beltway.
- I-66 Inside the Beltway – as part of the concurrent VDOT pilot project.

Figure 8: Map of BOS Study Corridors



MD 5/US 301 Corridor in Prince George's and Charles Counties

Bus Service

Bus service in the corridor is provided by MTA Commuter Bus, WMATA Metrobus, Prince George's The Bus, and VANGO (Charles County transit). Transit ridership ranges from 2,551 riders on a typical weekday in the southern section to 4,154 midway and 5,775 in the northern portion.

Traffic Congestion

Traffic speeds in the southern part of the corridor during the AM peak-hour, inbound, average only below 20 mph. This portion of the corridor is signalized, which limits travel speeds. Traffic falls below 35 mph almost all the time. In the northern portion of the corridor, past Surratts Road where the corridor becomes limited-access and grade-separated before connecting to the Beltway, travel speeds are typically in the 50 mph range, and speeds rarely fall below 35 mph.

Shoulder Conditions

SHA collected data on shoulder width along the segment of MD 5 between Surratts Road and Burch Hill Road, in the vicinity south of Clinton. While much of the shoulder along the corridor has widths greater than 10 feet, especially on the northbound side of the road, there are pinch points narrower than this at merging intersections and at some bridges.

This corridor consists of both limited-access and open-access sections (i.e., with parking lot entrances and driveways), totaling just over 15 miles in length. An SHA analysis of the corridor between the Capital Beltway (I-495) and the Charles County line identified 26 conflict points and 3 pinch points on the corridor.

- Conflict Points are points at which a highway user crossing, merging with, or diverging from a road or driveway conflicts with another highway user using the same road or driveway (e.g., ramps, intersections).
- Pinch Points are traffic congestion points, intersections, bridges or short lengths of road at which a traffic bottleneck exists slowing down the broader network (e.g., bridges).

In addition, the southern portion of the corridor has several signalized intersections, for which a system of queue jump lanes and/or transit signal priority might provide more practicable benefits than expanding or upgrading shoulders to enable shoulder use by buses.

Overall, it would appear that it would be feasible to have some BOS operations along the corridor, if some pinch points could be physically improved. SHA estimates necessary shoulder improvements to the MD 5/US 301 corridor as ranging between $4 and $8 million per mile, given the current 10-foot shoulder, the known pinch and conflict points, and the cost of making the shoulders safe for operation. This is a preliminary overall capital cost, and it is possible that shorter shoulder segments could be identified for BOS operation; however, this would require more detailed engineering studies.

I-270 Corridor from the City of Frederick to the Capital Beltway.

Bus Service

Bus service in the corridor is provided by MTA Commuter Bus, WMATA Metrobus, and Montgomery County Ride-On Bus. Transit ridership ranges from 3,088 riders on a typical weekday in the northern section up to 14,248 in the middle segment leading to the I-370 intersection. Most transit service is on a 5.2 mile segment between Germantown Road (MD 118) and I-370 (to Shady Grove station), which overlaps segments 2 and 3.

Traffic Congestion

Based on INRIX traffic data, speeds on I-270 in the AM peak, southbound from Frederick County heading to the Capital Beltway, range on average from 45 miles per hour down to 26 miles per hour on one segment. In worst-case conditions (10%), travel speeds are only about 16 miles per hour. Traffic falls below 35 mph approximately 75% of the time, indicating BOS operations would be common if implemented for general traffic speeds below this policy threshold.

Shoulder Conditions

There is little detailed data available on shoulder conditions along I-270, especially for the portion of the highway north of the collector/distributor (C/D) lanes, which would be the likely focus of BOS operations. South of the C/D lanes, which begin in the southbound direction just before the I-370 interchange, buses would ideally use the HOV (far left) lanes to keep moving. Further effort would be needed to collect more detailed shoulder data as well as available right-of-way information.

An SHA analysis of the corridor between the Capital Beltway (I-495) and the Frederick County line identified 22 conflict points and 17 pinch points on the corridor. SHA estimates necessary shoulder improvements to the I-270 corridor as ranging between $4 and $8 million per mile, given the current 10-foot shoulder, the known pinch and conflict points, and the cost of making the shoulders safe for operation. This is a preliminary overall cost, and it is possible that shorter shoulder segments could be identified for BOS operation; however, this would require more detailed engineering studies.

I-66 Inside the Beltway

Bus Service

In the case of I-66 transit operations data, VDOT focused on collecting the numbers of bus trips, with a maximum observed bus density of 33 buses per hour along some segments. The corridor was analyzed in 15-minute increments, with bus numbers at various segments along the corridor, to develop a more detailed picture of bus travel on the corridor. Bus ridership information was taken from more detailed reports provided by the transit bus operators. Bus operators include Loudoun County Transit, WMATA Metrobus, PRTC Omniride, and Fairfax County Connector.

Traffic Congestion

Average traffic speeds in the corridor during the AM peak-hour, inbound, are below 35 mph between Westmoreland Street and Sycamore Street. In the PM peak-hour, outbound, average speeds in this segment are below 30 mph.

Shoulder Conditions

VDOT has conducted substantial shoulder condition data collection along I-66 in support of previous multi-modal studies, including an aerial survey. They have identified several segments along which shoulders are wider than the planned minimum operating criterion of 11 feet. Other segments, however, are narrower, and there are also intersections to consider.

Based on their pilot program analysis, VDOT has identified three segments in the eastbound and two segments in the westbound direction on which they intend to pilot BOS operations. These are segments that meet VDOT's criteria of a minimum shoulder width greater than 11 feet with no lateral obstruction (11.5 feet with lateral obstruction). In addition, there are some additional segments identified for possible physical improvements to the shoulders to make BOS operations feasible in the longer run.

VDOT has completed the development of an operations protocol for buses using shoulders, which will allow all day operations for public transit buses and which permits those buses to use the shoulders when general traffic speeds fall below 35 miles per hour. However, the maximum bus operating speed on the shoulders for the pilot project will be limited to 25 mph. This speed limit for the pilot project is because of the unknown effects that bus use will have on the shoulders; however, VDOT anticipates that shoulder strength is adequate to support the pilot BOS project for a two year trial period.

Section E: Findings

This report summarizes the information collected and reviewed from technical research reports, national examples of bus on shoulders operations, and examples and studies of bus on shoulders operations in the Washington, DC metropolitan region. This information was used to assess the feasibility of expanded bus on shoulders operations in the region, as intended in Virginia for I-66 inside the Beltway in 2014 and as there may be potential for on corridors in Maryland.

The capital costs for improvements to highway shoulders to support BOS operations are the primary factor affecting the cost-effectiveness of assessed corridors. Corridors or corridor segments in which the shoulders are known to be largely of sufficient width and strength and meet other requirements could allow near-term implementation of BOS operations. Corridors and segments for which shoulders would require capital improvements generally require further analysis and planning to evaluate if BOS operations would be feasible and cost-effective.

Task force members noted that in several cases the terrain in this metropolitan region along some highway corridors has more turns and elevation changes than other urban regions. Though these conditions vary across corridors in the region, geography can limit the width and safety of shoulder lanes for use as auxiliary travel lanes for BOS operations.

This region's highway system, like much of the Northeastern United States (where there are relatively few BOS examples), was also laid out earlier than in some other major urban areas. This constrains the available right-of-way, in particular on highways that have already been widened several times over the past decades, or that travel through areas with historical urban development or historical significance (e.g., Monocacy Battlefield along I-270 in Frederick County).

The stand-alone cost of upgrading shoulders to support BOS operations might be significantly reduced if improvements were conducted in parallel with other road work, including periodic repaving/resurfacing or when bridges and intersections are rehabilitated and/or replaced. Travel lanes could also be repainted to widen a shoulder to sufficient width for bus use, though this may have to be balanced with the safety impact of a narrower shoulder on the other side.

Implementing bus on shoulders on long, continuous segments of highways is not generally effective due to costs and the limited bus use and ridership on long-haul routes, as well as the variable traffic conditions over long stretches. BOS implementation is likely to be more practical and cost-effective if targeted to short segments where there is high transit frequency and a high level of traffic congestion. With the advent of INRIX speed data, identification of traffic "hot spots" with significant congestion can be identified more easily than in the past.

For the two Maryland corridors further detailed engineering assessments would be needed to identify the shoulder conditions for disaggregated segments, for which the traffic speeds, bus ridership, and cost of necessary shoulder upgrades may be substantially different from the high-level analysis illustrated here. Preliminary cost estimates to make the Maryland corridor shoulders operable for bus were in the range of millions of dollars per mile; accordingly, refinement of more targeted potential segments for BOS and more detailed engineering assessments would be a necessary prerequisite for any further efforts towards potential implementation of BOS operations along either of these corridors.

Contingent upon funding, Maryland SHA, counties, and transit operators could continue evaluating the I-270 and MD 5/US 301 corridors or other corridors in order to identify shorter, more effective segments for potential BOS operations, such as I-270 SB between Germantown Road (MD 118) and I-370 (to Shady Grove station) or I-270 NB where I-270 goes from three lanes to two. Next steps include:

- Identifying specific segments for more detailed consideration.
- Refining shoulder condition information for these specific segments.
- Identifying capital improvements that would be necessary for BOS operations.
- Discussing operating protocols that would be needed to implement a pilot program.

In the long-run and for any potential corridors for BOS operations in the region, stakeholder agencies could:

- Assess the results of I-66 inside the Beltway BOS pilot project in Virginia. If BOS use begins in early 2014, initial results after six months of operation may be available towards the end of the calendar year.
- Review long-range roadwork schedule for opportunities to upgrade shoulders for BOS operations in conjunction with planned rehabilitation and resurfacing of highways, especially at intersections and for structures.

Section F: References

TCRP Synthesis 64: Bus Use of Shoulders, 2006

http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_64.pdf

TCRP Report 151: A Guide for Implementing Bus on Shoulder (BOS) Systems, 2012

http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_151.pdf

NCDOT I-40 BOSS Implementation and Operations Plan, May 2012

www.letsgetmoving.org/bossiop

Miami Dade MPO Bus on Shoulder Service Evaluation, January 2009

http://www.miamidade.gov/mpo/docs/MPO_bus_shoulders_eval_final_200901.pdf

FTA Bus-Only Shoulders in the Twin Cities, June 2007

http://www.hhh.umn.edu/img/assets/11475/Bus%20Only%20Shoulders%20Report%20FINAL.pdf

Appendix A: TPB BOS Task Force

Bus on Shoulders Task Force - Background

At the July 18, 2012 meeting of the Transportation Planning Board (TPB), it was requested that a task force be established to identify promising locations in the region to operate buses on the shoulders of highways. As requested by the TPB, 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 Bus On Shoulder (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. The proposed membership, work plan, and schedule for the Task Force were approved at the September 19, 2012 TPB meeting.

Task Force Membership

The task force co-Chairs are Ms. Carol Krimm, of the City of Frederick Board of Aldermen, and Mr. Chris Zimmerman, of the Arlington County Board. Other members were invited from the following:

Departments of Transportation

- District of Columbia (DDOT)
- Maryland (MDOT)
- Virginia (VDOT)

Transit Operators

- WMATA
- PRTC
- MTA Commuter Bus
- Loudoun Transit

Jurisdictions

- Fairfax County
- Frederick County
- Montgomery County
- Prince George's County
- Others…

Work Plan and Schedule

The regional assessment of BOS feasibility is being coordinated through a series of meetings, with necessary work assigned through discussion.

Task 1 – Summary of Local and National Experience with Bus On Shoulders

The task force will develop a summary of critical experience with current and previous BOS operations, to include an overview of safety, roadway engineering, and bus service operations aspects. In addition, a summary of national experience and its applicability and use in this region will be prepared and reviewed, including federal regulations, requirements for requesting design exceptions, and supporting state legislation. This information will be used as a resource for discussion and development of the assessment.

Task 2 – Assessment of the Feasibility of BOS at Specific Locations

Stakeholder agencies will identify potential corridors for BOS operation on the region's highway network, based on 1) existing highway congestion locations, 2) current bus service, and 3) highway shoulder conditions. This information will be used to screen out infeasible locations and to identify potential corridors and bus routes for further analysis.

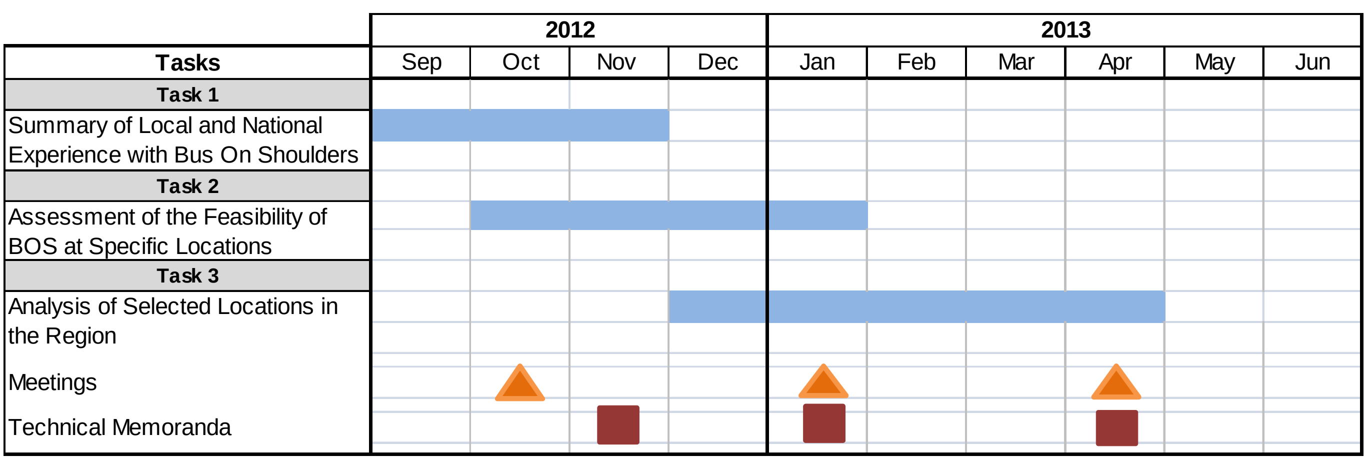
Task 3 – Analysis of Select Corridors/Routes in the Region

Using the results of Tasks 1 and 2, the TPB staff, with assistance from the respective highway and transit agencies, will conduct an analysis of the feasibility of BOS on the potential corridors/routes in the region. The analysis will:

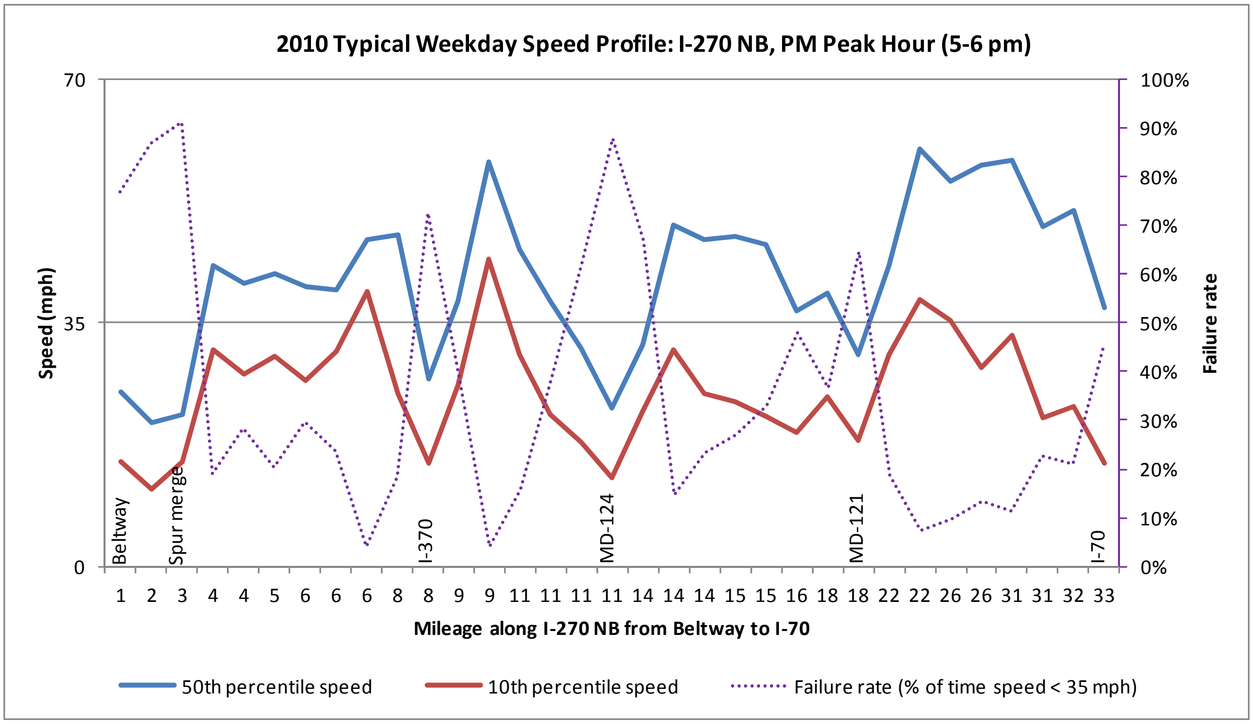
1. Identify issues and challenges with safe operation,
2. Develop capital cost and operating cost inputs, as provided by the stakeholder agencies.
3. Determine potential travel time savings for bus routes based on highway congestion,
4. Present a benefit-cost analysis of the prospective benefits to riders and traffic relative to the projected costs of implementation of BOS service on the selected corridors/routes.

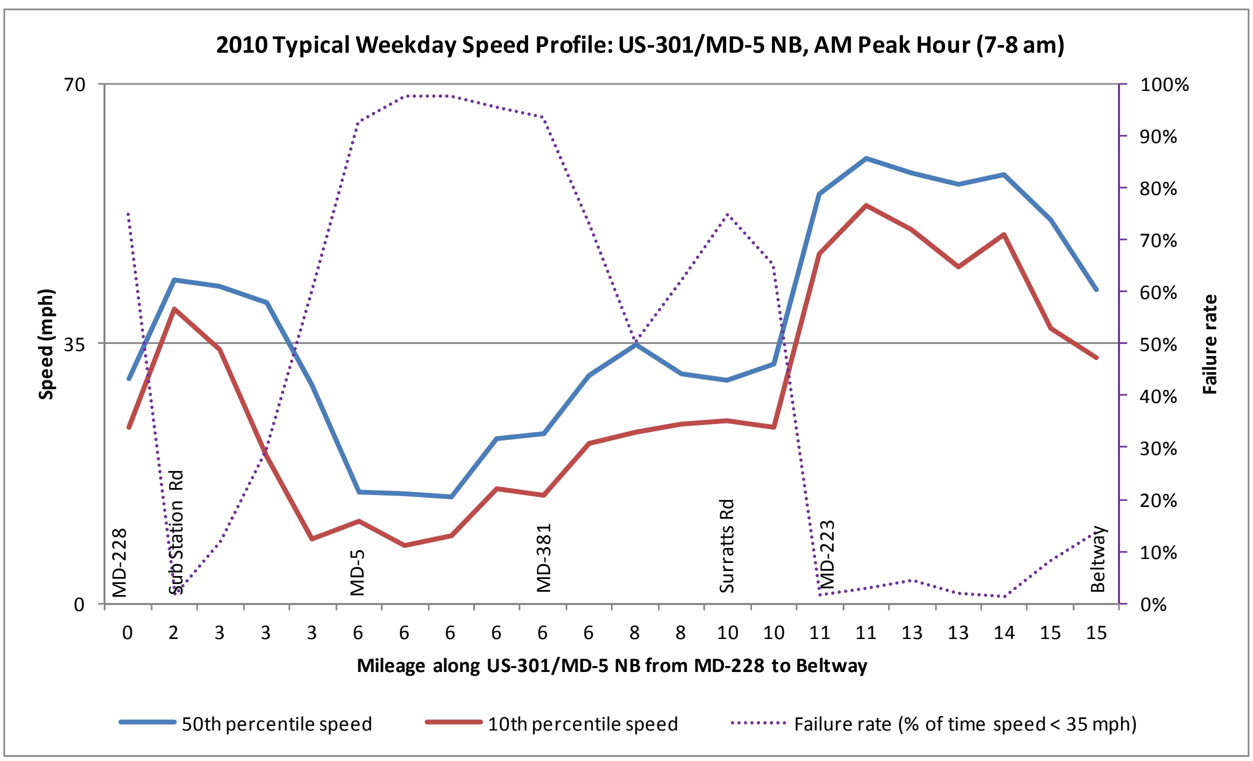
For each task, technical memoranda summarizing the results will be prepared, with supporting presentations for the task force. The work schedule and months for task force meetings and delivery of the technical memoranda are shown below in Figure 1.

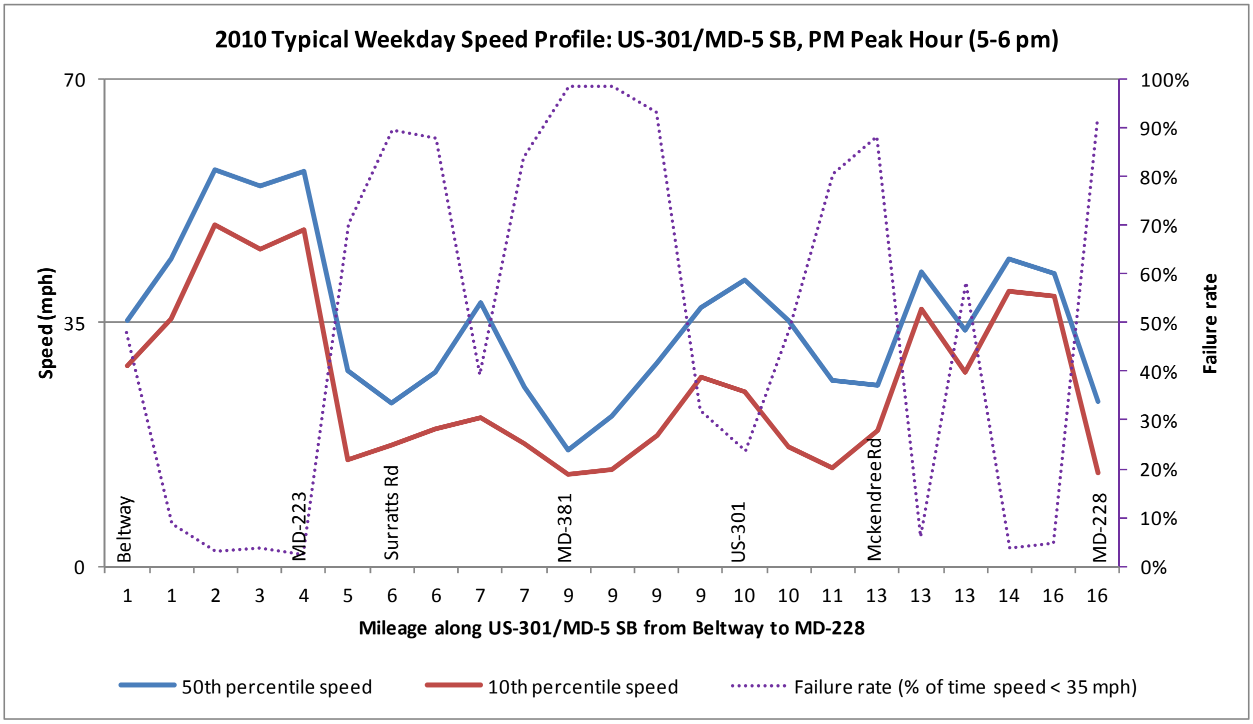
Figure 1: TPB BOS Task Force Work Plan and Schedule



Appendix B: Maps and Figures



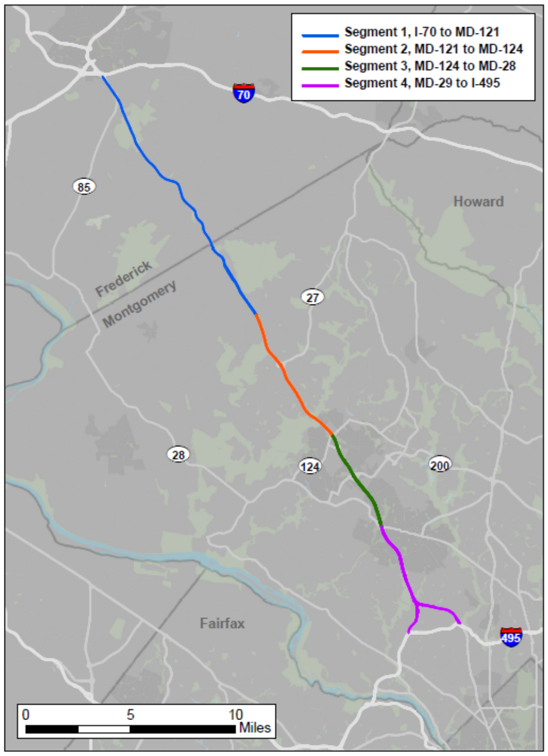




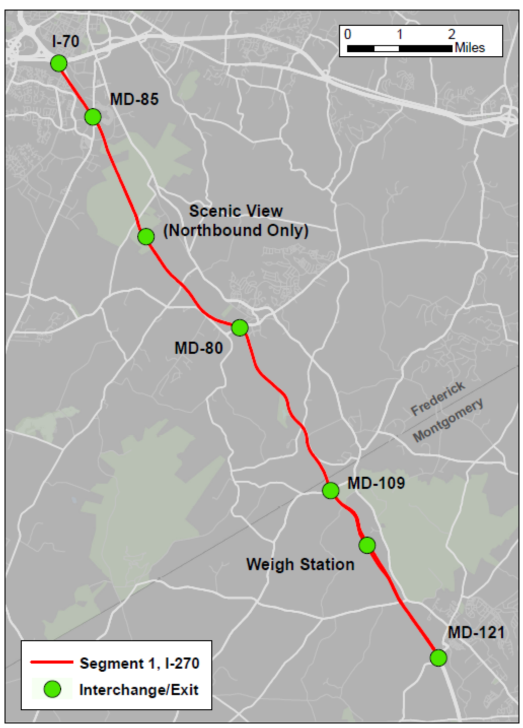
2010 Typical Weekday Speed Profile: US-301/MD-5 SB, PM Peak Hour (5-6 pm)
Speed (mph)
70
35
0
Failure rate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Beltway
MD-223
Surratts Rd
MD-381
US-301
MckendreeRd
MD-228
1 1 2 3 4 5 6 6 7 7 9 9 9 9 10 10 11 13 13 13 14 16 16
Mileage along US-301/MD-5 SB from Beltway to MD-228
50th percentile speed
10th percentile speed
Failure rate (% of time speed < 35 mph)

Map of VDOT I-66 Pilot BOS Locations (courtesy of VDOT)

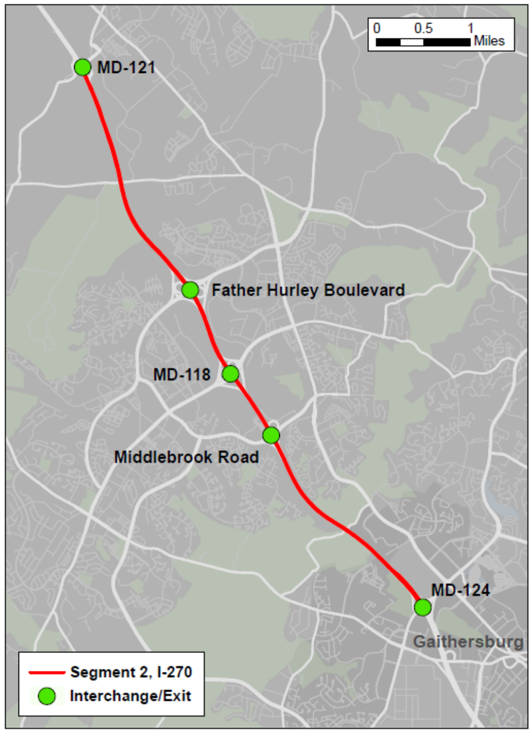
I-270 Bus on Shoulder Study Corridors



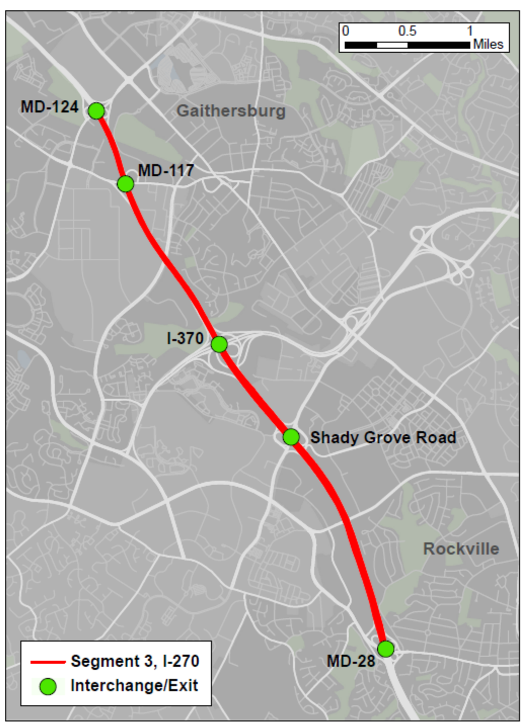
I-270 BOS Corridor, Segment 1: I-70 to MD-121



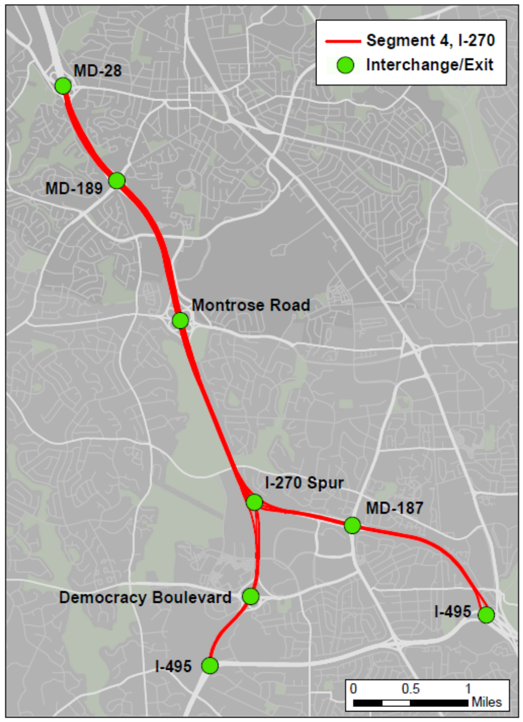
I-270 BOS Corridor, Segment 2: MD-121 to MD-124



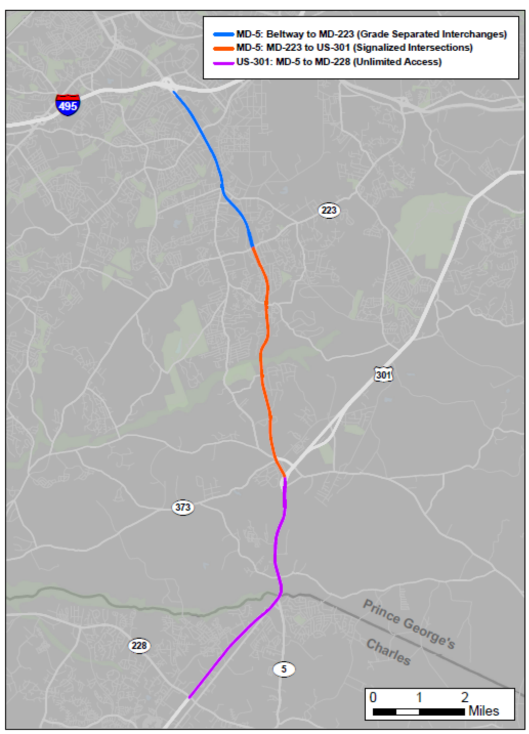
I-270 BOS Corridor, Segment 3: MD-124 to MD-28



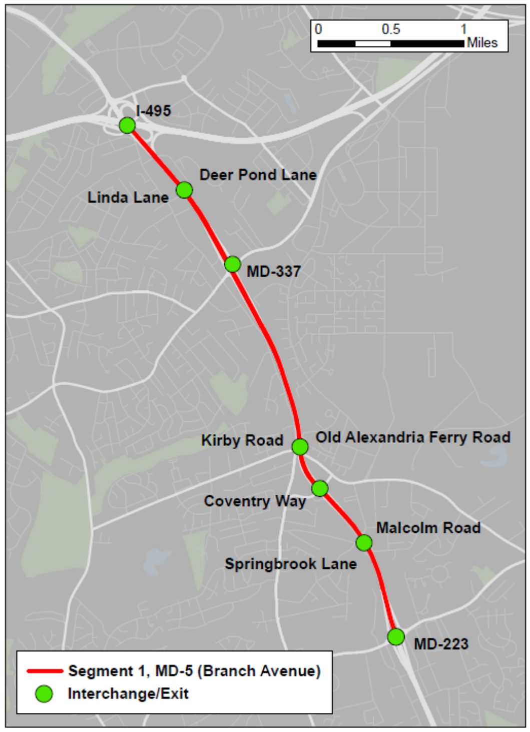
I-270 BOS Corridor, Segment 4: MD-28 to I-495



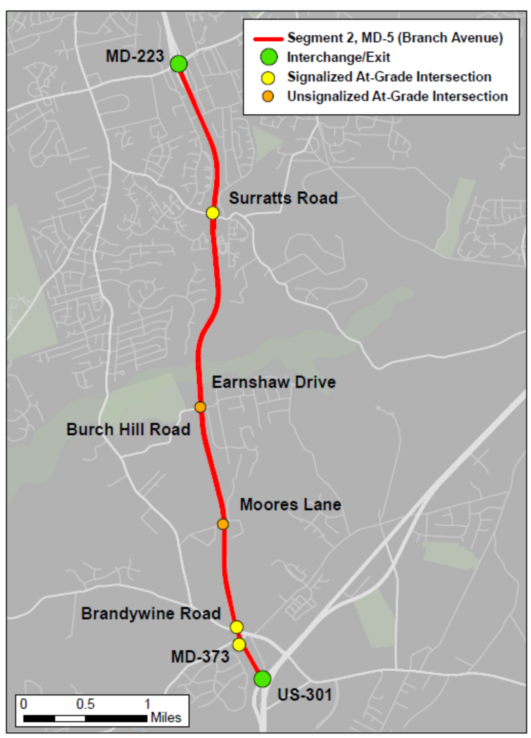
MD-5/US-301 Bus on Shoulder Study Corridors



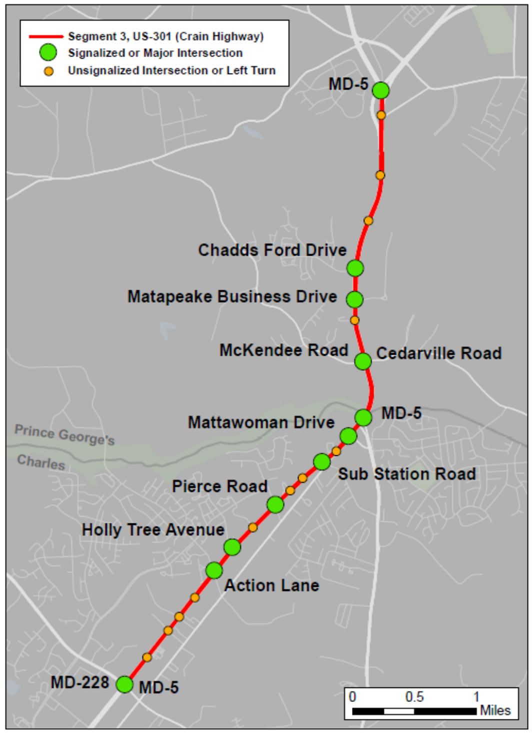
MD-5/US-301 BOS Corridor, Segment 1: I-495 to MD-223



MD-5/US-301 BOS Corridor, Segment 2: MD-223 to US-301



MD-5/US-301 BOS Corridor, Segment 3: MD-5 to US-228



Appendix C: Benefit-Cost Analysis Model

Using a benefit-cost analysis (BCA) model for assessing a proposed BOS project at a planning level can provide insight on the effectiveness of the proposed project. The BCA model developed for the task force uses available travel data and typical cost assumptions to calculate a benefit-cost ratio for the financial and/or passenger benefits a BOS project could bring compared to the capital cost for implementation. However, it is important to stress that use of the BCA model for planning purposes provides only a conceptual evaluation of a project that does not reflect the necessary engineering and coordination work needed for actual implementation.

While used as a planning tool, the BCA model can be used in a sensitivity analysis that varies the inputs to provide insight on the factors that would be important for a proposed BOS project. What bus use and ridership, what capital costs, what traffic speeds would make a BOS project feasible to evaluate further? A sensitivity analysis can compare different alternatives and forecast inputs to assist planners in evaluating these factors for a proposed project.

Corridor Characteristics and Transit Data

The characteristics of the corridor along which a BOS project will take place are the primary inputs for the benefit-cost analysis model.

- Length of Shoulders – The operable length of the proposed BOS segment being evaluated, which could be a short, queue jump-like location at a major intersection or a long, continuous segment of highway.
- General Travel Speed – The average speed of general traffic during the peak hour condition being analyzed. AM peak hour traffic data is typically more available, but the analysis could also be for a PM peak hour.
- Unreliable Travel Speed – The average speed of general traffic for the 10% worst days. Used to incorporate a measure for the unreliability of travel.
- Transit Data – There are two transit data elements to be included in the analysis, which are requested for both the peak hour and the peak period outside of the peak hour.
    - Number of Buses – This can be calculated from current bus schedules for those routes operating along a corridor along which BOS is being implemented. Alternatively, a planning forecast figure could be entered into the model as well.

    - Number of Passengers – This can be calculated from known ridership data, or can also be a forecast estimate.

- Peak Hour Adjustment – As noted, the BCA model is set up for average peak hour conditions. Conditions in the rest of the peak period might be nearly as congested as the peak hour, but are more likely not to be as bad, and to also have fewer bus trips and bus travelers. The peak hour adjustment thus scales for the fact that some BOS operations will take place in the peak period outside of the peak hour, but not as much. AM peak hour traffic data is typically more available, but the analysis could also be for a PM peak hour, which might have a longer peak period of congestion than the AM peak period.

Travel Time Savings and Reliability

This section takes the travel data and calculates the improvements in average travel time and in reliability from buses making use of shoulders to bypass congestion over the defined segment for analysis. Bus travelers and bus operators value both faster travel time and the improved schedule reliability that BOS operations can offer, and these results are used to calculate the financial and passenger benefits from BOS.

- Travel Time Savings – From the general travel speed, and applying the Twin Cities operations protocol for BOS operations (e.g., no more than 15 mph greater than general traffic speed and in no case more than 35 mph), the typical average travel time savings per bus trip for a proposed BOS segment can be calculated.
- Reliability Improvement – For analysis, this is measured by the time difference between travel at the average travel speed and travel when speed conditions are the worst ten percentile. The ability to use the shoulders will ensure the buses arrive on schedule more often, with benefits to both the bus travelers and bus operators.
- Shoulder Use – As noted, the BCA model uses average AM peak hour conditions. Buses will not use BOS all the time; some days traffic congestion may not be that severe or there may be a breakdown or other conditions that prevent shoulder use. The shoulder use adjustment scales the model to account for these factors; different factors are used for average conditions and for the ten percentile worst case conditions.

Financial Benefits and Costs

The financial costs of BOS operations include both the capital costs of implementation costs and the operating costs and benefits of ongoing operations.

- Capital Costs – One-time cost of implementation.
  - Shoulder Improvements – The cost per mile of any known or assumptive improvements to make shoulders useable for BOS operations.
  - Public Education – An assumptive cost for conducting a public outreach effort in conjunction with the start of BOS operations along a corridor to ensure the public understands the purpose of the project and the safety issues.
  - Operations Training – A cost for training bus drivers for BOS operations, including route familiarization, operations protocol, and driving techniques. Number of bus drivers typically calculated as a multiple of the number of buses in operation.
- Operations and Maintenance (O & M) Costs – Ongoing annual costs
  - Shoulder Clearance – An annual cost of keeping a mile of shoulder lane clear of snow and debris.
  - Enforcement – An annual cost per mile for additional enforcement and incident response to keep shoulder lanes available for bus use.
  - Bus Operations – An annual cost for supervision and ongoing driver training in support of BOS operations, calculated as a factor of the number of buses on the corridor.
- Travel Time & Reliability – Annual savings for bus operating agencies and personal benefits to passengers from better bus travel.
  - Bus value of time – Expressed in $ per hour, this represents the operating cost savings from faster and more reliable bus service due to BOS operations.
  - Passenger value of time – Expressed in $ per hour, this represents the value the passenger places on improved travel time and reduced unreliability, i.e., a faster and more reliable trip. Each passenger on a bus is presumed to have the same value of time and experience the same benefits.

Other benefits could also be provided by BOS operations, such as the environmental benefits from a reduction in traffic congestion and emissions due to travelers switching modes from auto to bus. However, given the very small proportion of travel on bus compared to auto travel on most corridors, these benefits and costs are expected to be minimal and are excluded from the model analysis for the sake of simplicity.

There could also be benefits and/or costs from changes in accident rates and severity from BOS operations, either positive or negative; however, reviews of BOS operating safety by TCRP research studies and other studies have not found any measureable change in accidents, so a safety element is not included in this BCA model.

Benefit / Cost Ratio

The BCA model's final result is a ratio calculated from the financial costs and benefits and the passenger (or social) benefits of the analyzed BOS project. The higher the value of the benefit-cost ratio, the greater the effectiveness of the project is regarded. A benefit-cost ratio greater than 1.0 for a proposed project is generally regarded as worthwhile in terms of the stand-alone benefits it brings compared to the cost of implementation and operation.

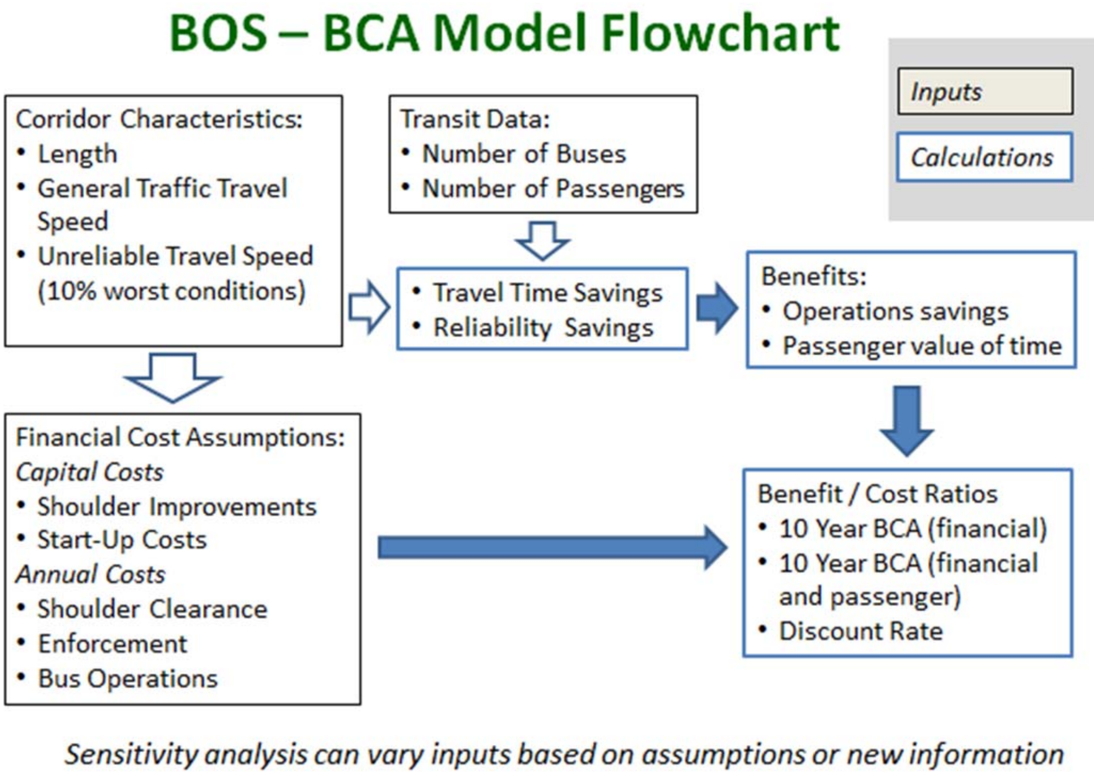
However, while this BCA model is a planning-level tool that includes the major characteristics of BOS operations, it does not capture all possible benefits or costs and may not reflect the full impacts of a proposed BOS project. The BCA model's primary application is likely to be in the initial evaluation of a project. The model can also be used to compare benefit-cost ratios relative to each other across a range of alternatives analyses or sensitivity tests, or among different proposed projects.

The BCA model makes the following benefit-cost ratio calculations.

- 10 Year BCA (financial) – Ratio calculated by taking the ten-year total of the financial operating benefits (minus O&M costs) and dividing by the capital costs of the project. Does not include passenger benefits.
- 10 Year BCA (financial + passenger) – Ratio calculated by taking the ten-year total of the financial operating benefits (minus O&M costs) and the benefits to passengers, divided by the capital costs of the project.
- Discount Rate – Applies a typical discount rate to the future stream of operating costs and benefits to allow comparison to other transportation projects. The two BCA ratios are re-calculated using this discount rate.

The following schematic provides an overview of the BCA Model:

Figure 1: Benefit-Cost Analysis Model Schematic



An illustration of the model in its Excel spreadsheet is shown in Figure 2.

Figure 2: BCA Model Results for I-66 – *For Illustrative Purposes Only*

Bus On Shoulders (BOS) Benefit-Cost Analysis Model		**I-66 Eastbound**			**I-66 Westbound**		**TOTAL**
		Pilot 1	**Pilot 2**	**Pilot 3**	**Pilot 4**	**Pilot 5**	
		Existing BOS on Dulles Connector to I-66	N. Sycamore Street to N. Jacksonville St.	Rte. 29 Overpass at Spout Run Pkwy to N. Nash St.	N. Nash Street to Rte. 29 Overpass at Spout Run Pkwy	Outside shoulder from N. Quincy St to Fairfax Drive merge point	
Corridor Characteristics							
Length of Bus On Shoulder Segment	miles	1.75	1.4	1.4	1.4	1.1	**7.05**
General Traffic Travel Speed	miles per hour	23	27	48	36	21	
Unreliable Travel Speed (10% worst conditions)	miles per hour	*15*	*15*	*25*	*15*	*15*	
Transit Data							
Number of Buses	Scheduled trips (peak hour)	32	32	30	31	30	**32**
	Scheduled trips (peak period)	122	122	122	122	122	**122**
	peak factor	33%	33%	33%	33%	33%	
Number of Passengers	Ridership (peak hour)	960	960	900	930	900	**960**
	Ridership (peak period)	3050	3050	3050	3050	3050	**3050**
Travel Time Savings	% of peak bus trips using shoulders	50%	50%	50%	50%	50%	
	BOS speed	25	0	0	0	25	
	average speed differential	2	0	0	0	4	
	segment length	1.75	1.4	1.4	1.4	1.1	
	Travel Time Savings (hr)	***0.003***	***0.000***	***0.000***	***0.000***	***0.004***	***0.0072***
Reliability Improvement	% of peak bus trips arriving on time	90%	90%	90%	90%	90%	
	BOS speed	25	25	0	25	25	
	average speed differential	10.00	10.00	0.00	10.00	10.00	
	segment length	1.75	1.4	1.4	1.4	1.1	
	Reliability Savings (hr)	***0.042***	***0.034***	***0.000***	***0.034***	***0.026***	***0.1356***
Benefits and Costs							
Capital Costs	***Assumptions***						
Shoulder Improvements (cost/mile)		$550,000	$350,000	$300,000	$300,000	$650,000	**$2,150,000**
Public Education (per project)	$50,000						**$50,000**
Operations Training (per bus driver)	$600						**$73,200**
O & M Costs							
Shoulder Clearance (annual, per mile)	$10,000	$17,500	$17,500	$17,500	$17,500	$17,500	**$87,500**
Enforcement (annual, per mile)	$5,000	$8,750	$7,000	$7,000	$7,000	$5,500	**$35,250**
Bus Operations (annual, per bus)	$2,500						**$305,000**
Travel Time & Reliability							
Operations Savings (weekday, $/hour)	$100	$278	$207	$0	$205	$185	**$875**
Passenger value of time ($/hour)	$12.00	$892	$665	$0	$657	$591	**$2,805**
Project Summary							
Capital Costs (once)		$550,000	$350,000	$300,000	$300,000	$650,000	**$2,273,200**
O & M Costs (annual)		$26,250	$24,500	$24,500	$24,500	$23,000	**$427,750**
Financial Benefits (annual)		$69,480	$51,828	$0	$51,265	$46,161	**$218,734**
Passenger Benefits (annual)		$222,925	$166,290	$0	$164,264	$147,706	**$701,184**
10 Year BCA (financial)		**0.786**	**0.781**		**0.892**	**0.356**	**-0.919**
10 Year BCA (financial and passenger)		**4.839**	**5.532**		**6.368**	**2.629**	**2.165**
Discount Rate	*3%*						
10 Year BCA (financial)		**0.670**	**0.666**		**0.761**	**0.304**	**-0.784**
10 Year BCA (financial and passenger)		**4.128**	**4.719**		**5.432**	**2.242**	**1.847**