Traffic Operations Analysis: Washington Boulevard (Rt. 27) and Columbia Pike (Rt. 244) Arlington County

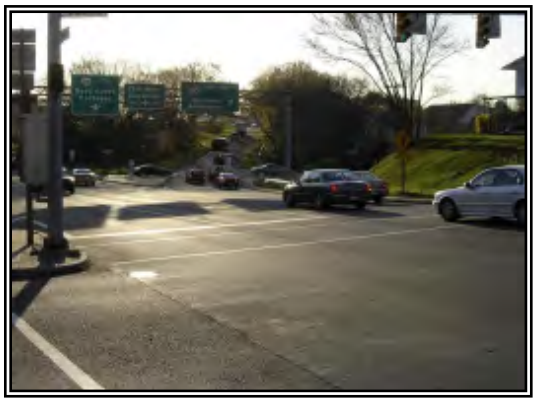

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Table of Contents

1. Introduction 1
   1.1 Overview 1
   1.2 Methodology and Organization 2
2. Operational Analysis of Build and No-Build Alternatives – HCS Software 6
   2.1 Operational Performance of Intersections on Columbia Pike 7
   2.2 Operational Performance of Ramps on Washington Boulevard. 13
   2.3 Weaving Analysis on Washington Boulevard 14
3. Operational Analysis of Build and No-Build Alternatives – CORSIM Software 17
   3.1 Operational Performance of Intersections on Columbia Pike 18
   3.2 Operational Performance of Washington Boulevard. 21
4. Qualitative Safety Considerations of the Modified B-2 Alternative relative to No-Build Alternative 24
   4.1 Vehicular Traffic 24
      South Quinn Street 24
      South Queen Street/Ramp E 24
      Ramp A/B 24
      South Orme Street and Ramp D 25
   4.2 Pedestrians 25
   4.3 Bicyclists 26
   4.4 Special Consideration for Traffic Control Devices 28
   4.5 Pavement Markings for Eastbound Columbia Pike 29
   4.6 Review Decision Distance for Ramp H 30
      Current Conditions 30
      Design Plans 30
      Design Requirements 30
      Assessment 31
5 Conclusions 32
Appendix A –Response to Arlington County's Request for Additional Information 33
Appendix B –CORSIM Analysis: Model Limitations and Fine-Tuning 42

List of Figures

Figure 1: No Build Alternative 4
Figure 2: Modified B-2 Alternative (Build Alternative)..... 5
Figure 3: 2031 Peak Hour Traffic Volumes for No-Build Alternative..... 8
Figure 4: 2031 Peak Hour Traffic Volumes for Modified B-2 Alternative (Build Alternative) ... 9
Figure 5: No-Build and Modified B-2 Alternative Weaving Volumes 15
Figure 6: Recommended Bicycle Signage..... 27
Figure 7: Signage to Indicate End of a Bicycle Lane 28

List of Tables

Table 1: Geometric and Operational Comparison between Build and No-Build Alternatives..... 10

Table 2: HCS MOEs for Operational Performance of Intersections on Columbia Pike under No-Build Condition..... 11

Table 3: HCS MOEs for Operational Performance of Intersections on Columbia Pike under the Modified B-2 Alternative (Build Alternative) 12

Table 4: MOEs for Operational Performance of Ramps on Washington Boulevard 14

Table 5: MOEs for Weaving Analyses on Washington Boulevard 14

Table 6: CORSIM MOEs for Operational Performance of Intersections on Columbia Pike under No-Build Condition 20

Table 7: CORSIM MOEs for Operational Performance of Intersections on Columbia Pike under Modified B-2 Alternative (Build Alternative) 21

Table 8: CORSIM MOEs for Operational Performance of Freeway Segments on Washington Boulevard under No-Build Conditions 22

Table 9: CORSIM MOEs for Operational Performance of Freeway Segments on Washington Boulevard under Alternative Build 23

1. Introduction

Columbia Pike is a major commuter route that runs east and west from the Annandale area of Fairfax County to the Pentagon, traversing through Arlington County. Washington Boulevard (Route 27) is another major route that links the Falls Church area to the Arlington Memorial Bridge. Rt. 27 traverses through Arlington County and wraps around the southern border of Fort Myer and Arlington National Cemetery. These two roadways intersect twice, the first being located adjacent to the Pentagon and the second being located between the Navy Annex building and the residential neighborhood of Arlington View. The latter is the subject interchange being studied herein. For the purposes of this report, Washington Boulevard is identified as running north and south. The existing bridge of Washington Boulevard over Columbia Pike is in need of replacement, hence the need for this analysis, to ascertain that the resulting interchange configuration from the proposed bridge replacement still maintains acceptable operations.

1.1 Overview

The objective of this VDOT interchange project is to replace the existing Washington Boulevard bridge structure that crosses over Columbia Pike with two bridges, one carrying each the northbound lanes and the southbound lanes, separated by a light well. Washington Boulevard will consist of four 12' lanes, standard shoulders, and an auxiliary lane in the northbound direction between adjacent loop ramps. Secondarily, a new typical section on Columbia Pike is to be incorporated that includes a raised median, 15' wide curb lanes to accommodate on-road bicyclists, a 10' shared use path, and a 7' sidewalk. Changes in the bridge width, length, and design would result in changes to ramps within the interchange and minor streets near the interchange, and ultimately neighborhood access for surrounding communities. Although the purpose of the interchange project is not to increase capacity on Columbia Pike or on Washington Boulevard, an operations analysis of the proposed configuration was performed to compare the No-Build and Build conditions, and to assess the impacts of the proposed conditions on operations, safety, mobility and access.

The original design, initiated in 1996, did not encompass the improvements to Columbia Pike called for in the Columbia Pike Revitalization Plan (adopted by the Arlington County Board in 2003). Additionally, the limits of the original design were from S. Scott Street to S. Orme Street, which would have displaced four families. The project funds that were allocated for the original proposed interchange configuration were not sufficient for construction of the proposed design. In order to reduce the projected cost of the interchange improvement, various Reduced Cost Alternative concepts were developed and studied by VDOT Location and Design with the intent to reduce the limits and minimize right-of-way impacts. Of the six concepts developed, the Alternative B, Phase 2 was selected by VDOT, Arlington County, and interested citizens as the desirable approach.

Design efforts commenced on the Alternative B, Phase 2 concept in 2005, but resulted in an unfavorable configuration in that it would have restricted access to S. Queen Street, except as a right in/right out from Ramp E only. As directed by a County Board Resolution, which followed the first Public Hearing in 1998, VDOT and Arlington County established the Bridge Working

Group. This citizen task force assisted VDOT in the development of bridge aesthetics, but also provided input into the overall design concept. In 2006, VDOT began a new study of alternative concepts based on the input received from the Bridge Working Group. The concepts developed included location-specific improvements to intersections within the study area, which were studied independently and then in combination, such that any of the configurations could be incorporated into the design if selected. This effort resulted in essentially three overall interchange configurations, yet two of the three configurations still precluded full access at S. Queen Street, which was the number one priority of the Bridge Working Group. The last and final concept developed, hereafter referred to as the Modified B-2 Alternative (or the Build Alternative), was determined to be successful in terms of the project goals and is the basis of this report.

VHB (formerly BMI-SG) was tasked with analyzing the final Build Alternative developed from:

1) The operational analysis of the concepts and their variations,
2) Input from Arlington County and VDOT Traffic Engineering Section,
3) Involvement with the Community, and
4) Coordination with Federal Highway Administration.

This new final Build Alternative is referred to as the Modified B-2 Alternative. Specifically, the goals of the new design are to provide for full access to and from S. Queen Street, prevent ramp spillback onto Washington Boulevard, address safety issues at intersections and ramp junctions, provide mobility with acceptable levels of delay along Columbia Pike, and to improve non-motorized accessibility.

1.2 Methodology and Organization

The purpose of this report is to present the operational and safety review of the two alternatives: the No-Build and Build configurations. The geometric design configurations analyzed are:

- No-Build Alternative: this configuration assumes no changes to the existing roadway geometric conditions would be made in the future years. The analysis of No-Build conditions was performed using the 2031 forecasted peak hour volumes provided by VDOT on February 6, 2007.
- Build Alternative: the preferred geometric interchange configuration, Modified B-2 Alternative, as provided by VDOT on June 17, 2008, which replaced an earlier concept of the same configuration (which incorporated only minor revisions, over the design developed and analyzed in 2007, to intersection geometry at Ramp G/S. Queen Street/Columbia Pike intersections in order to meet American with Disabilities Act (ADA) Guidelines and improve lane alignment).

Figures 1 and 2 depict the No-Build Alternative and the Modified B-2 Alternative. The specific details of the operational analyses, contained within this report, include:

1. Traffic operational performance for intersections in the Columbia Pike/Washington Boulevard interchange area using the *Highway Capacity Software* (HCS 2000). (See Section 2)

2. Traffic operational performance for ramp and weaving sections on Washington Boulevard in the Columbia Pike/Washington Boulevard interchange area using HCS 2000. (See Section 3)
3. Traffic operational analysis of the Columbia Pike/Washington Boulevard interchange area, including the Washington Boulevard and Columbia Pike approaches, using the micro-simulation software *Traffic Software Integrated System* (*CORSIM 5.1)*. (See Section 3)
4. Discussion of safety and pedestrian/bicyclist mobility of the Modified B-2 Alternative scenario in comparison to the No-Build conditions for all types of users – motorists, pedestrians, and bicyclists. (See Section 4)

This report is organized into five sections. Section 2 describes the operational analysis using the Highway Capacity Software. Section 3 presents the operational analysis using the CORSIM software. The qualitative safety and pedestrian/bicyclist mobility review of the No-Build Alternative and the proposed Modified B-2 Alternative are described in Section 4. Section 5 summarizes the key findings of the study.

Figure 1: No Build Alternative

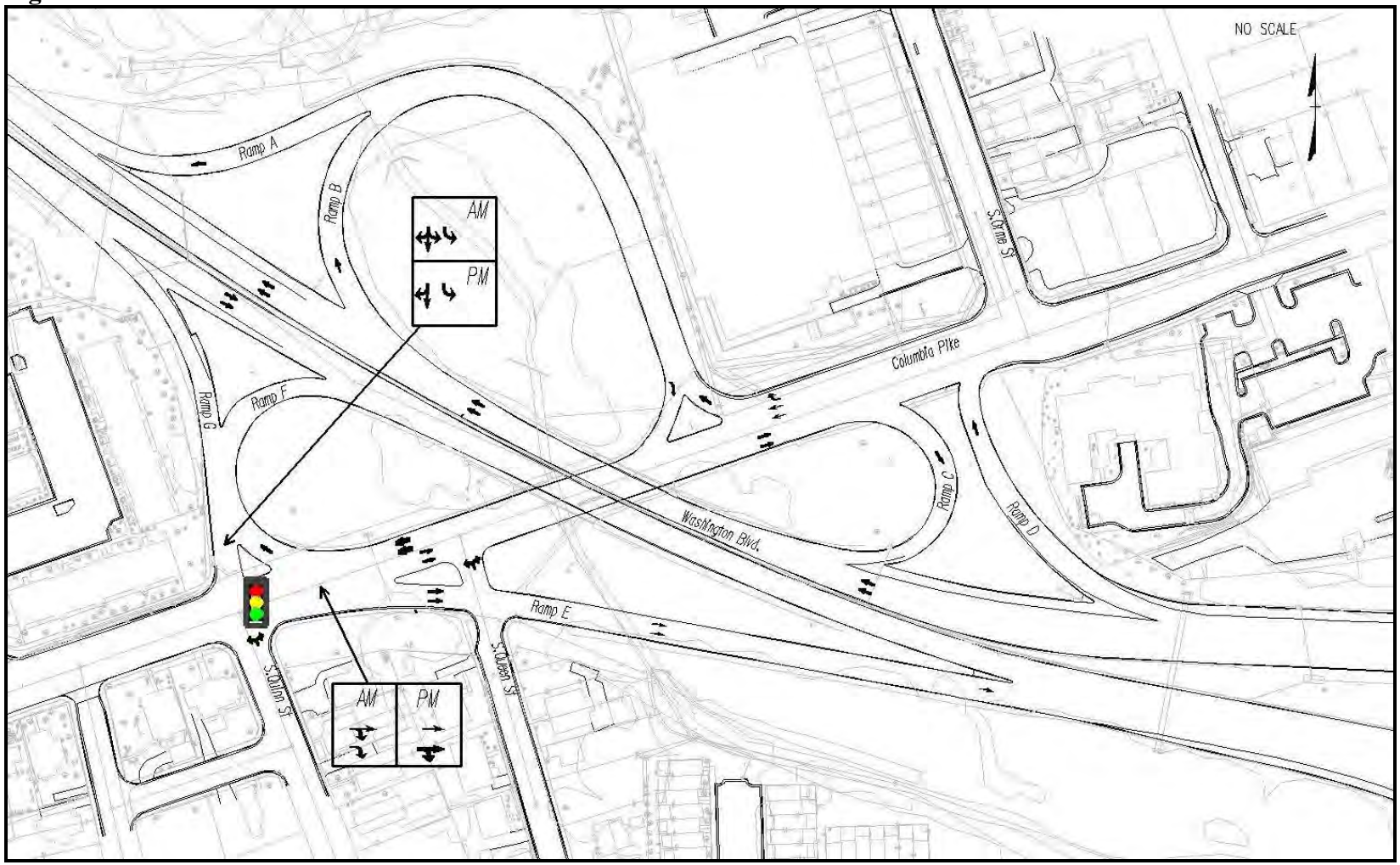
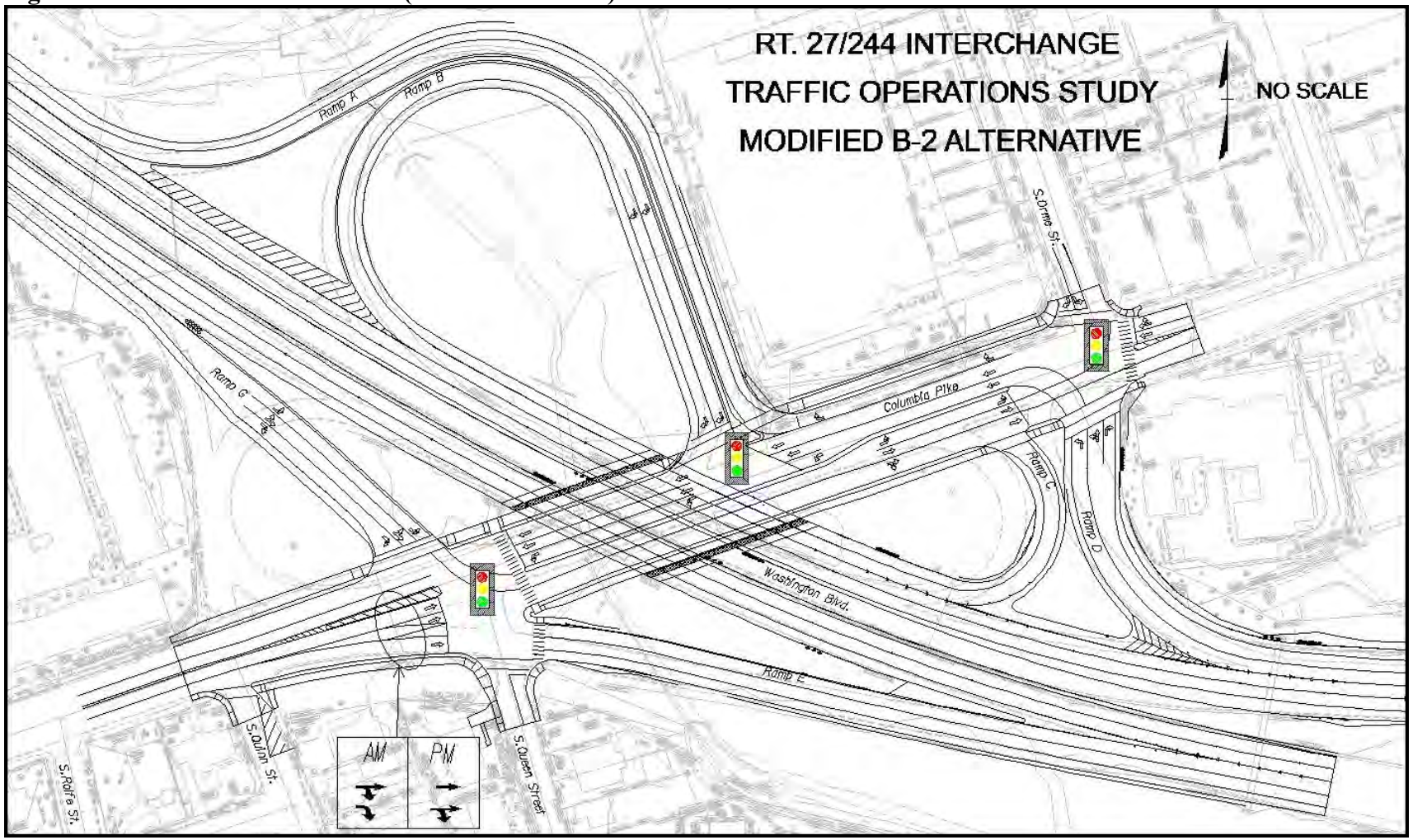


Figure 2: Modified B-2 Alternative (Build Alternative)



2. Operational Analysis of Build and No-Build Alternatives – HCS Software

Figures 3 and 4 summarize the 2031 projected traffic volumes for the study area. The operational analysis of the Build and No-Build alternatives was performed for the projected 2031 AM and PM peak hour traffic conditions using HCS 2000. The analysis did not consider any upstream traffic metering that may occur outside of the study area. It was assumed that traffic, per the demand estimates provided, was able to reach the study area. Under the No-Build Scenario, two-phase traffic signal operation similar to existing conditions was assumed for the intersection of Columbia Pike/Quinn St/Ramp G in the No-Build Alternative.

For the development of traffic volumes for the Build Alternative, it should be noted that assumptions were made for the volume redistribution. For the No-Build Alternative, northbound vehicles can exit the residential neighborhood via a signal at S. Quinn Street. Under the Build Alternative, no traffic may exit via S. Quinn Street. Thus vehicles would have to divert from S. Quinn Street to either S. Rolfe Street or S. Queen Street. It was assumed that half of the traffic would divert to S. Rolfe Street and the other half would divert to S. Queen Street. This assumption is based on the fact that under No-Build conditions, some vehicles from the western end of the neighborhood would utilize S. Queen Street since there is a signal making egress easier. However, it is not envisioned that all of these vehicles from the west end would proceed as far east as S. Queen Street due to travel distance. Furthermore, if all traffic was assumed to divert to northbound S. Queen Street, little difference in the delay would result due to the additional low volume increase (approximately 20 vehicles). With respect to vehicles from Ramp G, it was assumed that the turn movements from Ramp G remained the same. It is understood that it is possible under existing conditions that on Ramp G there are through vehicles onto S. Quinn Street, and left turning vehicles from the ramp that then turn right onto S. Queen Street. All of these vehicles would be destined for the same neighborhood area. Although technically the vehicles would all be through vehicles under the Build conditions, data was not sufficient to quantify this change so all Ramp G movements were assumed to remain the same for the purposes of the analysis. Given that the traffic signal operation is split phase, it is likely that the minor increase in through vehicles would have little effect on the overall findings.

Additionally, vehicles destined for westbound Columbia Pike traveling on northbound Washington Boulevard from the mainline Washington Boulevard would have two options under the Build Alternative: Ramp D and Ramp B. It was assumed that all traffic would utilize Ramp D, as it would not require the weaving movement between Ramps C and B, and is the more direct route. Vehicles traveling from I-395 northbound on Ramp H destined for Columbia Pike will be directed to use Exit 8B (which would take them to the other interchange between Columbia Pike and Washington Boulevard), rather than Exit 8A through the subject project area. As it is difficult to assess the likelihood that commuters would alter their behavior based on new signage on I-395, it was assumed that all vehicles that currently use Exit 8A to the project area would continue to do so. This represents the worst case scenario.

In addition to **Figures 1 and 2**, which illustrate the differences between the alternatives, **Table 1** summarizes a few important geometric design and traffic control differences between the Build and No-Build scenarios.

2.1 Operational Performance of Intersections on Columbia Pike

Prior to reviewing the results of the levels of service of the two scenarios, it is important to preface that these two geometric and traffic control configurations are challenging to compare on a "one-to-one" basis using level of service, since the number of intersections and approach locations are different, and the overall composition of the corridor includes the consolidation of movements in order to operate more efficiently with the projected traffic growth under the Build Alternative. For example, ramp approaches are shifted in the Build alternative to combine existing offset intersections into single four-leg intersections, and one ramp is to be removed such that another ramp can be re-aligned to create a new intersection in order to improve and maintain neighborhood access as traffic grows on Columbia Pike, etc. Lastly, some of the geometric changes in the Build Alternative require modified signal phasing (split phasing) with more phases per intersection. While this does increase the overall intersection delay, there are notable safety and pedestrian benefits that outweigh the minor differences found in operational characteristics.

Tables 2 and 3 present the Columbia Pike intersection measures of effectiveness (MOEs) in the interchange area for No-Build and Build alternatives respectively. Specifically, delay, level of service (LOS), and queue lengths were derived using the methodologies outlined in the *Highway Capacity Manual* (HCM) *2000*.

Analyses indicate that for the AM peak hour, the traffic operational performance of the Build Alternative is comparable to that of No-Build Alternative, but in comparing each overall intersection LOS, the No-Build conditions show only slightly better performance. In consideration of the three significant change factors outlined below, no individual lane group or movement would operate at LOS F, per the HCM analyses, and no intersection would operate at an overall LOS less than D in the Build Alternative. The pedestrian crossing times were not incorporated into the HCS analysis. They were, however, incorporated into the CORSIM analysis, which is presented in the next chapter.

Figure 3: 2031 Peak Hour Traffic Volumes for No-Build Alternative

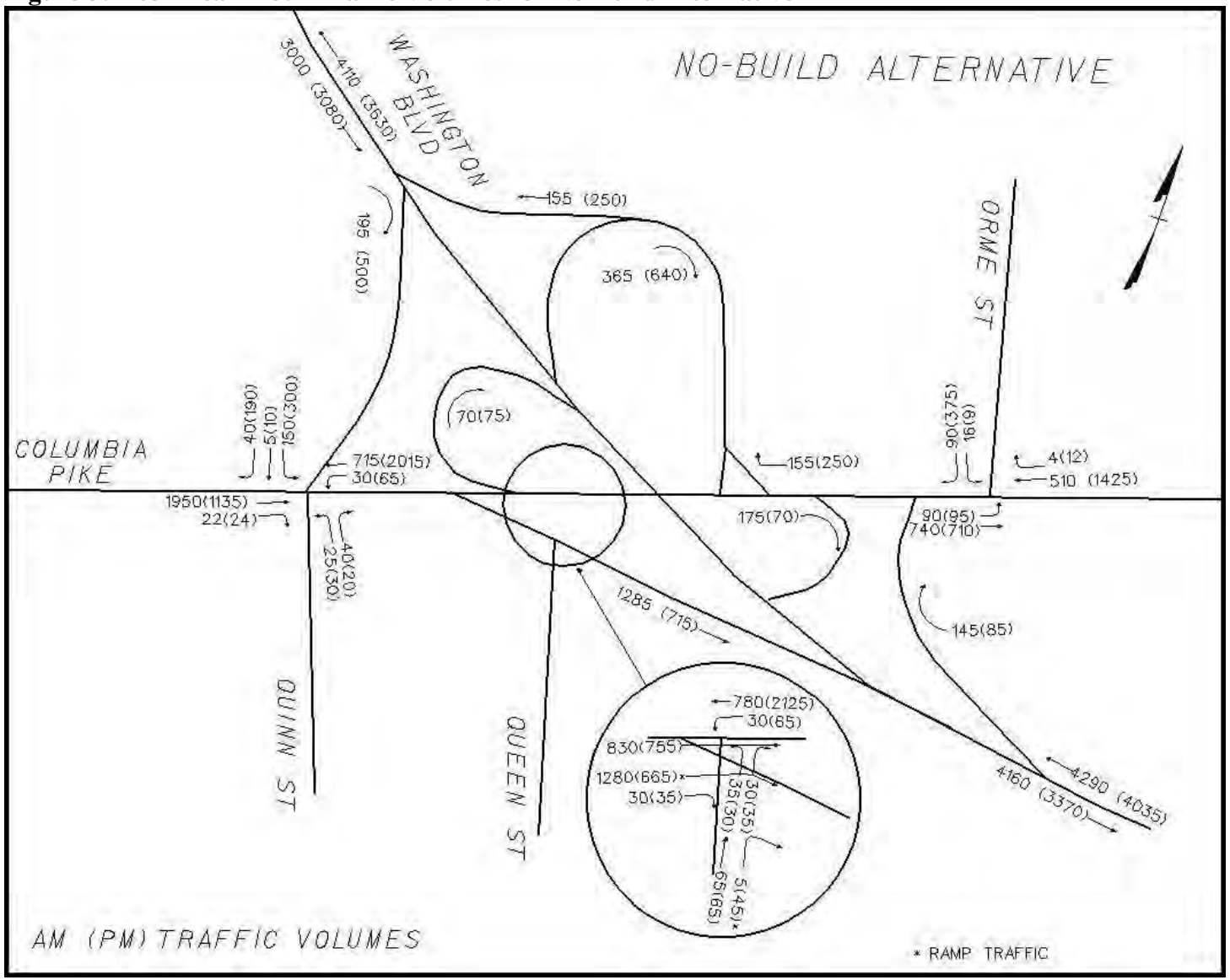


Figure 4: 2031 Peak Hour Traffic Volumes for Modified B-2 Alternative (Build Alternative)

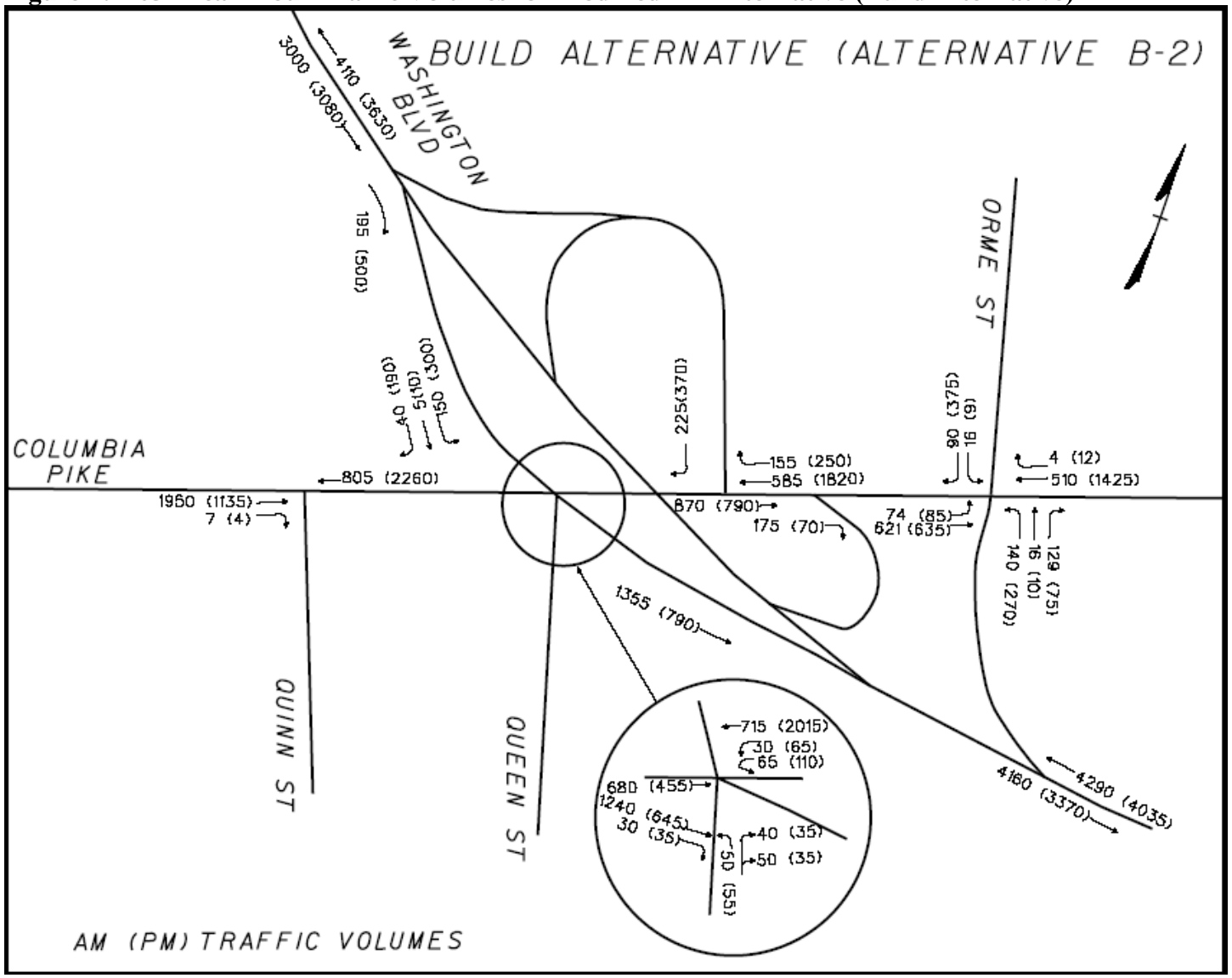


Table 1: Geometric and Operational Comparison between Build and No-Build Alternatives

Location	No-Build Alternative	Modified B-2 Alternative
Columbia Pike / Ramp G / S. Quinn St	1. Four-leg signalized intersection, with two-phase operation (concurrent-flow side streets). 2. Signal-controlled pedestrian crosswalks across both legs of Columbia Pike (both operate concurrently).	1. Unsignalized T-intersection. 2. Fourth leg of the intersection, Ramp G, is relocated to the intersection of Columbia Pike / S. Queen St. 3. Right-in access to S. Quinn St. from Columbia Pike only.
Columbia Pike / S. Queen St	1. Unsignalized T-intersection with full access. 2. No left-turn storage bay for westbound Columbia Pike.	1. Four-leg signalized intersection, with four-phase operation (split phase side streets). 2. Fourth leg of the intersection, Ramp G, is relocated from the intersection of Columbia Pike / S. Quinn St. 3. Signalized pedestrian crossing across Columbia Pike on the east leg of the intersection. 4. 300' of left-turn storage length for westbound Columbia Pike to accommodate traffic going to S. Queen St and U-turning traffic onto Ramp E (replacing loop Ramp F). 5. Additional storage for queued traffic on Ramp G.
Columbia Pike / Ramp A / Ramp B	1. Unsignalized T-intersection with right-in / right-out access, Ramp B is under yield control.	1. Westbound Columbia Pike and Ramps operate under "half" signal at T-intersection; right-in/right-out access only for Ramps A/B.. 2. Eastbound Columbia Pike is NOT under signal control.
Columbia Pike / Ramp D / S. Orme St	1. Four-leg unsignalized intersection. 2. Minor road approaches slightly offset. 3. Left turns from Ramp D are not permitted. Through movements to S. Orme St. must turn right and immediately left. 4. Ramp D is a single-lane ramp. 5. Unsignalized pedestrian crosswalk across Columbia Pike on the east leg of the intersection.	1. Four-leg signalized intersection, with four-phase operation (split phase side streets). 2. Left turns from Ramp D are provided with protected signal phasing (new movement). 3. 135' of left-turn storage length for eastbound Columbia Pike traffic turning left to S. Orme St. 4. Ramp D is a two-lane ramp with an additional 100' right-turn bay at the approach. 5. Signalized pedestrian crossing across Columbia Pike on the east leg of the intersection.
Columbia Pike / Ramp F	1. Loop ramp for westbound Columbia Pike traffic heading towards southbound Washington Boulevard.	1. Ramp F is eliminated; affected traffic would be served by left turn from westbound Columbia Pike to Ramp E.

Table 2: HCS MOEs for Operational Performance of Intersections on Columbia Pike under No-Build Condition

NO-BUILD INTERCHANGE CONFIGURATION										
	AM PEAK HOUR					PM PEAK HOUR				
Intersection Approach	Volume (veh)	Delay (sec/veh)	LOS	Avg Queue (veh)	95 Percentile Queue (veh)	Volume (veh)	Delay (sec/veh)	LOS	Avg Queue (veh)	95 Percentile Queue (veh)
COLUMBIA PIKE AND QUINN ST/RAMP G (SIGNAL CONTROL)										
EB TR	1972	41.7	D	60	91	1139	2.0	A	4	8
WB LT	745	1.6	A	2	4	2080	635.2	F	188	281
NB LR	65	38.5	D	2	4	50	39.3	D	2	4
SB LT	155	39.7	D	3	5	310	57.4	E	13	23
SB R	40	40.2	D	4	8	190	43.0	D	6	11
Overall		31.4	C				360.0	F		
COLUMBIA PIKE AND S. QUEEN STREET (STOP CONTROL)										
EB T	830	0.0	A	N/A	0	755	0.0	A	N/A	0
WB L	30	9.9	A	N/A	1	65	9.8	A	N/A	1
WB T	780	0.0	A	N/A	0	2125	0.0	A	N/A	0
NB LR	75	32.0	D	N/A	2	65	173.5	F	N/A	7
Overall		1.6	A				4.0	A		
RAMP E AND S. QUEEN STREET (STOP CONTROL)										
EB TR	1310	0.0	A	N/A	0	700	0.0	A	N/A	0
NB LR	115	46.1	E	N/A	5	100	16.4	C	N/A	2
SB T	35	36.8	E	N/A	2	75	17.9	C	N/A	1
Overall		4.5	A				3.4	A		
COLUMBIA PIKE AND RAMPA/B (STOP CONTROL)										
EB T	870	0.0	A	N/A	0	790	0.0	A	N/A	0
WB T	725	0.0	A	N/A	0	2090	0.0	A	N/A	0
WB R	155	0.0	A	N/A	0	250	0.0	A	N/A	0
SB R	365	20.4	C	N/A	5	640	410.0	F	N/A	238
Overall		3.5	A				69.6	F		
COLUMBIA PIKE AND S. ORME STREET/RAMP D (STOP CONTROL)										
EB LT	695	8.9	A	N/A	1	720	15.6	C	N/A	1
WB TR	514	0.0	A	N/A	0	1437	0.0	A	N/A	0
NB R	129	13.1	B	N/A	1	75	11.8	B	N/A	1
SB L	16	42.9	E	N/A	1	9	292.0	F	N/A	2
Overall		6.3	A				6.6	A		

Table 3: HCS MOEs for Operational Performance of Intersections on Columbia Pike under the Modified B-2 Alternative (Build Alternative)

MODIFIED B-2 ALTERNATIVE INTERCHANGE CONFIGURATION										
	AM PEAK HOUR					PM PEAK HOUR				
Intersection Approach	Volume (veh)	Delay (sec/veh)	LOS	Avg Queue (veh)	95 Percentile Queue (veh)	Volume (veh)	Delay (sec/veh)	LOS	Avg Queue (veh)	95 Percentile Queue (veh)
COLUMBIA PIKE AND S. QUEEN STREET/RAMP G/RAMP E (SIGNAL CONTROL)										
EB TR	680	43.9	D	52	80	1135	8.0	A	10	18
EB R	1270	39.6	D	51	78	N/A	N/A	N/A	N/A	N/A
WB L	95	75.7	E	5	9	175	79.2	E	9	18
WB T	715	1.7	A	2	4	2015	70.5	E	73	111
NB LR	105	75.3	E	5	9	85	79.8	E	5	10
SB L	150	52.4	D	3	6	300	74.7	E	8	15
SB LT	5	52.6	D	4	7	10	76.2	E	9	16
SB R	40	50.6	D	1	2	190	74.4	E	8	14
Overall		34.8	C				53.4	D		
COLUMBIA PIKE AND RAMP A/B (SIGNAL CONTROL)										
EB T	870	0.0	A	0	0	790	0.0	A	0	0
WB T	585	1.9	A	2	3	1820	9.6	A	27	43
WB R	155	12.0	B	0	0	250	13.5	B	0	0
SB R	225	31.6	C	4	8	370	46.0	D	9	17
Overall		4.9	A				11.5	B		
COLUMBIA PIKE AND S. ORME STREET/RAMP D (SIGNAL CONTROL)										
EB L	74	2.2	A	1	1	85	3.1	A	1	1
EB T	621	2.3	A	2	3	635	2.2	A	2	4
WB TR	514	18.0	B	6	12	1437	10.2	B	25	41
NB L	140	42.5	D	3	6	270	74.4	E	8	15
NB LT	16	42.5	D	3	5	10	76.1	E	8	14
NB R	129	44.3	D	3	6	75	68.3	E	2	3
SB L	16	56.5	E	1	2	9	66.4	E	1	1
SB R	90	37.8	D	2	4	375	59.3	E	9	16
Overall		15.7	B				18.9	B		

Major changes to the interchange configurations:

1. Traffic is consolidated into three intersections rather than five under the No-Build alternative.
2. Traffic controls would be different under the two scenarios (removal of the traffic signal at S. Quinn Street, and the addition of signals at S. Queen Street, S. Orme Street, and a half signal at Ramps A/B).
3. By realigning the Ramp G to intersect Columbia Pike opposite of S. Queen Street in the Build Scenario, the intersection would operate at LOS C, but with an overall increase in delay of less than 4 seconds over the S. Quinn Street/Ramp G intersection with Columbia Pike in the No-Build Scenario, all while processing a greater amount of traffic.

It is in looking at the PM operations and projected traffic growth, where one can see the need for the proposed Build changes, and how they provide improved overall operations for the corridor. In the PM peak hour, the traffic operational performance of the Build Alternative is projected to be better than that of No-Build Alternative at the major intersections in the interchange area:

Ramp B, Ramp G, and Quinn St. The major cause of intersection delay in the PM peak hour for the No-Build Alternative at the intersection of Columbia Pike/Ramp A/Ramp B is the southbound right-turning Ramp B traffic. Ramp B is under yield-control in the No-Build Conditions. With over 1,800 veh/hr on westbound Columbia Pike, very few gaps are available to the 640 veh/hr turning right from Ramp B. Under the Build Alternative, many of the right turn movements from Ramp B can instead be accommodated at Ramp D by turning left onto Columbia Pike under traffic signal control – thereby improving the conditions at Ramp A/B and slightly impacting the operations of the Ramp D/S. Orme Street intersection. Under the No-Build Alternative, it is important to note that two of the five intersections analyzed would operate at LOS F in the PM Peak with one movement in each intersection experiencing significant delays of no less than 170 seconds per vehicle. Under the Build Alternative, the overall intersection operations would be LOS D or better. Although it is important to recognize that some approaches are projected to operate at LOS E. These are offset by the non-peak direction operations projected at LOS A and B, which result in the overall LOS D.

The HCM analysis shows that the 95th percentile westbound left-turn queue length is projected to exceed the length of the turn bay in the Build alternative. However, further analysis completed in CORSIM, as discussed in the next section, more accurately reflect vehicles arrivals, overall progression, and influence of signals in close proximity to each other. These three factors can influence the intersection performance and LOS. Furthermore, while just the left-turn queue may appear "worse," it is important to note the overall benefits to the system and in particular the overall intersection. In the No-Build Alternative for the PM peak hour, queues on Ramp G are projected to spill back onto Washington Boulevard and impede the through movement. In the Build alternative, the queues could be maintained within the ramp area. Also, under No Build conditions, where vehicles would turn left at a signal at S. Quinn Street to access the residential community, there would be no separate left-turn area. Thus, through vehicles would be impeded by these left-turn vehicles sitting in the left lane waiting for an available gap in the opposing traffic stream. By reconfiguring the westbound leg at S. Queen Street to include a left-turn bay in the Build Alternative, the queue length for the approach would be reduced from over 250 vehicles to approximately 75 vehicles. In other words, by adding the left-turn bay, the impact to the through movement would be reduced.

2.2 Operational Performance of Ramps on Washington Boulevard.

On and off-ramps on Washington Boulevard were analyzed using methodologies outlined in Chapter 25 of HCM 2000, for both No-Build and Build Alternatives. Both AM and PM peak hours were analyzed.

The ramps analyzed included: Ramp A (on-ramp/merge), Ramp F (on-ramp/merge), and Ramp G (off-ramp/diverge). The analysis results are included in **Table 4**. In the northbound direction the performance of Ramp A remains similar for the Build and No-Build Alternatives. In the southbound direction the performance of Ramp G is similar for both the Build and No-Build Alternatives. Ramp F was eliminated in the Build Alternative and hence was not analyzed, and the affected traffic was redirected to Ramp E. Ramps B, C and D are each part of a weave section, and are discussed in the next section.

Table 4: MOEs for Operational Performance of Ramps on Washington Boulevard

RAMPS												
Description	NO-BUILD						MODIFIED B-2 ALTERNATIVE					
	AM PEAK HOUR			PM PEAK HOUR			AM PEAK HOUR			PM PEAK HOUR		
	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)
SOUTHBOUND ROUTE 27												
Ramp G	B	19.5	47.5	C	20.5	47.1	B	19.5	47.5	B	17.0	47.1
Ramp E	D	32.2	48.0	C	27.4	50.0	N/A			N/A		
NORTHBOUND ROUTE 27												
Ramp A	E	38.1	47.0	D	34.1	49.0	E	36.1	47.0	D	32.0	49.0

2.3 Weaving Analysis on Washington Boulevard

Weaving analysis was performed using methodologies outlined in Chapter 24 of HCM 2000. The weaving segments analyzed included:

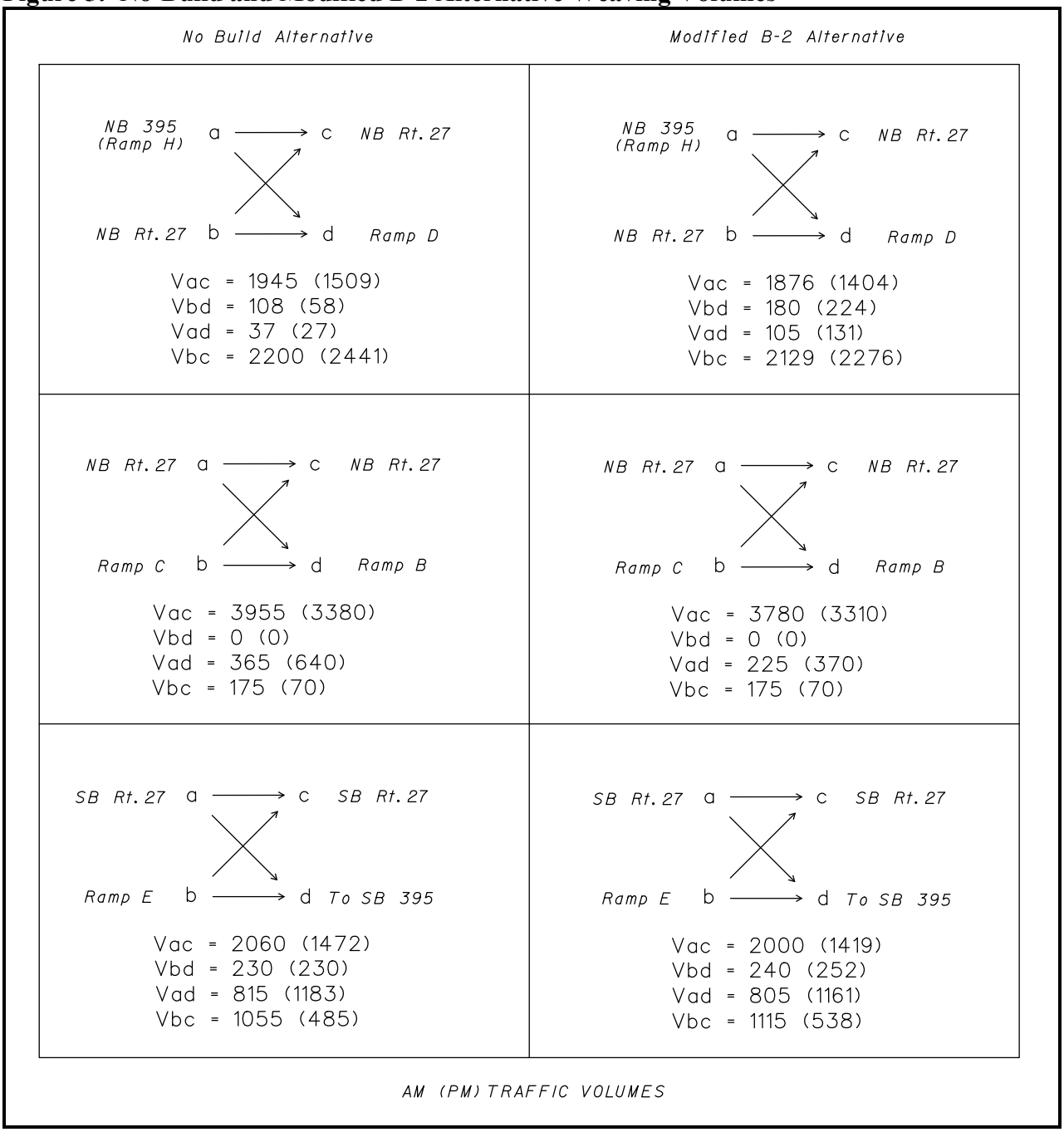
- Northbound Washington Boulevard from: (1) the on-ramp from I-395, to (2) the off-ramp to Columbia Pike (Ramp D).
- Northbound Washington Boulevard from: (1) the on-ramp from eastbound Columbia Pike (Ramp C), to (2) the off-ramp to westbound Columbia Pike (Ramp B).
- Southbound Washington Boulevard from (1) the on-ramp from eastbound Columbia Pike (Ramp E), to (2) the off-ramp to southbound I-395.

The analysis results are summarized in **Table 5**. Analysis results reveal that performance of the weaving sections is very similar for both the Build and No-Build Alternatives during the AM and PM peak hours. The addition of a full auxiliary lane on northbound Washington Boulevard between Ramp C and Ramp B improves traffic operation on Washington Boulevard. Additionally, operational analyses indicate an improvement in the performance for the Build Alternative during the PM peak hour for the northbound freeway section between Ramp C and Ramp B, because of lower traffic volumes on Ramp B and thus fewer weaving maneuvers. **Figure 5** illustrates the weaving volumes for the No-Build and Modified B-2 Alternative.

Table 5: MOEs for Weaving Analyses on Washington Boulevard

WEAVING SECTIONS												
Description	NO-BUILD						MODIFIED B-2 ALTERNATIVE					
	AM PEAK HOUR			PM PEAK HOUR			AM PEAK HOUR			PM PEAK HOUR		
	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)	LOS	Density (veh/ln/mi)	Speed (mph)
SOUTHBOUND ROUTE 27												
Between Ramp E and I-395 Ramp	E	39.7	27.8	D	31.7	28.3	E	39.7	27.8	D	31.7	28.3
NORTHBOUND ROUTE 27												
Between I-395 ramp and Ramp D	D	34.9	32.7	D	34.2	31.3	D	34.9	32.7	D	34.2	31.3
Between Ramp C and Ramp B	E	39.9	39.9	D	32.0	42.3	E	35.2	42.0	D	31.3	42.5

Figure 5: No-Build and Modified B-2 Alternative Weaving Volumes



For the Build configuration, to fully understand the impact of queuing on Ramp D on the Washington Boulevard through-movement, it is important to note how the ramp diverges from Washington Blvd (i.e., how the multiple lanes on the ramp align with the right lanes on Washington Blvd. prior to the diverge). Under the proposed configuration, the left-turn lane on Ramp D would be a lane drop of the right-most travel lane on Washington Boulevard at the diverge. The next lane to the right, the shared through-left lane on Ramp D, would open up in advance of the ramp with a deceleration lane in which vehicles could queue out of the travel way

of through vehicles. The HCS analysis shows that the 95th percentile queue length on Ramp D would be 15 vehicles per lane, a length of 375 feet. However, the CORSIM analysis includes signal timings that would not permit spillback. Through periodic review of the implemented signal operation plan and making adjustments to the timing plan, sufficient green time can be provided to the Ramp D movement, which will prevent the queue spillback from affecting the Washington Blvd. through movement. The CORSIM analysis documentation, in the next section of the report, will further address this issue.

3. Operational Analysis of Build and No-Build Alternatives – CORSIM Software

The CORSIM analysis of the Build and No-Build alternatives was performed for the projected 2031 AM and PM peak hour traffic conditions. Like the HCS analysis, any upstream metering that may occur outside of the study area was not considered. It was assumed that the forecasted traffic volumes would be able to reach the study area. Downstream bottlenecks were also not considered, i.e. the analysis did not consider the effects if traffic on roadways downstream "backed-up" into the study area. A CORSIM model was developed for each alternative for the AM and PM peak hour. The CORSIM model includes the arterial street network of Columbia Pike (from S. Quinn Street to S. Orme Street), the freeway segments of Washington Boulevard and the ramps that link the two facilities.

Timings that would accommodate pedestrians were incorporated into the CORSIM analysis. It was assumed for the purpose of the analysis that the pedestrian movement across Ramp E would occur in a separate phase from pedestrian movement across the east leg of Columbia Pike at the intersection of Columbia Pike, Ramp G, Ramp E and S. Queen Street. By computing the crossing distance across the east leg, the minimum "Flash Don't Walk" (FDW) time can be determined by using the current MUTCD standard of 4 feet per second walking time. Including the walk time, FDW time, yellow and all-red time, the S. Queen Street (northbound) phase would need to be 32 seconds each time a pedestrian was present.

It was assumed for the purpose of the CORSIM analysis that there would be a pedestrian actuation at every cycle, which would mimic worst-case conditions. Existing pedestrian counts were available, however, accurately projecting the change/increase in pedestrian numbers and the change in pedestrian travel patterns given the upgraded facilities is not practical within the scope of this analysis. A brief review of existing counts and the likely effect on the overall operations does yield some better understanding. Existing counts indicate that during the AM peak hour a maximum of 8 pedestrians cross Columbia Pike at the signal-controlled crossing, with very few pedestrians during the remainder of the day. Even though the pedestrian counts are very low now, Arlington County is making every effort to increase transit and improve pedestrian facilities, so these numbers will increase. However, projecting those numbers at this time is not realistic as it is difficult to assign the number of pedestrian calls at the traffic signal without more sufficient origin-destination data. Because it was challenging to judge the new pedestrian travel patterns given the improvements in the area, the CORSIM model was developed assuming a true "worst-case" scenario by having a pedestrian actuation for every cycle. This translates to approximately 25 pedestrian calls per hour. If only half of the pedestrian actuations were made during the peak hour, the effect would be a reduction in average delay by approximately 2 seconds/vehicle for the overall intersection.

In summary, the signal timings were set so that Ramp G did not spill back onto Washington Boulevard, the westbound left-turn bay did not spill back into the through lane, and additional green time to accommodate the pedestrian minimum green time, all would come at the expense of the through movements on Columbia Pike.

For the No-Build Alternative, signal timings used in the model have the same cycle length as the existing signal timings, that is, a cycle length of 130 seconds. The proposed alternative includes

intersections with new signal control and modified ramp configurations. Therefore, new signal timings were developed using the Synchro software, including coordination between adjacent signals. The cycle length for the proposed configuration was increased to 140 seconds.

One goal in developing new signal timings was to ensure that the new signals at the ramp termini with Columbia Pike did not cause the ramps to spill back onto Washington Boulevard. A consequence to this signal timing plan, is that priority is then given to the ramps over Columbia Pike traffic, which would potentially affect eastbound traffic flow (west of S. Quinn Street) in the AM peak and westbound traffic flow (east of S. Orme Street) in the PM peak on Columbia Pike. The optimal signal timings were incorporated into CORSIM network for AM and PM peak hour. The bus routes along Columbia Pike were also included in the CORSIM model coding.

During the development of the CORSIM models, limited calibration was performed. The performances of the models were compared to field observations completed for the overall study. Since vehicular flow and queues within the model closely matched the observed flows and queues, and because the project scope was to replace the existing bridge structure and attempt to provide limited, low cost, safety improvements to the interchange area, detailed CORSIM calibration was not performed. The CORSIM traffic model was run five times for the AM and PM peak periods, and the "middle" run was used for reporting purposes.

3.1 Operational Performance of Intersections on Columbia Pike

Tables 6 and 7 present the projected LOS and delay for the No-Build and Build alternatives, respectively. The results of the analyses show that with the appropriate signal timing, the interchange ramps would <u>not</u> spill back onto Washington Boulevard; however, the preferential treatment for the ramp traffic at the signals would affect the through movement of traffic on Columbia Pike. For the Modified B-2 Alternative, total delay for Columbia Pike would increase for both time periods compared to the No-Build Alternative, mainly due to the introduction of new traffic signals and split-phase timing plans to accommodate modified intersection configurations. However, under the No-Build alternative, while the delay to Columbia Pike traffic is lower, the occurrence of ramp spill-back onto Washington Boulevard is more prevalent. The introduction of these traffic signals on Columbia Pike for the Modified B-2 Alternative helps reduce the occurrence of ramp spill-back that would be occurring in the No-Build Alternative.

In the AM peak period for the two alternatives, intersections along Columbia Pike would perform at LOS C or better. The introduction of signals would not cause ramp spillback onto Washington Boulevard, as the timings provide sufficient green-time to the ramps. This does increase the delay on Columbia Pike. However, these approaches would remain at LOS C or better.

For the PM peak period, CORSIM analyses indicate that under the No-Build Alternative, vehicles queued on Ramp G and Ramp B would spill back onto Washington Boulevard. Allocating more green time for Ramp G in the Modified B-2 Alternative does eliminate the occurrence of ramp spillback; however, it causes the Columbia Pike eastbound approach to drop from LOS B to D. Also under the Build Alternative, the analyses indicate that the introduction of a "half signal" at the intersection of Ramp B and westbound of Columbia Pike would prevent

queue spillback of the ramp onto Washington Boulevard (note that the eastbound direction is not under signal control at this location). This does cause the delay for the westbound approach to increase by approximately 20 seconds compared to the No-Build configuration, since signal control is introduced. However, it greatly reduces the delay on the Ramp B approach compared to the No-Build configuration, where Ramp B is a single right-turn lane operating under yield control. With over 1,800 veh/hr on westbound Columbia Pike, very few gaps would be available to the 640 veh/hr turning right from Ramp B, and the ramp would spill back onto Washington Boulevard according to the CORSIM analysis. By placing a signal at this location in the Modified B-2 Alternative and allowing two lanes to make the maneuver, traffic on Ramp B can turn right onto Columbia Pike and prevent the queues on the ramps from spilling back onto Washington Boulevard. One thing to consider is that in CORSIM, the ramp was coded as "no-turn-on-red" which is the worst case. In actual Build conditions, the ramp may be signed to permit right turn on red from the right lane only. CORSIM does not have a functionality that would permit vehicles in the right lane to turn on red, while vehicles in the left lane cannot. CORSIM can only permit both lanes as "right-turn-on-red" or both lanes as "no-turn-on-red". Should right-turn-on-red be permitted from the right lane, actual performance would then be better for this approach than was modeled in CORSIM. The results indicate the "worst case" for the approach.

For the westbound left turn bay on to S. Queen Street/Ramp E, the analysis shows that approximately 300-350 feet will be needed for storage. For the eastbound left turn bay onto S. Orme Street, the analysis showed that approximately 100 to 125 feet of storage is needed.

Also in the PM peak period, the signalization of Columbia Pike/S. Queen Street would improve the ingress to and egress from the residential neighborhood to the south of Columbia Pike. The proposed configuration also includes a left-turn bay for the westbound approach, which limits the occurrence of left-turning vehicles from blocking westbound through traffic, which would occur in the No-Build scenario.

Table 6: CORSIM MOEs for Operational Performance of Intersections on Columbia Pike under No-Build Condition

Intersection Approach	NO-BUILD INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)
COLUMBIA PIKE AND S. QUINN STREET/RAMP G (SIGNAL CONTROL)												
EB	1972	15.6	B	24.3	5	29	1166	13.5	B	18.5	2	18
WB	798	6.4	A	7.8	1	9	1758	10.1	B	13.9	2	17
NB	65	25.6	C	27.0	0	3	50	26.4	C	27.3	0	2
SB	226	44.3	D	54.0	2	10	300	149.6	F	165.4	4	12
Overall		15.5	B	22.3				24.3	C	29.6		
COLUMBIA PIKE AND S. QUEEN ST (STOP CONTROL)												
EB	982	0.9	A	2.9	0	12	916	0.3	A	1.6	0	0
WB	862	0.4	A	1.6	0	2	1846	0.6	A	1.6	0	5
NB	65	10.8	B	16.6	0	2	55	115.0	F	124.1	2	5
Overall		1.0	A	2.8				2.7	A	4.0		
RAMP E AND S. QUEEN STREET (STOP CONTROL)												
EB	1178	0.1	A	0.6	0	1	560	0.1	A	0.5	0	0
NB	70	6.0	A	7.0	0	1	114	64.2	F	72.1	2	16
SB	30	4.2	A	11.8	0	2	62	3.9	A	10.7	0	4
Overall		0.5	A	1.2				10.3	B	12.4		
COLUMBIA PIKE AND RAMP A/B (YIELD CONTROL)												
EB	1017	0.1	A	0.7	0	1	948	0.1	A	0.7	0	0
WB	602	0.4	A	1.6	0	2	1801	0.7	A	2.4	0	4
SB	395	4.1	A	5.4	0	5	301	190.0	F	200.5	31	37
Overall		1.0	A	1.9				19.2	C	21.4		
COLUMBIA PIKE AND RAMP D/S. ORME STREET (STOP CONTROL)												
EB	965	1.1	A	2.1	0	8	956	2.3	A	3.8	1	10
WB	519	0.5	A	6.5	0	1	1437	1.1	A	12.9	0	4
NB	148	2.6	A	3.5	1	3	92	2.9	A	3.5	1	2
SB	106	3.9	A	5.0	0	1	383	14.9	B	16.4	1	4
Overall		1.2	A	3.7				3.4	A	10.0		

Note: Columbia Pike and Ramp D/S. Orme Street modeled as two closely-spaced T-intersections.

Table 7: CORSIM MOEs for Operational Performance of Intersections on Columbia Pike under Modified B-2 Alternative (Build Alternative)

Intersection Approach	MODIFIED B-2 ALTERNATIVE INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)
COLUMBIA PIKE AND S. QUEEN STREET/RAMP G/E.												
EB	1948	20.5	C	32.0	3	33	1132	51.3	D	65.2	6	20
WB	840	15.5	B	17.2	2	7	2192	19.9	B	23.5	4	13
NB	141	47.1	D	51.2	2	5	126	48.8	D	52.8	2	5
SB	207	18.6	B	19.9	1	2	517	42.5	D	45.3	3	9
Overall		20.3	C	28.1				32.7	C	39.2		
COLUMBIA PIKE AND RAMPA/B												
EB	709	0.2	A	1.2	0	2	808	0.7	A	2.9	0	5
WB	764	2.8	A	5.3	0	5	2060	14.2	B	21.4	5	18
SB	223	59.8	E	63.1	3	9	359	143.3	F	153.3	13	29
Overall		9.2	A	11.2				25.2	C	31.4		
COLUMBIA PIKE AND S. ORME STREET/RAMP D												
EB	578	2.8	A	4.4	0	7	750	8.1	A	10.3	1	10
WB	518	6.1	A	13.6	0	6	1438	18.8	B	30.5	4	21
NB	325	39.4	D	40.6	2	7	416	39.5	D	41.3	3	8
SB	106	15.6	B	17.4	0	3	382	5.3	A	6.8	0	8
Overall		12.6	B	16.1				17.3	B	23.9		

3.2 Operational Performance of Washington Boulevard.

The Columbia Pike/Washington Boulevard interchange is in close proximity to the I-395/Washington Boulevard interchange. Thus, any design changes to the interchange configuration should ensure that the operations of the I-395 interchange are not negatively affected compared to No-Build conditions. The CORSIM models developed for this analysis include the southbound weave on Washington Boulevard between Ramp E and the ramp to SB I-395, as well as the ramp carrying traffic from NB I-395 merging with northbound Washington Boulevard traffic, prior to Ramp D to Columbia Pike.

Tables 8 and 9 present the present the projected LOS and delay for the No-Build and Build alternatives for the weaving and ramps sections on Washington Boulevard according to the CORSIM analysis. The analysis indicates little difference between the two alternatives in the AM peak hour, where the No-Build performs slightly better than the Build Alternative on the SB Washington Boulevard segment between Ramp E and the I-395 ramp. This is due to slightly higher volumes in the Build Alternative on Ramp E, as Ramp F was eliminated for the proposed Build Alternative. However, the Build Alternative performed better for the NB Washington Boulevard segment between the I-395 ramp and Ramp D, as vehicles on Washington Boulevard destined to westbound Columbia Pike now can exit at Ramp D instead of Ramp B, which reduces the volume prior to Ramp B and enables the I-395 traffic to merge onto Washington Boulevard with less competing traffic.

In the PM peak hour, the two alternatives perform similarly in the southbound direction. However, in the northbound direction the Build Alternative performs better than the No-Build

Alternative. This is due to the operations of the intersection of Columbia Pike and Ramp B. Traffic on Ramp B is under yield control for the No-Build Alternative. Due to the lack of acceptable gaps on Columbia Pike under the No-Build conditions, analysis shows traffic on Ramp B cannot turn onto Columbia Pike and will spill back onto Washington Boulevard. Subsequently, this queue spillback affects the through movement on Washington Boulevard and decreases the speed to approximately 10 mph. The queue spills back further onto the ramps in the I-395/Washington Boulevard interchange.

The configuration in the Modified B-2 Alternative permits left turns from Ramp D onto westbound Columbia Pike, which is not permitted in the No-Build configuration. It was assumed for the purpose of the CORSIM analysis that all northbound vehicles on Washington Boulevard would choose to use Ramp D in lieu of Ramp B if destined to westbound Columbia Pike, as they would be permitted to turn left at the signal at the terminus of Ramp D. It was assumed that those drivers would choose to exit via the first exit in order to avoid the weave area of Ramps C and B on Washington Boulevard. Ramp B would still be used by vehicles from the northbound I-395 ramp that wish to exit to westbound Columbia Pike. This assignment reduces the volume on Washington Boulevard between Ramps D and B, thus improving merging from the northbound I-395 ramp and weaving conditions of the Washington Boulevard weave section between Ramps C and B. The signalization of Ramps B and D also prevents queue spillback onto Washington Boulevard, thereby eliminating any impact to the through movements on Washington Boulevard.

Table 8: CORSIM MOEs for Operational Performance of Freeway Segments on Washington Boulevard under No-Build Conditions

Description	NO-BUILD INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)
SOUTHBOUND ROUTE 27												
Between Ramp G and Ramp F	2771	39	2.8	0.2	26.8	51.8	2579	34	2.8	0.1	24.8	52.0
Between Ramp F and Ramp E	2846	507	7.9	0.8	21.4	49.5	2627	373	7.9	0.6	19.3	50.7
Between Ramp E and I-395 Ramp	3996	2802	5.1	1.1	23.9	41.8	3236	1906	5.0	0.6	17.7	45.7
NORTHBOUND ROUTE 27												
Between I-395 ramp and Ramp D	4256	558	5.7	8.2	49.3	21.6	3748	407	5.7	33.5	122.3	7.7
Between Ramp D and Ramp C	4104	1156	3.0	5.3	89.6	19.6	3651	1154	3.0	10.3	127.2	12.3
Between Ramp C and Ramp B	4305	853	6.8	3.9	41.7	34.4	3735	989	7.2	30.4	127.4	9.8
Between Ramp B and Ramp A	3906	168	4.1	1.6	49.7	39.3	3434	255	4.1	2.6	50.8	33.8

Table 9: CORSIM MOEs for Operational Performance of Freeway Segments on Washington Boulevard under Alternative Build

Description	MODIFIED B-2 ALTERNATIVE INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)
SOUTHBOUND ROUTE 27												
Between Ramp G and Ramp E	2792	158	7.9	1.0	28.7	48.6	2576	88	7.9	0.5	24.9	51.7
Between Ramp E and I-395 Ramp	4210	3237	5.1	2.7	31.8	33.0	3377	2203	5.2	0.5	18.9	44.7
NORTHBOUND ROUTE 27												
Between I-395 ramp and Ramp D	4290	656	5.5	1.2	23.9	44.9	4030	958	5.6	0.3	19.7	51.1
Between Ramp D and Ramp C	3964	76	3.0	1.8	58.2	34.0	3616	83	3.0	0.4	37.1	48.7
Between Ramp C and Ramp B	4098	532	6.7	3.5	38.0	36.0	3683	706	6.8	2.0	29.3	41.9
Between Ramp B and Ramp A	3884	162	4.1	1.5	48.7	39.9	3307	163	4.1	1.6	42.1	39.3

4. Qualitative Safety Considerations of the Modified B-2 Alternative relative to No-Build Alternative

This section presents an overview of safety and mobility of alternate modes in the Columbia Pike corridor due to the reconfiguration of the interchange.

4.1 Vehicular Traffic

South Quinn Street

The performed accident study identified a significant number of crashes that were angle type involving vehicles attempting to enter or exit the neighborhood at South Quinn Street. All of these crashes were caused by vehicles traveling eastbound on Columbia Pike and disregarding the red signal indication. With the elimination of the signal and providing for a right-in only maneuver from eastbound Columbia Pike, this will eliminate the potential for angle type crashes at this intersection. Under the Build condition, traffic exiting the neighborhood would either need to use S. Rolfe Street or S. Queen Street. There is better sight distance for vehicles exiting S. Rolfe Street than at S. Quinn Street under the No-Build Alternative, and S. Queen Street would be signalized under the Build Alternative, thus providing protected left- and right-turning maneuvers as motorists would have an independent green phase.

South Queen Street/Ramp E

Under the No-Build condition, this intersection is stop-controlled with angle crashes involving vehicles turning left into and out of the neighborhood at South Queen Street. There is a refuge area for which vehicles exiting S. Queen Street must make the movement in two steps: 1) crossing the two-lane Ramp E, and 2) turning left or right onto Columbia Pike. Under the Build scenario, Ramp E has been moved closer to Columbia Pike, reducing the crossing distance for vehicles exiting S. Queen Street, and improving sight distance. The proposed signal at South Queen Street, operating in a coordinated system, should significantly reduce the angle type crashes experienced at this location. The proposed protected phasing for left-turn traffic from westbound Columbia Pike and for traffic exiting the neighborhood from South Queen Street will aid in reducing and/or eliminating the potential for angle crashes.

The installation of the left-turn bay on westbound Columbia Pike will reduce conflicts between vehicles attempting to turn left onto South Queen Street and Ramp E from the through movements on Columbia Pike and may reduce the rear-end type crashes.

Ramp A/B

Ramp B provides a right-turn only movement under the No-Build conditions. Furthermore, the single lane operates under Yield conditions, with a high volume of right turning vehicles attempting to merge onto saturated westbound Columbia Pike. This condition may lead to drivers taking smaller-than-acceptable gaps in order to merge. Under the Build Alternative configuration, the intersection is signalized for westbound Columbia Pike traffic and right turning Ramp B traffic. Likewise, right turning movements from Ramp B will be accomplished

from two lanes. Generally speaking, the signal control is a safer condition compared to merging with no exclusive right-of-way provided under the No-Build conditions. A median will separate eastbound and westbound traffic on Columbia Pike, such that eastbound Columbia Pike is not affected by the signal control. With traffic from Washington Boulevard bound for westbound Columbia Pike being able to make the move from Ramp D, also means that traffic on Ramp B will be reduced, improving the operations and decreasing conflicts at Ramp B.

South Orme Street and Ramp D

With the realignment of Ramp D, a split-phase traffic signal would be provided for both minor roadways, providing exclusive green time to each approach. This signal would allow for a safe movement for the side street traffic. Also, a left-turn bay for eastbound Columbia Pike traffic would provide storage for the movement and may reduce the risk of an eastbound through vehicle striking the rear of a vehicle waiting to turn left from the through travel lane. Additionally, the realignment of Ramp D to intersect opposite of S. Orme Street would mean that vehicles destined from Ramp D to S. Orme Street would not be required to maneuver right only to turn left on S. Orme Street in a short distance. Illegal left-turn movements from Ramp D to Columbia Pike under the No-Build Alternative lead to potential conflicts and safety concerns. This will be rectified under the Build Alternative with the realigning of Ramp D.

4.2 Pedestrians

Under the Build Alternative, signal-controlled pedestrian crosswalks are provided at two locations across Columbia Pike:

1. Ramp G/South Queen Street/Ramp E
2. Ramp D/South Orme Street.

Under the No-Build alternative, there is one signalized crossing across Columbia Pike at South Quinn Street/Ramp G. Location (1) above would essentially "replace" the existing pedestrian signal at Ramp G/South Quinn Street under the No-Build configuration, and would also include a signalized pedestrian crossing across Ramp E. Furthermore, the No-Build pedestrian crossing at South Quinn Street involves left-turning vehicles in conflict with pedestrians, as both side streets operate under a concurrent phase. The split phase provided at South Queen/Ramp G/Ramp E provides a crossing environment free of left-turning vehicles. The signal-controlled pedestrian crossing at location (2) would be a new controlled crossing in the interchange area, which would greatly enhance pedestrian safety, as there are few opportunities for pedestrians to cross comfortably on the east side of the interchange.

Under the Build Alternative, the reconstruction of Columbia Pike would include ADA compliant pedestrian curb cuts along the north and south side of the roadways. A shared use path (for both pedestrians and adult bicyclists with average riding skills) would exist along the north side of Columbia Pike.

4.3 Bicyclists

The FHWA classifies adult bicyclists as either Type A (highly skilled who are comfortable riding in traffic) or Type B (all other adults). The average adult bicyclist (with Type B skills) will act as a pedestrian utilizing the sidewalk, the shared use path, and the crosswalks due to his/her low speed.

Type B bicyclists (and children riding bikes) will have one of two opportunities to travel along Columbia Pike through the project area:

1. The 10-foot shared use path on the north side of Columbia (along the westbound lanes), or
2. The seven-foot sidewalk on the south side of Columbia Pike (along the eastbound lanes).

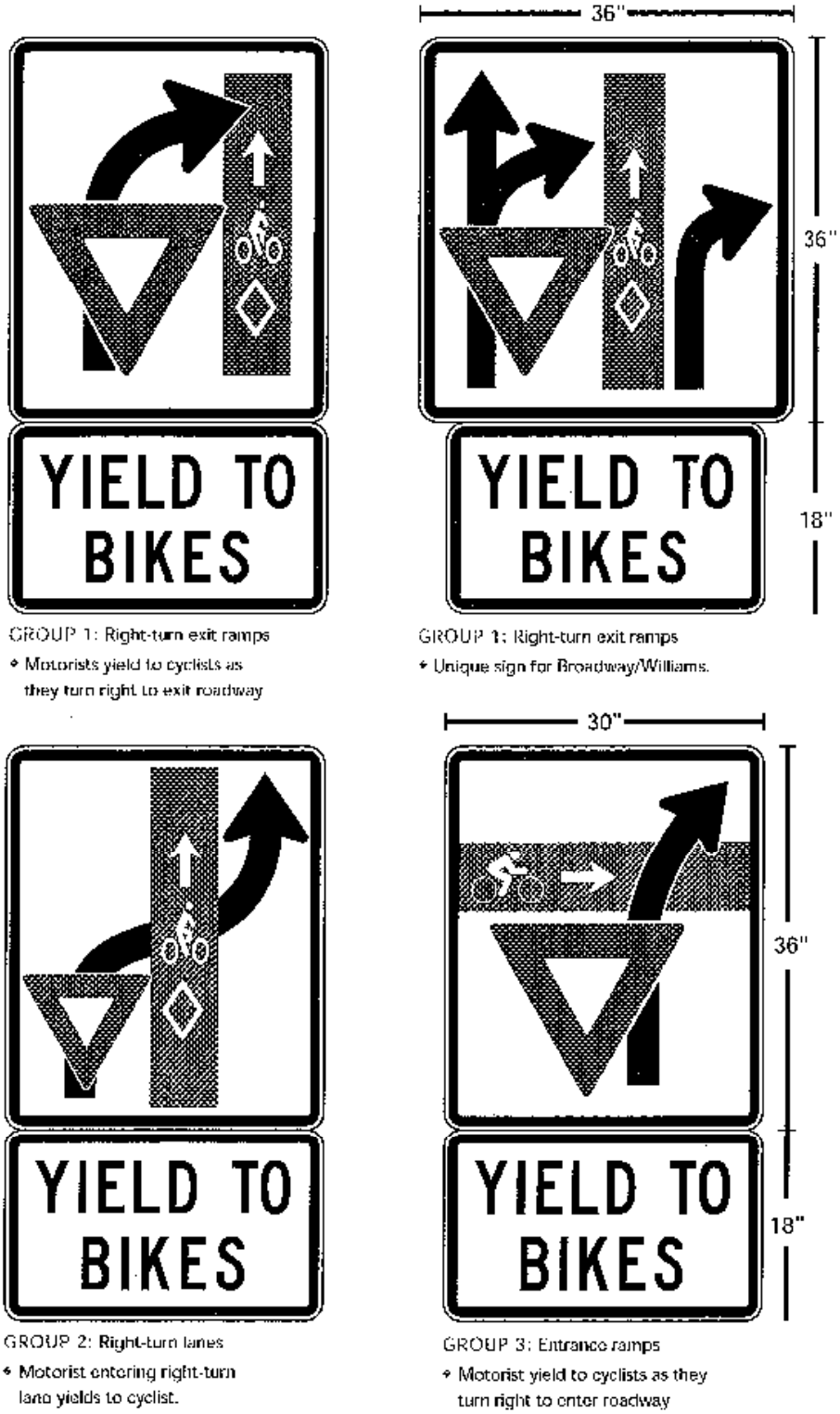
For highly skilled Type A bicyclists, acting as a pedestrian is undesirable as it increases their chance of injury due to the increased number of vehicular conflicts and the unpredictability of slow moving pedestrians. Fifteen-foot wide curb lanes accommodate more experienced bicyclists and would facilitate their movement along Columbia Pike. The biggest area of concern, however, is in the eastbound direction of Columbia Pike between S. Quinn and S. Queen streets where motorists in both lanes may turn right onto Ramp E between 6:30 AM and 9:00 AM on weekdays. All other times of day, motorists may only turn right from the outside lane, which is also shared with through movements to eastbound Columbia Pike. Type A bicyclists (who are very comfortable riding in traffic often at speeds between 20 and 30 mph) will traverse this area by legally acting as a vehicle and merging into the nearest through traffic lane (or in this instance, the combined through/right lane) to avoid conflicts with right turning vehicles. The situation may be improved once the remainder of the widening of Columbia Pike is completed whereby a dedicated, continuous bike lane may be established in the both directions.

On-road bicycle lanes should be located to the left of any right-turn only lanes as per Section A-5, "Bicycle Facility Guidelines", of the Virginia Department of Transportation's *Road Design Manual*. In the westbound direction, this means that bicyclists will be adjacent to the curb through the project limits, except between S. Orme Street and Ramp A where bicyclists will ride in the wider through lane, adjacent to the dedicated right-turn lane. In the eastbound direction, a bike lane will be more difficult to stripe due to the time of day lane use and will depend on the configuration of future improvements along Columbia Pike west of this interchange. National guidance documents for bike lanes through interchanges are expected in the near future and may provide the necessary design tools to address these particular issues.

Additional signing at the exit ramps from Columbia Pike to alert motorists to the presence of bicyclists should be considered in the final design. The intent is to increase awareness by both bicyclists and motorists and encourage yielding behavior by motorists. If the latest MUTCD does not have signage for bike lanes traversing through interchanges by the time the bicycle lanes are striped, the following signage examples may be considered. **Figure 6** depicts ramp crossing signage taken from *Portland's Blue Bike Lanes: Improved Safety Through Enhanced Visibility*. **Figure 7** depicts recommended signage for end of bicycle lanes from the *1995 Oregon Bicycle and Pedestrian Plan.*. Note that any non-standard MUTCD sign should undergo

human factors testing and be submitted to the FHWA for experimental status approval before installation to protect VDOT from liability.

Figure 6: Recommended Bicycle Signage



GROUP 1: Right-turn exit ramps
- Motorists yield to cyclists as they turn right to exit roadway

GROUP 1: Right-turn exit ramps
- Unique sign for Broadway/Williams.

GROUP 2: Right-turn lanes
- Motorist entering right-turn lane yields to cyclist.

GROUP 3: Entrance ramps
- Motorist yield to cyclists as they turn right to enter roadway

Figure 7: Signage to Indicate End of a Bicycle Lane

4.4 Special Consideration for Traffic Control Devices

Given that three signals would be installed in close proximity to one another under the Build Alternative, special consideration should be given to using select-view or programmable signal heads. In close urban settings there is a potential for drivers to be mistakenly looking downstream at the next signal indication and ignoring the signal indication for their particular intersection. To help alleviate this potential, programmable signal heads appear dark to oncoming motorists until such time the driver enters the influence area for their respective intersection. These signal heads help drivers determine which signal indication belongs to which intersection, whereby reducing driver confusion.

Due to bus stop locations and required lane changing, it is desired to maintain the *Time-of-Day* lane use on the eastbound approach of Columbia Pike to the intersection with Ramp E and S. Queen Street. For the Build conditions, during the AM peak period, the left lane is a shared through-right lane, while the right lane is a right-turn only lane. All other times of the day, including the PM peak period, the left lane is through only, while the right lane is a shared through-right lane. Currently, there are advanced static signs on the side of the road in the buffer zone between the road and the sidewalk, as well as overhead signs prior to the intersection and at the existing intersection of Columbia Pike, Ramp G and S. Quinn Street. These signs indicate that the right lane of eastbound Columbia Pike must exit at the signal during the 6:30 to 9 AM time period Monday through Friday (see picture on cover). It is recommended that VDOT consider replacing the overhead static signs with dynamic/variable overhead lane use signs that change depending on the time of day. These signs should be placed over the center of each lane. It is also recommended that the existing advance static signs with text only be replaced with a diagrammatic sign showing lane use by time of day.

Also at the intersection of Columbia Pike, S. Queen Street and Ramp G/E, a small raised concrete median will be installed on the west leg of Columbia Pike to separate the eastbound and westbound traffic flow. The raised median will also better guide eastbound traffic into the receiving lanes of the downstream link that is slightly offset. The raised median will extend

approximately half the distance back towards S. Quinn Street. At this point, flexible bollards in the narrow median area will be used to prevent westbound traffic from turning left onto S. Quinn Street and northbound lefts from exiting S. Quinn Street.

4.5 Pavement Markings for Eastbound Columbia Pike

The proposed Build Alternative includes maintaining the existing Time-of-Day (TOD) lane use on eastbound Columbia Pike. To do so, the lane markings on the eastbound approach of Columbia Pike to the intersection with S. Queen Street and Ramp G/E should assist in providing clear direction of the vehicular travel path for the TOD lane use. It is expected dynamic lane use signs will be provided overhead (see discussions under Section 4.4) and the existing overhead static signs would be replaced with panels providing messages to augment the dynamic signs, to provide the guidance of the lane use by TOD, and provide advance warning for motorists to align them into the proper lane before reaching Queen Street. Original concepts proposed diverge lane markings upstream of a proposed stop bar at the median nose. In essence, the area behind the stop bar would be wide enough to accommodate three vehicles side-by-side, which could potentially lead to driver confusion among vehicles on the approach bound for different locations, when the approach is supposed to operate as two lanes.

Figure 7 illustrates an alternate concept to provide the layout of the stop bar and diverge pavement markings. By pulling the stop bar back by approximately 50 feet, diverge markings can begin at the stop bar. The purpose of doing this is to reduce the potential for driver confusion discussed above. This layout also would help build the flexibility of the TOD lane use and provide clarity for the drivers of where to align until the decision point is reached for committing to their turn movement, and would encourage vehicles to remain in the lane until they reach the decision point. The conceptual layout of these lane markings consider that TOD lane use traffic control devices are also in place.

Figure 7: Conceptual Layout of the Stop Bar and Diverge Pavement Markings

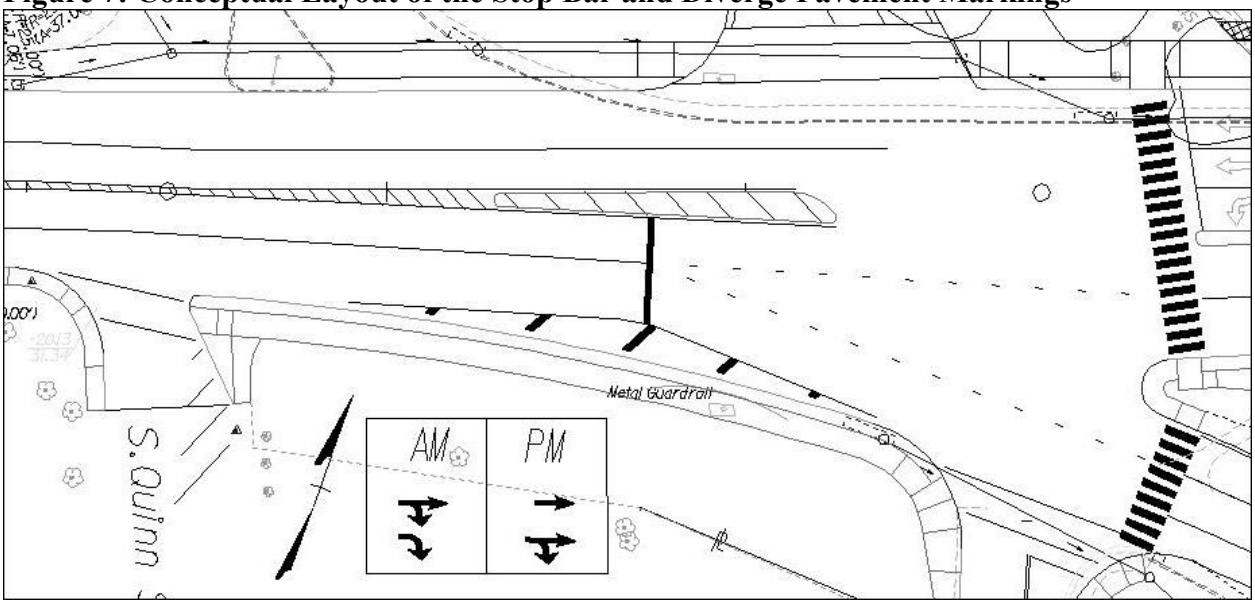


Figure 7 is conceptual in nature; the final designs, if using this concept as a guide, should conform to all VDOT and the MUTCD requirements.

4.6 Review Decision Distance for Ramp H

The current proposed design for Modified B-2 Alternative includes design changes for Ramp H, specifically pulling back the merge from two lanes to a single lane approximately 300 feet upstream compared to existing conditions. This configuration change will require the relocation of the advance warning signs for the lane drop on Ramp H.

Current Conditions

Currently traffic exiting I-395 NB at Exit 8A does so via a one-lane ramp, which then merges with a one-lane ramp from Arlington Ridge Road to form a two-lane roadway. This two-lane roadway then splits into two separate single lane ramps: the first ramp (Ramp H) to the left that leads to northbound Route 27 (Washington Blvd) and Route 244 Columbia Pike, and the second ramp to the right leading to northbound I-395. After the split, Ramp H gradually widens to two lanes and remains as two lanes up until approximately the gore area for the exit to Route 244 East Columbia Pike, at which point the left lane is dropped with a transitional merge for a distance of about 325 feet. There are three advance warning signs for the lane ending. The first sign the motorist sees is LANE ENDS MERGE RIGHT, positioned at about 650 feet from the beginning the lane drop (defined by the last lane marking by the gore), the next is a warning sign that says LANE ENDS 500 ft (a word sign), and then followed by a LANE ENDS symbol sign placed about 250 feet from the beginning of the lane merge. Under current conditions, a motorist would have about 775 feet of horizontal sight distance to the beginning of the lane merge.

Design Plans

The proposed design would move the lane merge point back (towards I-395) by about 300 feet. This would leave about 1,450 feet for the full two-lane section back to the aforementioned split, with approximately 1,100 feet on a horizontal curve section partially under an overpass. There is also a slight vertical crest curve in this section. Under this plan, the motorist using this ramp would come from a one lane section to a short (1,450 feet) section of two lanes and then, if in the left lane, need to merge into one lane, prior to Ramp H merging with Route 27.

Design Requirements

The relevant design standards are for providing sufficient sight distance to the lane reduction and providing sufficient warning through signing that the left lane is being dropped and the need to merge right. Decision sight distance would be an appropriate design principle to follow in this situation. Assuming a design speed of 40 mph (there is a ramp speed advisory of 30 mph, but higher speeds were observed and should be expected), there should be a sight distance to the beginning of the lane merge of at least 715 feet (Case D in Exhibit 3-3 in AASHTO Geometric Design of Highways and Streets, 2004). It is estimated that only about 350 feet would be available given the horizontal curve section that precedes the lane merge.

According to the Manual on Uniform Traffic Control Devices the LANE ENDS MERGE RIGHT word sign (W9-2) or the Lane Ends (W4-2) symbol sign, which is used to warn of the reduction in the number of lanes in the direction of travel, should be placed in advance of the lane reduction. According to Table 2C-4 in the MUTCD, the sign should be placed at 550 ft (for 35 mph) or 650 feet (for 40 mph) in advance of the lane reduction. Also, a LEFT LANE ENDS word sign or the LANE ENDS MERGE RIGHT word sign may be placed in advance of the aforementioned signs as additional warning or to emphasize that the traffic lane is ending and that a merging maneuver will be required. There is no specific requirement as to how far ahead of the required signs this sign should be placed, but 200 feet would be reasonable. The placement of these signs would put them on the curved section of Ramp H and be out of view of the lane reduction.

Assessment

The proposed concept may cause a safety concern for three reasons. First, the design creates a violation of driver expectancy. The motorist will have come from one lane (prior to the split) to a two-lane section for only about 1,450 feet and then have to merge back to one lane (if in the lane that is being dropped). Having come from essentially a one-lane section and then being provided two lanes, a motorist will expect that the two lanes will continue for some significant distance. The need to change lanes would be unexpected. This would constitute a violation of driver expectation and could cause vehicle conflicts or driver confusion. The second reason is that there is insufficient sight distance to the beginning of the lane reduction. Decision sight distance, which is applicable for this situation, calls for 715 feet, but approximately 350 feet would be available. The third reason is that the advance signing for the lane reduction would have to be placed on the curve section and sight distance to these signs would be limited. For these reasons, the design of this ramp and the need for retaining two lanes should be considered and reviewed further in the final design phase of the project.

5 Conclusions

In comparing the No-Build and Build Alternatives, the HCM operational analyses show:

- During the PM peak hour, operations at intersections along Columbia Pike are greatly improved under the Build conditions. All lane groups operate at LOS E or better.
- During the AM peak hour, operations at intersections along Columbia Pike are similar under both alternatives, but marginally decreased under the Build Alternative. Considering the consolidation of five intersections into three and the changes in traffic control, it should also be noted that no intersection under the Build Alternative would operate at an overall LOS worse than D, with only a marginal increase in delay of less than 4 seconds per vehicle. Under the No-Build Alternative, two of the five intersections operate at LOS F.
- During both the AM and PM peak hour, operations on Washington Boulevard (ramps and weaving sections) are comparable under the No-Build and Build conditions, with marginally improved densities and speeds under the Build Alternative.

The CORSIM operational analyses show:

- That the corridor can operate with intersection LOS of D or better with three closely spaced signals, provided adequate signal coordination is incorporated.
- Signal timing plans can be developed to prevent queue spillback onto Washington Boulevard.
- Signal timing plans can accommodate the pedestrian movement across Columbia Pike.
- The reconfiguration of the interchange will not impact operations on I-395, and associated ramps to/from Washington Boulevard.
- The neighborhood access from Arlington View would be improved with the new signal at S. Queen Street.

Noted safety benefits of the Build Alternative are summarized in this technical memorandum, which illustrate recognizable benefits to vehicular and pedestrian users. This includes safer pedestrian crossing conditions, safer vehicle turning conditions, and likely reduction in angle crashes, which are prominent under the No-Build geometric and traffic control conditions.

Lastly, the proposed Build configuration is part of a bridge replacement project and therefore significant improvements to capacity are not proposed, as this is not the intent of the overall effort. In summary, this operational analysis and safety review finds that the Build Alternative is preferred for the 2031 project traffic conditions, as it would be more efficient and safer for all categories of intersection users when compared to the No-Build Alternative.

Appendix A –Response to Arlington County's Request for Additional Information

Technical Appendix
Response to Arlington County's Request for Additional Information

NOTE: The analysis and response was developed in December 2007 when conditions were such that both alternatives had the crosswalk at S. Queen Street on the west leg.

VDOT and Arlington County met on September 25th, 2007 to discuss the Route 27/244 interchange modification project, including the CORSIM summary report submitted by VHB on September 21st, 2007. As a result of the meeting, Arlington County requested that additional items be considered and reviewed. This appendix summarizes additional analyses performed and responses to six of the issues raised during the meeting.

NOTE: The analysis and response was developed in December 2007 when conditions were such that both alternatives (Original B-2 Alternative and Modified B-2 Alternative) had the crosswalk at S. Queen Street on the west leg of the intersection. Due to ADA ramp design requirements, the crosswalk was relocated to the east leg, after this memorandum was prepared to respond to Arlington County's comments. Please see Figure A-1for an illustration of the Build Alternative as discussed in this appendix.

Specifically, the comments from the County that VDOT requested VHB investigate include the following:

1. Re-consider allowing left turns from Ramp B to eastbound Columbia Pike (this would be the original B-2 Alternative).
2. Determine if a 130 second cycle is feasible to maintain consistency with the current system cycle length.
3. Determine how/if pedestrians are incorporated into the CORSIM model.
4. Provide a break-out of the MOEs on the eastbound approach of Columbia Pike to S. Queen Street and Ramp E; to separate the traffic continuing eastbound on Columbia Pike, versus traffic destined to Ramp E.
5. Provide the Synchro files used in the analysis to VDOT to transmit to Arlington County.
6. Determine if concurrent flow phasing at the Ramp G and S. Queen Street intersection can be accommodated with a single left-turn lane from Ramp G. Consider the interim year that a single lane would work, before the second left-turning lane would need to be added.

Task 1. Analyze the Original B-2 Alternative (allowing left turns from Ramp B) with Updated Future Traffic Projections

The main difference between the B-2 Alternative and the Modified B-2 Alternative is that left turns from Ramp B to eastbound Columbia Pike are permitted in the B-2 Alternative, but are not permitted in the Modified B-2 Alternative. VHB previously analyzed Alternative B-2 using the volumes derived January 26th, 2006. Since that time, VDOT reviewed the traffic forecasts and revised the volumes for the study area based on more current information, resulting in volume projections utilized for all analyses performed since February 5th, 2007.

To re-assign traffic appropriately for the original Alternative B-2, the volumes for the Modified B-2 Alternative were reassigned from Ramp D to Ramp B to reflect the movement from the northbound I-395 ramp to eastbound Columbia Pike that can use Ramp B to travel eastbound. **Figure A-1** illustrates the proposed interchange configuration and **Figure A-2** presents the volumes for Alternative B-2. The MOEs are summarized in **Tables A-1** and **A-2** that follow. Overall, in the AM peak, the analysis indicates that speeds along northbound Washington Boulevard are slightly higher for the original Alternative B-2 (by less than 2 mph for each segment prior to Ramp B) compared to those in Modified B-2 Alternative for the same segments, while the speeds are slightly lower in the PM peak (less than 2 mph for each segment prior to Ramp B). In summary, the reduction in vehicles weaving to use Ramp D does not significantly affect operations on Washington Blvd and one can conclude that from the perspective of operations on Washington Blvd, one alternative is not significantly better than the other.

For operations along Columbia Pike at the intersection with Ramp B, for the AM peak hour the comparison shows that the two intersections perform similarly to each other. In the PM peak hour, the Ramp B intersection under Alternative B-2 does not perform as well as it does for the Modified B-2 Alternative conditions. Overall intersection delays are slightly higher, as are the average delays projected for the southbound ramp approach and the westbound Columbia Pike approach.

However a more critical issue associated with the original Alternative B-2 is that by allowing left turns from Ramp B to eastbound Columbia Pike, the median has to be open and this breaks the storage bay for the westbound left turns at S. Queen Street, thereby removing necessary storage space. The simulation was observed at this location to determine whether the queue in the turn bay at S. Queen Street would spill back into the intersection with Ramp B. It was observed in several instances while watching the simulation that the queue in this storage bay did spill back into the intersection. This queue spillback impedes left turns from Ramp B from turning onto Columbia Pike, which in turn also affects the high volume of right turning traffic, potentially lengthening the queue on the Ramp.

In summary, Alternative B-2 with left turns permitted from Ramp B, would result in longer delays, reduced flow of traffic along Columbia Pike, longer queues on Ramp B, and undesirable crossover spacing on the arterial.

Task 2: Assess the Potential for a 130-Second Cycle

VHB performed "back-of-the-envelop" calculations to determine whether a 130-second cycle would be possible. At each intersection critical lane volumes were determined for each phase. The green times necessary for the volumes were calculated also taking into account lost time. Then taking into consideration the clearance times necessary for each phase, the resulting overall cycle length was computed and compared to the proposed cycle length. The analysis assumed an initial cycle of 140 seconds and then the calculations at each intersection were recomputed with a 130-second cycle length.

The analysis indicates that 130 seconds is sufficient to accommodate the projected volumes at the intersection with Ramp B. At the other two intersections, Ramp G/S. Queen Street and Ramp D/S. Orme Street, the calculations indicate that 2-3 additional seconds are needed beyond the 130 second cycle. However, it should be noted that this analysis was performed with projected year 2031 volumes. Upon implementation of timings for the modified configuration, traffic volumes will be lower. Therefore, engineering judgment indicates that in the short term a 130-second cycle length could be utilized.

Task 3: Determine how/if Pedestrians are Incorporated into the CORSIM Model

Two signal-controlled pedestrian crossings are proposed in the vicinity of the interchange:

- The west leg of the intersection of Columbia Pike and S. Queen Street/Ramp E/Ramp G. This pedestrian crossing would operate with the southbound vehicular phase and would clear both Columbia Pike and Ramp E in one movement, as the refuge area between Columbia Pike and Ramp E is not large enough to accommodate pedestrians.
- The east leg of the intersection of Columbia Pike/S. Orme Street/Ramp D, which would operate with the associated northbound vehicular phase.

The CORSIM model does not include pedestrian actuation, but instead includes signal timings set for the associated vehicular phases such that the minimum green time meets the requirements for the crossing time needed by pedestrians. This crossing time for pedestrians was calculated by setting the interval of the "Walk" display as 7 seconds plus the "Flash Don't Walk" display as the crossing distance divided by walking speed of 4 feet per second. So a crosswalk 100 feet in length would be given a crossing time of 7 + (100/4), or 32 seconds. Since minimum green times for the associated vehicular phases meet the needed crossing times, the results of the operational analysis represent a *worst case scenario*, assuming the pedestrian phase is actuated at every single cycle.

Task 4: Provide More Detailed MOEs for Eastbound Columbia Pike Movements at the Intersection with Ramp G/Ramp E/S. Queen Street

The Total Delay was broken out for both movements on the eastbound approach of Columbia Pike at the intersection with Ramp G/Ramp E/S. Queen Street. This particular MOE is the only one summarized thus far for which CORSIM provides the information by movement.

Original Alternative B-2

The eastbound Columbia Pike approach at the intersection with Ramp G/Ramp E/S. Queen Street operates with an average total delay of 21.3 seconds per vehicle in the AM peak hour. This represents an average total delay for the through movement of 20.6 seconds and for the right turn movement (to Ramp E and to S. Queen Street) of 21.6 seconds per vehicle.

In the PM peak hour, the eastbound Columbia Pike approach operates with an average total delay of 32.5 seconds per vehicle. This represents delay for the through movement of 28.9 seconds per vehicle and for the right turn movement 35.2 seconds per vehicle.

Modified B-2 Alternative

For the Modified B-2 Alternative, the eastbound Columbia Pike movement at S. Queen Street has an average Total Delay of 20.3 seconds per vehicle in the AM peak hour, of which the delay for the through movement is 20.1 seconds per vehicle and for the right turn movement is 20.3 seconds per vehicle.

In the PM peak hour, the eastbound Columbia Pike approach operates with an average total delay of 32.5 seconds per vehicle. This represents delay for the through movement of 29.3 seconds per vehicle and for the right turn movement of 34.8 seconds per vehicle.

Task 5: Provide Synchro files

The Synchro files for both alternatives discussed herein were copied to CDs and are being transmitted to VDOT under separate cover.

Task 6: Assess Concurrent-Flow Phasing for Ramp G/S. Queen Street

Arlington County requested that the feasibility of concurrent flow phasing for the minor approaches be investigated at this intersection. The proposed configuration of Ramp G includes two left-turn lanes. If concurrent flow phasing was implemented, the rightmost left-turn lane could not operate in the same phase with the northbound left turn from S. Queen Street, as vehicle paths would cross. Therefore, for this assessment it was assumed that Ramp G would operate with a single left-turn lane.

The main concern with a single left-turn lane from Ramp G is the high volume for the left-turn movement and potential queuing that would result with the reduced capacity and storage area from two lanes to one. To evaluate queuing with a single lane for left turns VHB performed a basic queuing analysis, calculating average number of vehicles per cycle and then using the Poisson distribution method to determine estimated maximum queue lengths. This calculation was performed with: (1) existing volumes on Ramp G and the proposed Modified B-2 Alternative configuration and (2) projected volumes and the proposed Modified B-2 Alternative configuration.

The queuing analysis for the AM peak hour indicates that queue spillback would not occur under existing volume conditions or for projected 2031 volumes. In the PM volume conditions, however, the left turn volumes are higher and the projected queues longer. The analysis indicates that the vehicle queue on the ramp would not spill back onto Washington Blvd under existing volume conditions with the estimated maximum queue approximately 375 to 400 feet. Applying the projected 2031 volumes (which includes an additional 31 vph turning left

compared to existing counts) the estimated maximum queue would be approximately 450 feet. The 450 ft queue would place the back of the queue at the gore point between mainline Washington Blvd and the ramp. Although there is a deceleration lane for the exit from Washington Boulevard, vehicles exiting would have to slow down well before entering the deceleration lane as they would have to come to a complete stop at the very top of the ramp. This could conceivably affect the through movement on Washington Boulevard by the slowdown of exiting vehicles on the mainline, and potentially result in rear-end crashes.

Although estimated maximum queuing does not demonstrate a *significant* problem in terms of spillback, there are other more important impacts of concurrent-flow phasing that should be taken into account in the determination of feasibility. The first of which is the safety provided to pedestrians in crossing the west leg of the intersection. Under split phase conditions, pedestrians cross with no vehicle conflicts during the southbound vehicular movement. This is an ideal situation for pedestrian safety. If concurrent phasing were employed, northbound left turning vehicles would be in conflict with pedestrians. It is much less desirable to have pedestrians cross against left turn vehicles and this is exacerbated by the fact that the drivers of these northbound vehicles would be focusing more on the opposing Ramp G traffic and thereby focusing less on pedestrians crossing Columbia Pike.

In addition, the intersection itself is unconventional due to the slightly skewed approach from Ramp G, along with the northbound movement across Ramp E and then onto Columbia Pike. With concurrent-flow phasing, northbound drivers would be challenged to accurately identify a southbound left turning vehicle vs. an opposing southbound through vehicle. And for the northbound movement, the vehicles would have to contend with crossing over Ramp E, adding another piece of information for drivers to process as they move through the intersection, prior to assessing opposing vehicles and also the pedestrians. Lastly, due to the tight geometry of the intersection, the occasional large vehicle could impact traffic in the opposite direction if phasing were concurrent.

It is clear that concurrent-flow phasing is more desirable from a pure vehicle operations perspective, with reduced vehicular delay compared to split phase operations. But this intersection is not a typical four-leg 90-degree intersection, and driver behavior and attention through the intersection should be a significant factor in determination of signal phasing. The trade-offs in pedestrian safety, and diversion of driver attention in what is already an unconventional situation, do not substantiate the more efficient vehicle phasing.

Figure A-1: Alternative B-2 Interchange Configuration (previous considered Build Alternative)

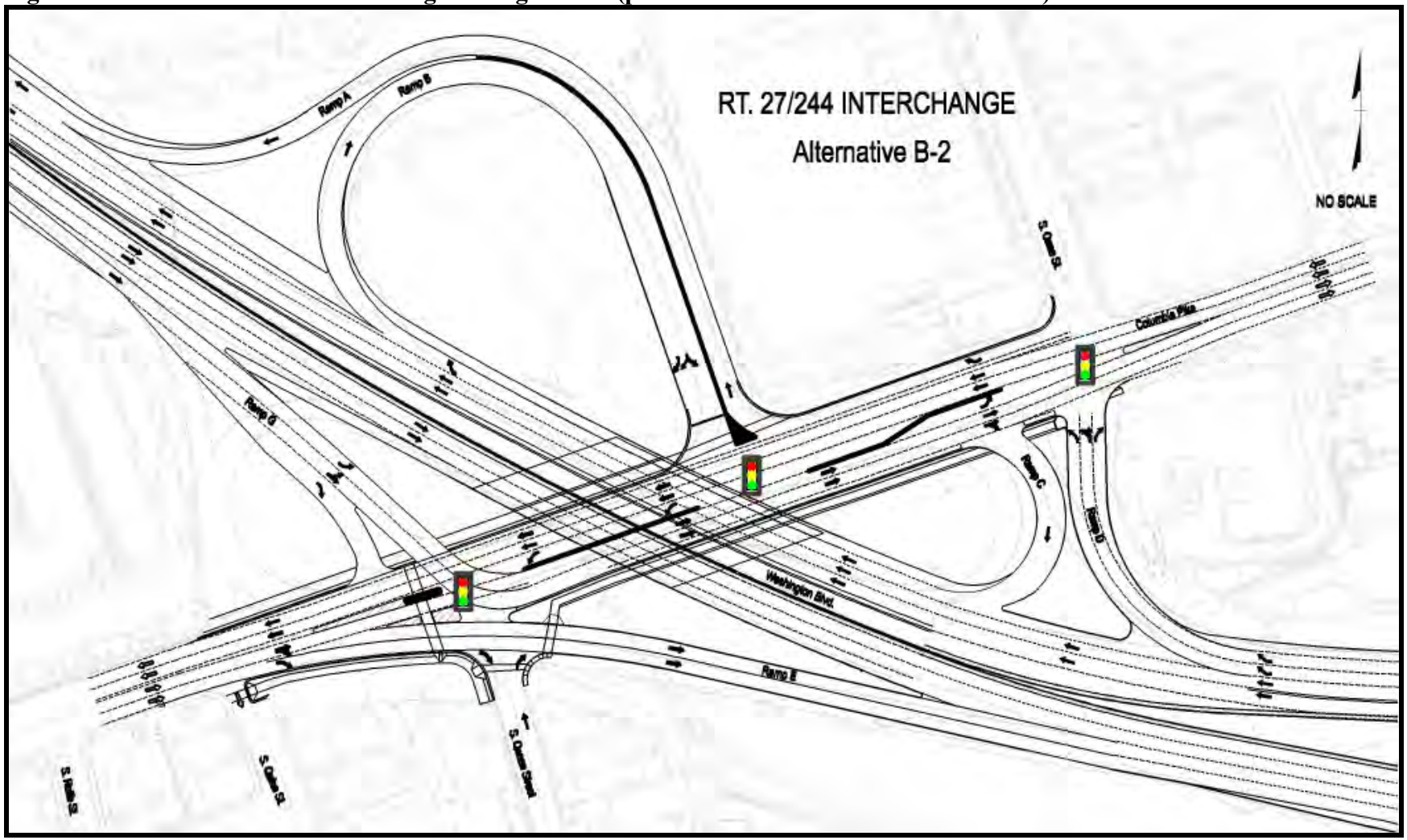


Figure A-2: 2031 Peak Hour Traffic Volumes for Alternative B-2

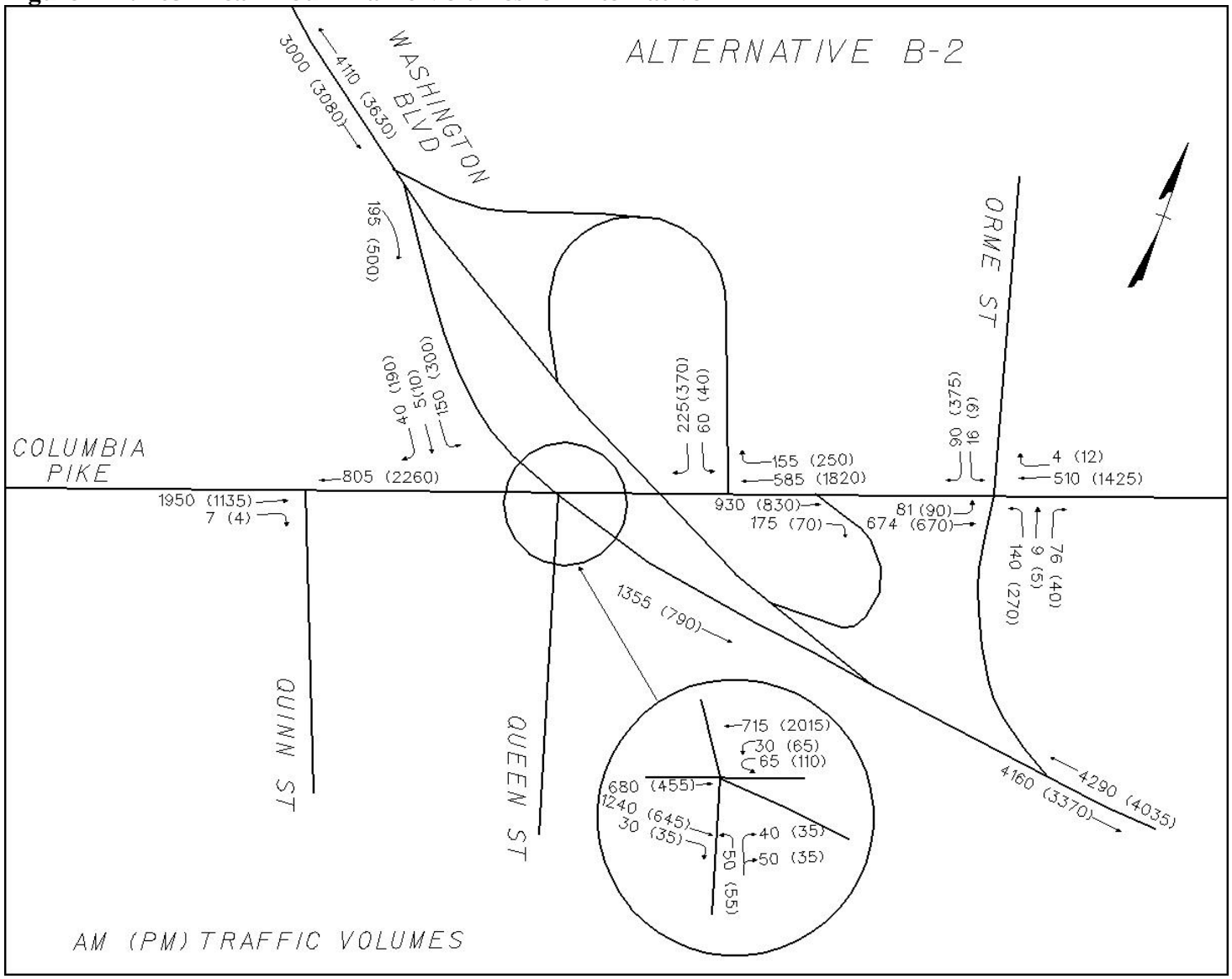


Table A-1: MOEs for Operational Performance of Intersections on Columbia Pike for the Alternative B-2 Configuration

Intersection Approach	ALTERNATIVE B-2 INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)	Trips (veh)	Control Delay (sec/veh)	LOS	Total Delay (sec/veh)	Avg Queue (veh)	Max Queue (veh)
COLUMBIA PIKE AND S. QUEEN STREET/RAMP G/E.												
EB	1945	12.0	B	21.3	1	16	1152	24.5	C	32.5	2	18
WB	810	10.5	B	12.1	2	7	2169	17.4	B	20.6	4	13
NB	140	78.7	E	83.4	2	6	125	69.2	E	73.2	2	6
SB	213	17.7	B	19.0	1	3	533	42.5	D	44.9	3	8
Overall		15.0	B	21.5				24.4	C	29.0		
COLUMBIA PIKE AND RAMPA/B												
EB	756	5.0	A	6.6	1	8	805	6.1	A	8.9	1	10
WB	744	3.1	A	5.4	0	7	2024	8.5	A	14.4	3	18
SB	281	52.4	D	54.9	3	9	420	107.1	F	114.2	8	20
Overall		11.7	B	13.7				20.7	C	25.9		
COLUMBIA PIKE AND S. ORME STREET/RAMP D												
EB	657	2.1	A	5.0	0	7	772	7.2	A	10.1	1	13
WB	517	4.3	A	10.6	0	5	1447	14.4	B	24.6	3	21
NB	233	38.0	D	38.9	1	5	315	42.9	D	45.0	2	8
SB	106	8.7	A	10.2	0	2	382	5.1	A	6.6	0	2
Overall		8.8	A	12.5				14.4	B	20.6		

Table A-2: MOEs for Operational Performance of Freeway Segments on Washington Boulevard for the Alternative B-2 Configuration

Description	ALTERNATIVE B-2 INTERCHANGE CONFIGURATION											
	AM PEAK HOUR						PM PEAK HOUR					
	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)	Trips	Lane Changes	Move Time	Delay (Sec/veh)	Density (veh/ln/mi)	Speed (mph)
SOUTHBOUND ROUTE 27												
Between Ramp G and Ramp E	2785	178	7.9	1.0	28.1	49.6	2556	111	7.9	0.6	24.9	51.3
Between Ramp E and I-395 Ramp	4141	3102	5.1	1.5	26.3	39.4	3375	2270	5.3	0.8	19.7	42.8
NORTHBOUND ROUTE 27												
Between I-395 ramp and Ramp D	4288	537	5.5	1.7	25.6	41.9	4030	715	5.5	0.4	19.9	50.7
Between Ramp D and Ramp C	4051	98	3.0	2.2	64.1	31.6	3723	92	3.0	0.6	40.6	45.8
Between Ramp C and Ramp B	4206	684	6.8	3.7	39.8	35.3	3787	767	6.8	2.8	33.1	38.1
Between Ramp B and Ramp A	3927	166	4.1	1.4	48.1	40.8	3355	148	4.1	1.9	44.5	37.7

Appendix B –CORSIM Analysis: Model Limitations and Fine-Tuning

The CORSIM model does have some modeling limitations that can limit the effectiveness of the tool. No single software exists that is free of modeling quirks. Using one software program to avoid a problem that second software has, will introduce another tweak that the user would have to explain. Understanding these limitations and how they impact the modeling will allow the user to improvise and tweak the models accordingly. It will allow for better understanding of the output and the user would have to make observations on how expected conditions would differ from the observed model outputs. The purpose of this section is to present the observations and limitations to the CORSIM models developed for this analysis.

Model Limitations/Observations for No-Build CORSIM Model

- Ramp B traffic must yield to WB Columbia Pike traffic. Due to the lack of gaps in the traffic stream, very little opportunity exists for Ramp B traffic to merge onto WB Columbia Pike. Traffic spills back onto Washington Boulevard.
- Although the northbound travel lanes on the Washington Boulevard bridge offer a very short acceleration area for Ramp C and a deceleration are for Ramp B, it was modeled as a full auxiliary lane between the ramps due to the following issues with the CORSIM model.
    - Due to the spillback of Ramp B onto Washington Boulevard with the geometrics of acceleration and deceleration lanes, vehicles desiring to exit at Ramp B that could not get into the deceleration lane would eventually "give up" and continue through along NB Washington Blvd. Thus the exiting volume to Columbia Pike is lower and the through volume is higher than the traffic assignment/projections.
    - Another quirk of the model that occurred when analyzed without an auxiliary lane was that vehicles from Ramp C attempting to merge onto Washington Blvd could not merge into the traffic stream due to the congestion. So the vehicles would sit at the end of the ramp and then literally disappear from the model all together (CORSIM removes the vehicles at the end of ramp C).
    - Due to the two points above, the congestion modeled is less than what would truly occur. If other simulation software is used, such as VISSIM, these phenomena would occur in those models as well. For all of these reasons, a full length auxiliary lane was used on NB Washington Blvd for the No-Build condition, such that the phenomenon described above occurred at a much less frequency in the model. We believe this provides a truer projection of traffic conditions.
- The outer lane channelization on EB Columbia Pike in the AM and PM Peak are coded differently, as time-of-day lane use is applied. This is intentional. The split with Ramp E is a right-turn only lane and a shared through-right lane; such that both eastbound lanes feed Ramp E and one feeds Columbia Pike east of the ramp split. In the PM, the lane use is a shared through-right lane and a through lane; such that only one lane feeds Ramp E while both lanes feed Columbia Pike.
- On NB S. Queen Street, periodically the reviewer may notice that vehicles queued at the stop bar will spill back across Ramp E, whereas in reality, drivers will likely leave the space across Ramp E open. However, CORSIM does not have a "do not block the box" function.

Limitations/Observations of Modified B-2 Alternative CORSIM Model

- The signal timings were set to prevent queuing of ramp traffic back onto Washington Blvd – this comes at the expense of Columbia Pike traffic.
- For NB S. Queen Street, all vehicles should stop at the stop bar south of Ramp E. However, due to CORSIM link length limitations and adjacent lane use limitations, the intersection of Queen St with Ramp E and then with Columbia Pike had to be coded at two separate junctions. Although in operation they work as a single signal-controlled intersection. The model periodically has a NB vehicle trapped between Ramp E and S. Queen Street, but this phenomenon would not occur in actual conditions. However, the CORSIM coding was complex for this unconventional junction, and we feel this represents the best projection of traffic conditions.
- WB queues at S. Orme Street in the PM will spill back and affect S. Ode Street. For this reason, "don't block the box" signs will need to be included into the designs at this location.
- Buses are assigned a specific route – there are some instances where CORSIM is using the turning percentages to apply their actions at each node. This causes a bus to be assigned to turn left from WB Columbia Pike to S. Queen Street so the bus moves from the right lane into the left-turn bay, then once the bus gets to the intersection, CORSIM then forces the bus to move back over to the right lane to follow the assigned bus route. Therefore the impedance caused by these lane changes reflects worst-case operations. For this reason, we modeled both with and without bus routes to examine the flow on Columbia Pike, but reported MOEs for the scenario with the bus routes – this would give the more conservative results on Columbia Pike.
- Vehicles making right turns from Ramp B intending to make a left turn from Columbia Pike onto Queen St may not get the opportunities to enter left-turn pocket because of existing queues in the PM peak period. Occasionally, these vehicles block the WB thru traffic on Columbia Pike in the left through lane, and eventually change from left-turning vehicles to thru vehicles and continue on WB Columbia Pike. Typically, in Northern VA, other drivers will likely not be tolerant of this behavior and therefore one would not expect as many blockages of this kind. Hence the CORSIM model is conservative.
- The two signal controllers at the intersection of Columbia Pike/Ramp E/Queen St and the intersection of Ramp E/ Queen St have mutually common detector sets to make them function as a single signal controller which is how they will function in reality.

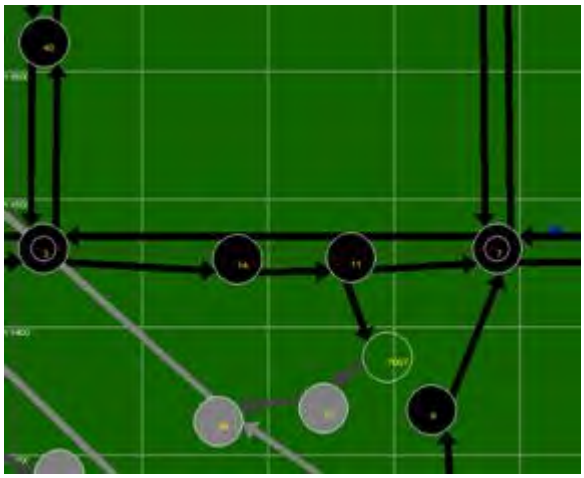
Warning messages

CORSIM routinely has warning messages when running. These messages are a typical occurrence for complicated models or unusual networks, including an abnormal intersection layout. THE following is an explanation of the CORSIM warning messages that one would see when running the model. The warning messages fall into 6 basic categories. Clarification is provided for each category of warning messages, as follows:

a. **The initialization period will be extended to the time specified.** Normally, CORSIM's initialization period ends when total vehicles "in" equals total vehicles "out." To ensure that the CORSIM model sufficiently preloaded the network and would therefore model initial conditions properly, the initialization period was manually forced to go to the desired amount of time. The effect on the output would be a more heavily

loaded network at the beginning of the simulation, which we believe more appropriately represents traffic conditions in this area, as the peak period extends far outside of just the peak hour. The same initialization period was used in all files.

b. ***** **WARNING - 500 - Link (10,7) may not have been specified correctly on Record Type 11. Its traffic opposes traffic on link (11,7), but no receiving link (7,11) was input. Check Record Type 11.** This message is a warning from CORSIM asking the user to make sure the network is coded correctly. Based on how one link is coded, CORSIM expects an opposing link. These links were coded this way intentionally and this warning will not affect behavioral patterns of vehicles in the model in the vicinity of these links. For example, when coding the link between Ramp D and Ramp A, the EB direction was coded with different nodes than the WB direction due to the presence of Ramp C. If the segments in both directions were coded with the same nodes, that would shorten the link distance of the last link prior to Ramp A, and potentially cause some unrepresentative lane-changing behavior. Please refer to screenshot of segment in question below.



c. ***** **WARNING - 663 - The turn decisions for all traffic entering link (13,41) are specified on Record Type 22. Therefore, the turn movement distribution at the downstream end of link (13,41) can differ from that specified on Record Type 21.** This is a common warning message (for the NETSIM portion of the network) whenever the Record Type 22 conditional turning movement is used with the Record Type 21 turning movement. This does not affect the way the model behaves, rather, CORSIM is letting the user know that both Record Types are present and that it will use Record Type 22. It is a caution to the user as a reminder if he/she makes any changes to the Record Type 21, that he/she should also be updating Record Type 22. Record Type 22 is used wherever turn movements at one intersection are dependent on the entry from the preceding link. The final turn movements assigned in the model for Columbia Pike are reflected in Record Type 22, so the warning does not affect the model run or the output.

d. ***** **WARNING - 702 - The specified position for the off-ramp warning sign, for the off-ramp at node 33 is 2500 feet upstream from the off-ramp gore. This is upstream from the start of the freeway. Therefore, the warning sign is positioned at**

the start of the freeway 1853 feet upstream from the off-ramp. This is a common message whenever a link is specified shorter than the typical distance for the related warning signs. It does not affect the operational behavior of vehicles moving within the network and has no affect on output.

e. **LINK (33,7006) ESTIMATED APPROACH SPEED FOR A TYPE 10 DRIVER = 91 FT/SEC; ACTUAL LENGTH = 74 FEET. BASED ON ESTIMATED APPROACH SPEEDS THESE LINKS MAY BE TOO SHORT. THEY NEED TO BE AT LEAST AS LONG AS A TYPE 10 DRIVER CAN TRAVEL IN ONE SECOND. OTHER FACTORS SUCH AS CONTROL DEVICES MAY REDUCE THE APPROACH SPEEDS AND THEREFORE REDUCE THE REQUIRED MINIMUM LINK LENGTHS. IN THAT CASE THIS WARNING CAN BE IGNORED. SHORT LINKS CAN CAUSE UNPREDICTABLE RESULTS INCLUDING FATAL ERRORS.** This is a warning for the user to check that the link distance coded is correct. It does not affect behavioral patterns of vehicles within this network. The links were intentionally coded as such in order to model the configuration appropriately. There are no short links in the network that cause the unpredictable results and fatal errors mentioned.

f. **NODE 33 DESTINATION VOLUME SPECIFIED BY ENTRY VOLUMES AND TURN PCT IS 85.0 THE OD CALIBRATED DESTINATION VOLUME IS 102.5.** This is a common warning message (for the FRESIM portion of the network) and is comparable to the warning message described in (c) above for Record Type 21 and Record Type 22. Essentially the warning message is flagging the fact that the way in which the two items were coded may not match each other exactly. This error occurs even if the volume is different by 1 vehicle. The final freeway ramp exiting traffic percentages are reflected in the *O/D numbers*, so the warning has no effect on the output.