Washington Street Corridor Traffic Operations and Safety Analysis

April 25, 2011

Introduction

This study analyzes a 19 block section of Washington Street, with specific focus on intersection crashes during HOV hours and potential mitigation measures that could be implemented to reduce crash frequencies. The study analyzes crash data from the previous three year period (2008-2010), and breaks the crashes down by crash type and time of day, with specific emphasis on left turn failure to yield crashes during high occupancy vehicle (HOV) hours. The study also analyzes crash rates for the Washington Street corridor as well as crash rates for similar comparison intersections along both the Duke Street and Route 1 corridors. Finally, the study analyzes five potential alternatives to reduce the number of left turn failure to yield crashes during HOV hours and provides implementation recommendations.

Existing Conditions

Washington Street is a six-lane undivided (with portions divided) arterial with three travel lanes in each direction. During peak hours Monday through Friday, there are three travel lanes in the peak direction of travel and two travel lanes with an adjacent curb parking lane in the off peak direction of travel. Peak travel times during the AM peak are 7 to 9 AM for northbound traffic. Peak travel times during the PM peak are 4 to 6 PM for southbound traffic. At all other times, Washington Street has two travel lanes in each direction with an adjacent curb parking lane in each direction. During the peak hours, the parking lane becomes the third lane, which is reserved for high occupancy vehicles (HOV) with two or more persons. There are dedicated turn lanes at the intersections of First, Montgomery, Madison, and Wythe, as shown in Figure 1. All other intersections in the study area lack dedicated left turn lanes. Currently, there is insufficient right-of-way to create dedicated turn lanes.

Issue

High through traffic volumes in the regular traffic lanes lead to long queues that extend several blocks during the peak hours. Through traffic in the regular traffic lanes is often forced to stop even with a green signal display because of inadequate downstream capacity, while the curb HOV lane typically operates at free flow speeds (approximately 25 MPH). There is a conflict between vehicles using the curb HOV lane at free flow speeds and vehicles travelling in the opposite direction on Washington Street and turning left across the peak hour traffic. Stopped vehicles in the regular traffic lanes effectively block the view of vehicles travelling in the HOV lane from drivers attempting to turn left. There is a safety issue at these intersections. Some drivers attempting to turn left safely cross the two regular travel lanes, but due to the limited sight distance, described above, fail to see and yield to vehicles in the HOV lane, causing unsafe vehicle interactions and in some cases angle collisions.

Alternative Modifications to Address Left Turn Issue

Staff developed five potential alternatives to address the safety issue described in the previous section. The alternatives below are explored in depth in the study:

1. Implement left turn prohibitions at all intersections without dedicated left turn lanes during HOV hours (turn restrictions would be for off peak direction of travel).
2. Use lane control signals during HOV hours to convert an existing through lane in the non-peak direction of travel into a dedicated left turn only lane. During the AM HOV hours, a southbound through lane would be converted to a dedicated left turn lane. During the PM HOV hours, a northbound through lane would be converted to a dedicated left turn lane. The lane configuration

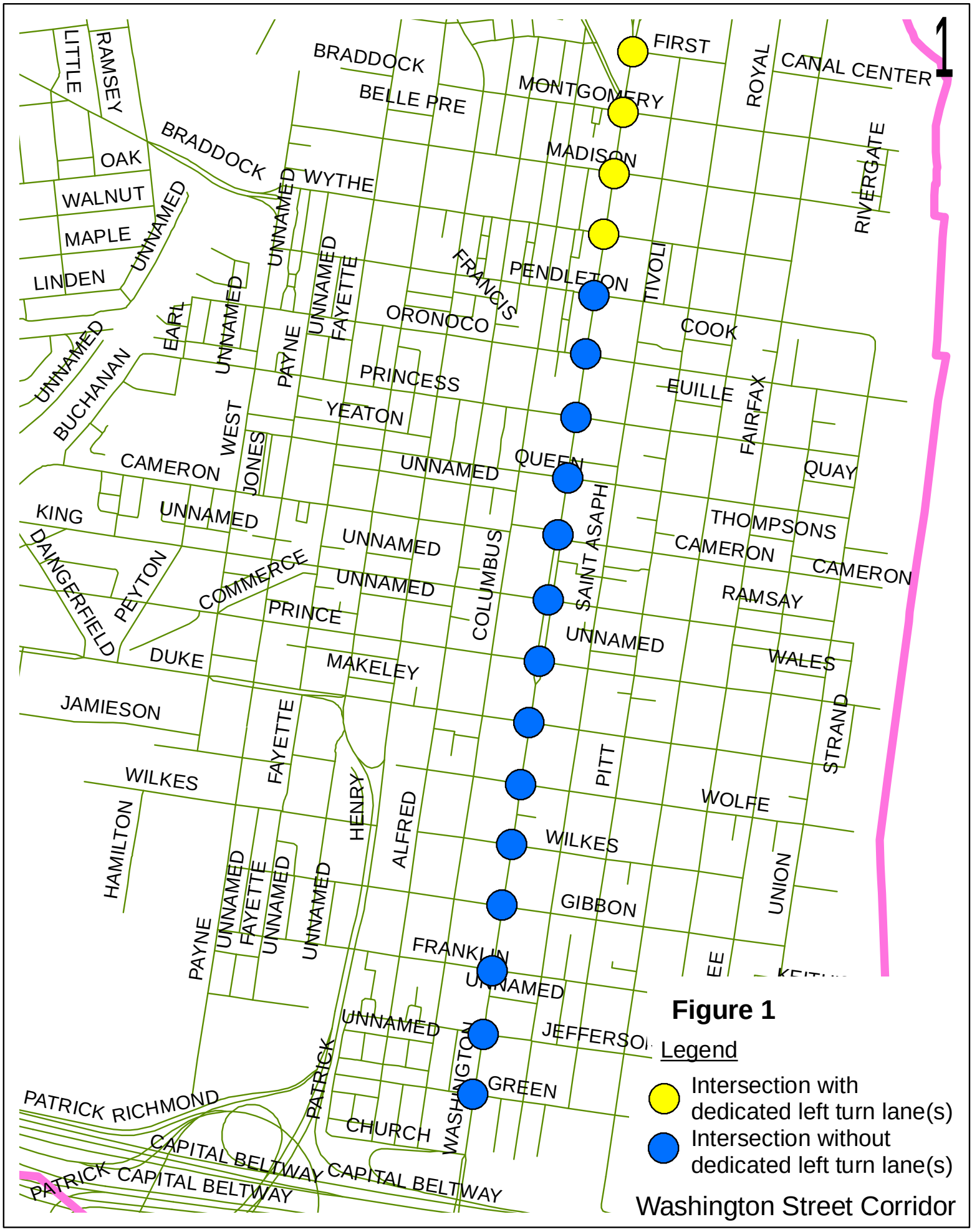
during non-HOV hours would remain unchanged from existing conditions. See Figure 6 on Page 14 for a graphic representation of this concept.
3. Leave existing lane configurations, but allow left turns on green arrow only during HOV hours for left turns from the off peak direction of travel.
4. Move HOV lane from curb lane to inside lane adjacent to median/double yellow line.
5. Remove HOV lane restrictions.

Data Collection

Crash data for a three year period from 1/1/2008 to 12/31/2010 was collected for the intersections along the Washington Street Corridor from Green Street to First Street (a total of 18 intersections). For the aggregate three year period, there were approximately 17 crashes per intersection, with 3.3 left turn failure to yield crashes per intersection during HOV hours (both AM and PM HOV hours). Approximately 20% of all crashes were left turn failure to yield during HOV hours. The left turn failure to yield crashes are balanced by direction, with 55% of crashes in the northbound direction and 45% of crashes in the southbound direction. A summary of the crash data is attached as Appendix A.

Several crashes were recorded with left turn failure to yield during HOV hours into private driveways along Washington Street. These crashes were omitted from the analysis. The presence of a dedicated left turn lane (Wythe, First) results in a lower left turn yield on green crash rate, but does not eliminate all left turn yield on green crashes during HOV hours.

Crash data from the intersection of Washington Street and Madison Street is especially important to consider, as this intersection provides insight into a crash mitigation measure that has proven highly successful during HOV hours. In October of 2007, the traffic signal at Washington Street and Madison Street was completely rebuilt. As part of this rebuild, pedestrian signals were added, and lanes were restriped on Washington Street to create an exclusive southbound left turn lane. In addition, a 4-section Flashing Yellow Arrow (FYA) left turn signal head was installed for the southbound direction. This FYA signal operates in a protected only mode during northbound HOV hours (7 AM to 9 AM Monday through Friday), which effectively prevents conflicts between left turning vehicles and the northbound curb lane HOV vehicles. At all other times, the signal operates in a permissive only mode (FYA only). Prior to striping a dedicated left turn lane and converting the signal to protected only mode during northbound HOV hours, there were approximately six southbound left turn failure to yield crashes per year during HOV hours. Subsequent to the protected only left turn phasing installation, there have been no left turn failure to yield crashes during HOV hours.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FIRST
CANAL CENTER
ROYAL
MONTGOMERY
BRADDOCK
BELLE PRE
LITTLE
RAMSEY
OAK
BRADDOCK
MADISON
WYTHE
WALNUT
MAPLE
LINDEN
UNNAMED
RIVERGATE
PENDLETON
TIVOLI
FRANCIS
ORONOCO
COOK
EARL
PAYNE
FAYETTE
PRINCESS
EUILLE
FAIRFAX
BUCHANAN
YEATON
WEST
JONES
CAMERON
QUEEN
QUAY
KING
THOMPSONS
SAINT ASAPH
DAINGERFIELD
PEYTON
COMMERCE
COLUMBUS
CAMERON
RAMSAY
PRINCE
DUKE
MAKELEY
WALES
JAMIESON
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PITT
WILKES
HENRY
ALFRED
WOLFE
HAMILTON
UNION
GIBBON
FRANKLIN
JEFFERSON
GREEN
WASHINGTON
PATRICK
CHURCH
PATRICK RICHMOND
CAPITAL BELTWAY
Legend
Intersection with dedicated left turn lane(s)
Intersection without dedicated left turn lane(s)
Washington Street Corridor

Figure 1

Crash Rate Analysis

Overview

Average crash rates over the three year study period (January 2008 to December 2010) were compiled at each study intersection along the Washington Street Corridor. In addition, several comparison intersections with similar geometric and volume characteristics were selected and analyzed. The selected comparison intersections were Duke & Paxton, Duke & Reynolds, Route 1 & Howell, Route 1 & Custis, Route 1 & Swann, and Route 1 & Hume. A detailed description of the criteria used to select the comparison intersections is included in Appendix B. As shown in Table 1, four separate crash rates for each study corridor were calculated:

- Overall Intersection Crash Rate (# of crashes per million entering vehicles)
- AM Peak Hour Left Turn Crash Rate (# of crashes per million left turning vehicles)
- PM Peak Hour Left Turn Crash Rate (# of crashes per million left turning vehicles)
- Overall Mainline Left Turn Crash Rate (# of crashes per million mainline left turning vehicles)

Table 1: Intersection Crash Rates by Corridor

Corridor	Overall Intersection Crash Rate	AM Peak Left Turn Crash Rate	PM Peak Left Turn Crash Rate	Overall Left Turn Crash Rate
Washington Street (18 intersections)	**0.425**	**19.96** (SB Lefts Only)	**40.74** (NB Lefts Only)	**7.03** (NB & SB Lefts)
Route 1 (JD Hwy) (4 Intersections)	**0.161**	**N/A** (No SB Lefts)	**0.00** (NB Lefts)	**0.54** (NB Lefts)
Duke Street (2 Intersections)	**0.412**	**0.00** (EB & WB Lefts)	**2.20** (EB & WB Lefts)	**2.75** (EB & WB Lefts)

Review of Crash Rate Data

The overall intersection crash rate includes all crashes recorded at each intersection, and is an overall corridor average for each study corridor. The overall intersection crash rates indicate that the Route 1 corridor had the lowest overall crash rate at 0.161 crashes per million entering vehicles. The overall crash rates for the Duke Street and Washington Street corridors were similar, with crash rates of 0.412 and 0.425 respectively. Complete crash data calculations for each individual intersection are included in Appendix B.

The AM peak left turn crash rate was analyzed to determine the effects of morning rush hour traffic on left turn crash rates. The AM peak was analyzed from 7-9 AM, consistent with the HOV hours on the Washington Street corridor. For the Washington Street corridor, the difficult left turn maneuver during the AM peak is the southbound left turn against the peak northbound direction traffic volumes, so the southbound left turn crash rate was calculated for the Washington Street corridor in the AM peak. The Route 1 corridor did not have any southbound left turns during the AM Peak since the intersections along Route 1 are T-intersections, so the AM peak crash rates for the Route 1 corridor are not applicable for the southbound left turns. The Duke Street corridor included both eastbound and westbound left turns in the crash rate analysis since traffic during the peak hours is less directional and more balanced than the Washington Street and Route 1 traffic volumes.

No left turn crashes were recorded along the Duke Street corridor during the AM peak. There were 25 southbound left turn crashes during the AM peak over the three year study period on the Washington Street corridor for a crash rate of 19.96 crashes per million left turning vehicles.

The PM peak left turn crash rate was analyzed to determine the effect of afternoon rush hour traffic on left turn crash rates. The PM Peak was analyzed from 4-6 PM, consistent with the HOV hours on the Washington Street corridor. For the Washington Street corridor, the difficult left turn maneuver during the PM peak is the northbound left turn against the peak southbound direction traffic volumes, so the northbound left turn crash rate was calculated for the Washington Street corridor in the PM peak. The Route 1 corridor has similar peak directionality as the Washington Street corridor; therefore the northbound left turn crash rate was also calculated for the Route 1 corridor in the PM peak. Similar to the AM peak, the Duke Street corridor PM peak left turn crash rate includes both the eastbound and westbound left turns in the analysis since traffic during the PM peak is directionally balanced along the Duke Street corridor
One left turn crash was recorded on the Duke Street corridor during the PM peak for a crash rate of 2.20 crashes per million left turning vehicles. No northbound left turn crashes were recorded along the Route 1 corridor during the study period. There were 29 northbound left turn crashes during the PM peak over the three year study period on the Washington Street corridor for a crash rate of 40.74 crashes per million left turning vehicles.

The overall left turn crash rate was analyzed for each corridor with all recorded mainline left turn crashes along each corridor during the three year study period included in the analysis. For the Washington Street corridor, there were 96 recorded mainline left turn crashes at the 18 study intersections during the three year study period for an overall crash rate of 7.03 crashes per million left turning vehicles. The Route 1 corridor recorded one mainline left turn crash at the four study intersections for an overall left turn crash rate of 0.54. The Duke Street corridor recorded 12 mainline left turn crashes at the two study intersections for an overall left turn crash rate of 2.75.

Crash Rate Analysis Findings
The overall left turn crash rate for the Duke Street corridor of 2.75 is comparable to the Duke Street PM left turn crash rate of 2.20. Overall, the number of left turn crashes on the Duke Street corridor appears to be spread evenly throughout the day.
When compared to the Duke Street corridor, the Washington Street corridor has an overall left turn crash rate of 7.03, which is 300% higher than the Duke Street crash rate of 2.20. Of particular concern is the pronounced spike in the left turn crash rate during the peak hours along the Washington Street corridor. While the overall left turn crash rate was comparable to the peak hour crash rates on the Duke Street corridor, the peak hour left turn crash rates on the Washington Street corridor are approximately three times higher during the AM peak and six times higher during the PM peak when compared to the overall left turn crash rate on the corridor. When compared to the Duke Street corridor PM peak crash rate, the peak hour crash rates on the Washington Street corridor are approximately nine times higher during the AM peak and eighteen times higher during the PM peak.

The overall left turn crash rates along the Washington Street corridor are significantly higher when compared to the Route 1 and Duke Street corridors. The left turn crash rates during the morning and afternoon peak hours are exceptionally high when compared to the Route 1 and Duke Street corridors, indicating significant safety issues in turning left along the Washington Street corridor during the peak hours.

Analysis of Alternatives

In order to address the capacity issue described in the previous section, staff developed five alternatives for evaluation. These alternatives are described in this section of the report.

Alternative 1 - Left Turn Prohibitions

This alternative would prohibit left turns in the non-peak direction of travel during HOV hours for all intersections with an above average left turn failure to yield angle crash rate. An analysis of the crash data indicates that this would result in turn restrictions along the northern portion of the corridor, from Wolfe Street to Pendleton Street (streets north of Pendleton Street have dedicated left turn lanes and can be effectively treated with protected only phasing during HOV hours). Existing turn restrictions are in place at Prince Street and King Street along the corridor. Additional turn restrictions would be installed at seven intersections: Wolfe, Duke, Cameron, Queen, Princess, Oronoco, and Pendleton. A graphical representation of the existing turn prohibitions as well as the proposed turn prohibitions during the AM and PM peak hours is shown in Figures 2 through 5. Taking a piecemeal approach (i.e., restricting turns at only one or two intersections) is not recommended, as it would be expected that the turning vehicles would just move to the adjacent intersection, where the same sight distance problems would be experienced.

Advantages

Left turn prohibitions have the advantage of being a low cost solution with a quick implementation time frame. The left turn restrictions would be installed in the non-peak direction of traffic during HOV hours (left turn prohibitions would be in place southbound from 7-9 AM and northbound from 4-6 PM).

Disadvantages

The biggest disadvantages to this potential solution are the additional maneuvers that would be required for drivers to get to their destination and increased traffic on side streets. With the left turn restrictions in place, the drivers will either have to turn at the far northern end of the corridor at locations with dedicated turn lanes (First, Madison, Powhatan, or Wythe) or at the southern end of the corridor where queuing is typically less severe and no turn restrictions are proposed (Wilkes, Jefferson, or Green) Alternately, drivers may make a right turn one block before the intersection with the turn prohibition, make a left at the next block (St. Asaph's Street for NB drivers; Columbus Street for SB drivers), make a second left onto the street that is the turn prohibition street, and then traverse straight across Washington Street. Alternately, drivers may go one block past the turn prohibition and make a series of three right hand turns, and then cross Washington Street. Approximately 280 drivers currently making left turns during the AM peak and approximately 270 drivers currently making left turns during the PM peak would be affected by the left turn prohibitions. The turn restriction will be felt by northbound drivers during the PM peak most acutely. Starting with Wolfe Street, there would be nine consecutive intersections where left turns would be prohibited. The next intersection, Wythe Street, has a dedicated northbound left turn lane. It is likely that this left turn would see a marked increase in left turn volumes if the turn prohibitions were put in place. North of Wythe Street, the only other northbound left turn is at Powhatan Street. The left turn onto Powhatan Street is not ideal as the street angles northwest away from the Old Town core. Also of concern is the effectiveness of the turn restriction signage in preventing left turns (i.e., drivers making left turns while ignoring the turn prohibition), and the associated difficulty in enforcing the left turn restrictions at such a large number of intersections. The intersection of Washington and Prince Street, which is signed with "No Turns" signage, had three crashes caused by illegal left turn movements over the three year study period. This crash history indicates that turn

restriction signage may not effectively prevent all restricted left turn movements and therefore may not fully address the crash problem. Enforcement of the turn restrictions will be a necessary and key component to ensure the alternative is effective.

Evaluation

This proposal is viable when viewed from an engineering standpoint. Driver acceptance and compliance of such sweeping restrictions will initially be low. Targeted enforcement after implementation will likely be required to achieve compliance. A review of changes in traffic patterns should be conducted after implementation to ensure acceptable levels of service have been maintained on both Columbus Street and St. Asaph Street.

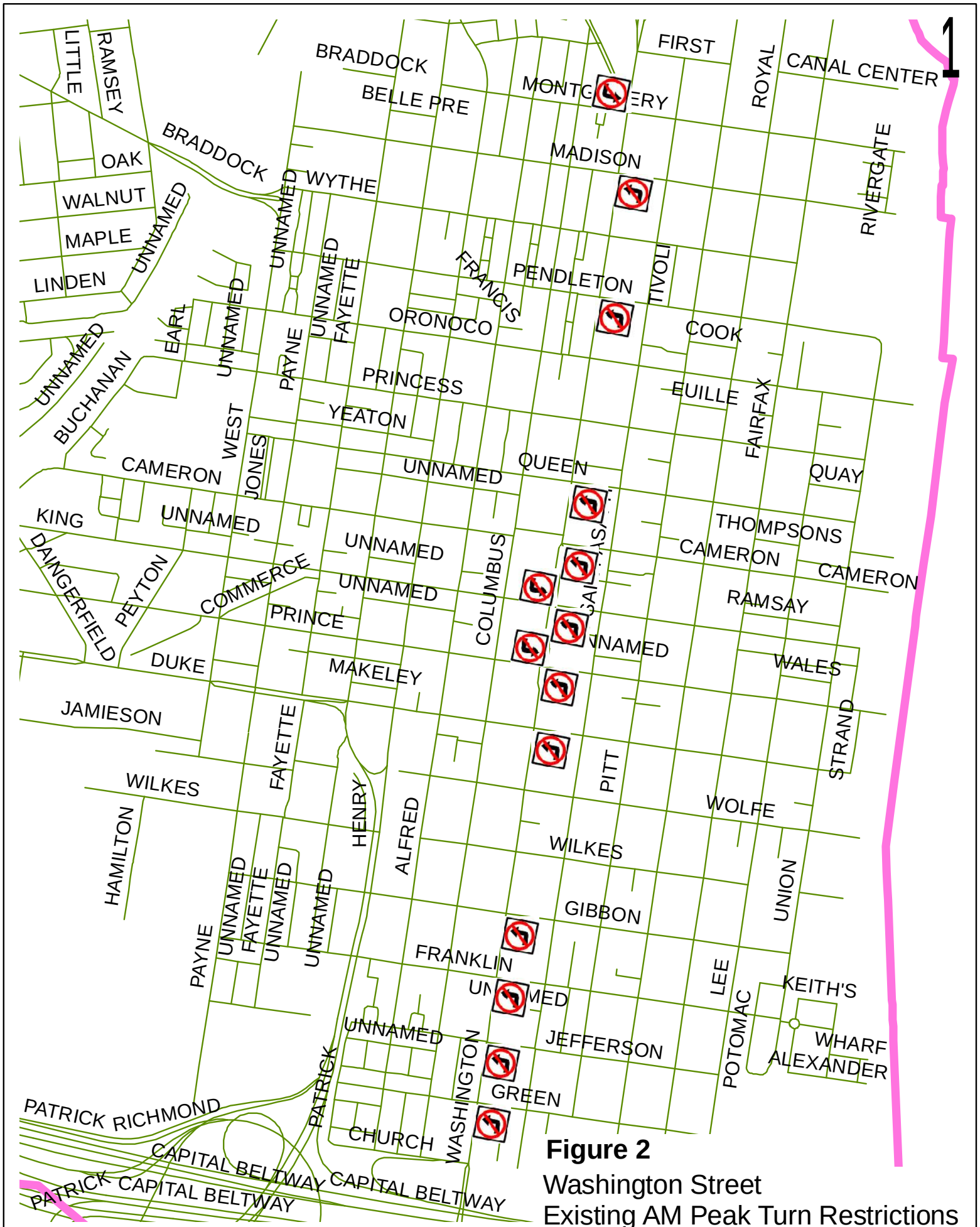


Figure 2
Washington Street
Existing AM Peak Turn Restrictions

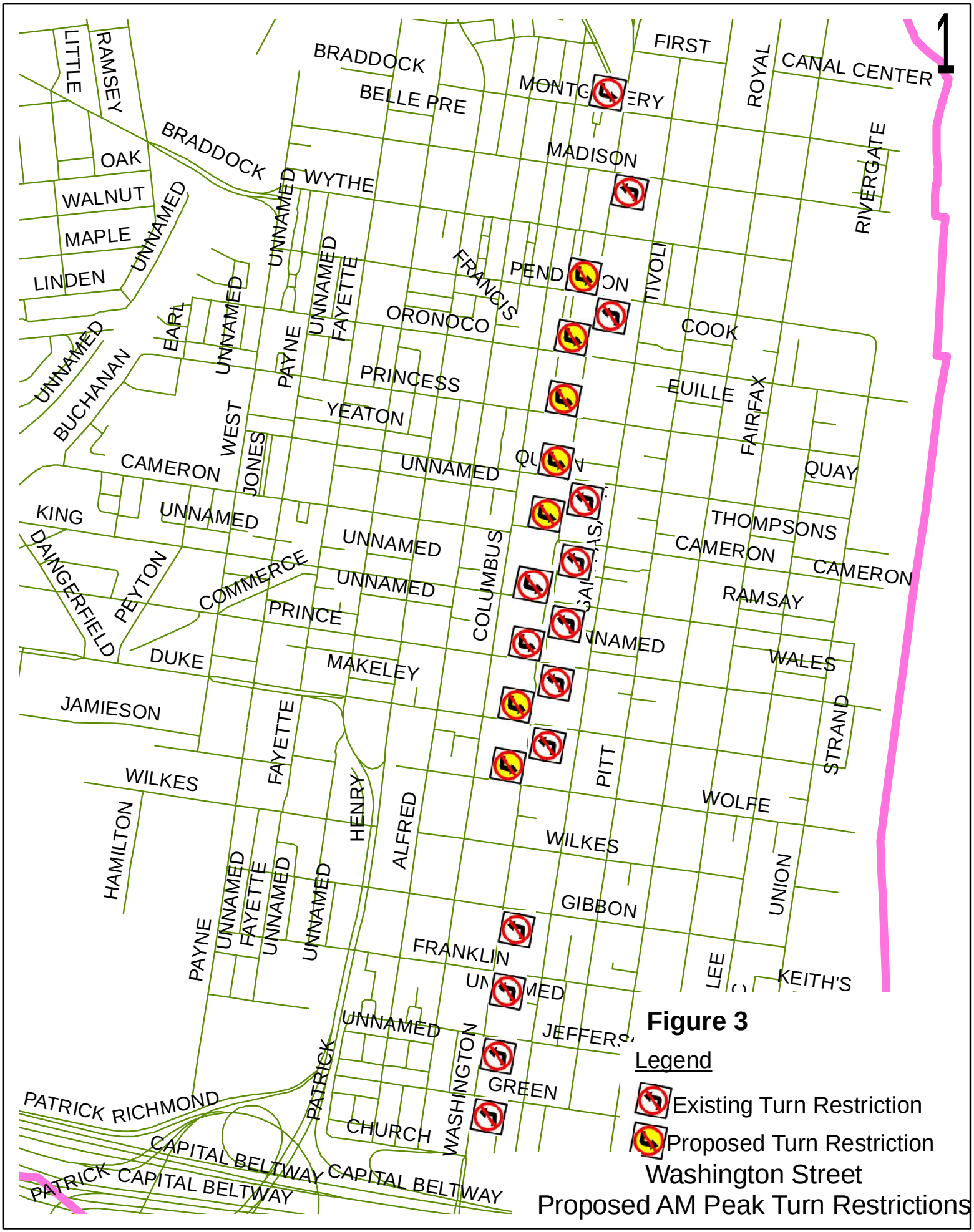


Figure 3

Washington Street
Proposed AM Peak Turn Restrictions

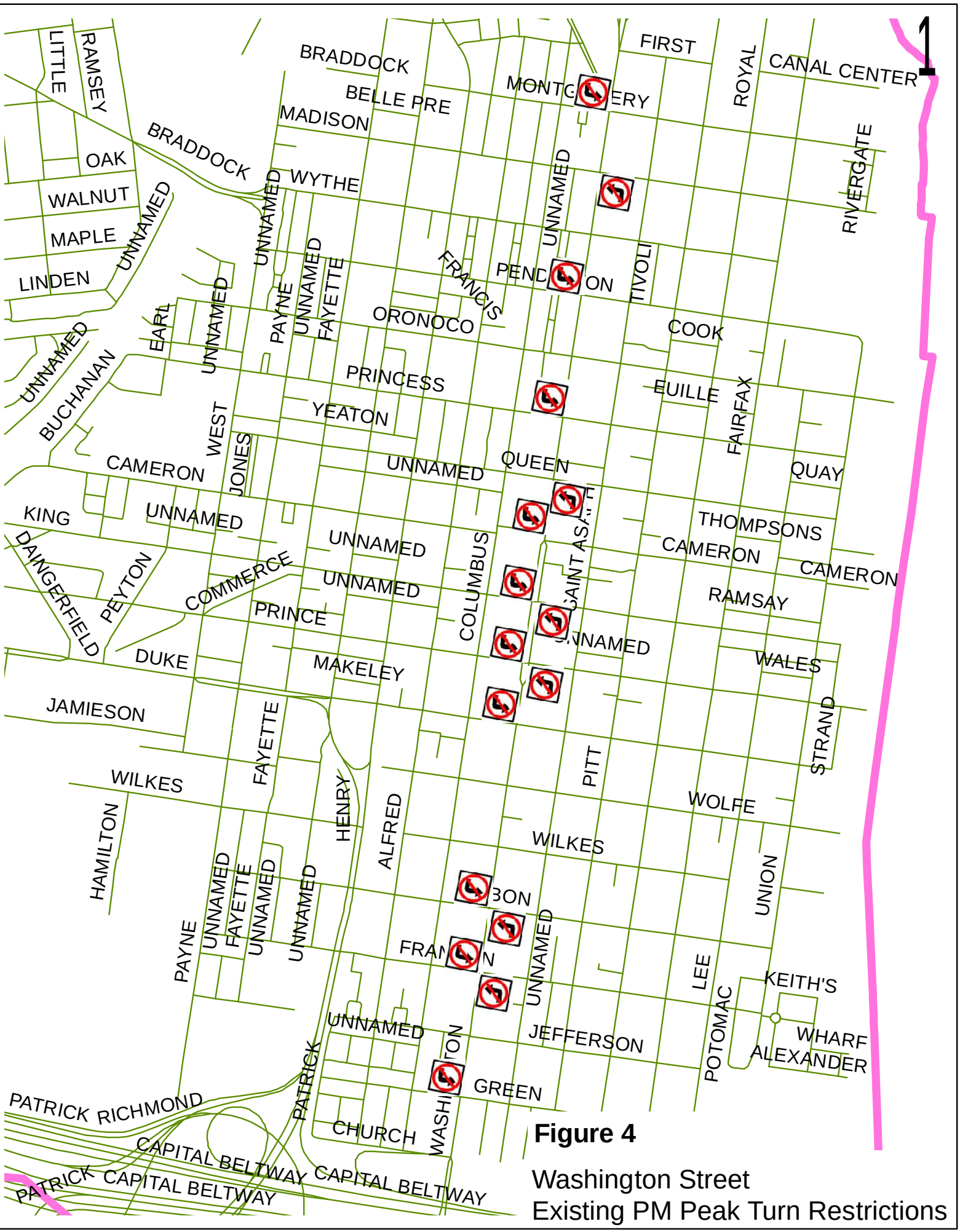
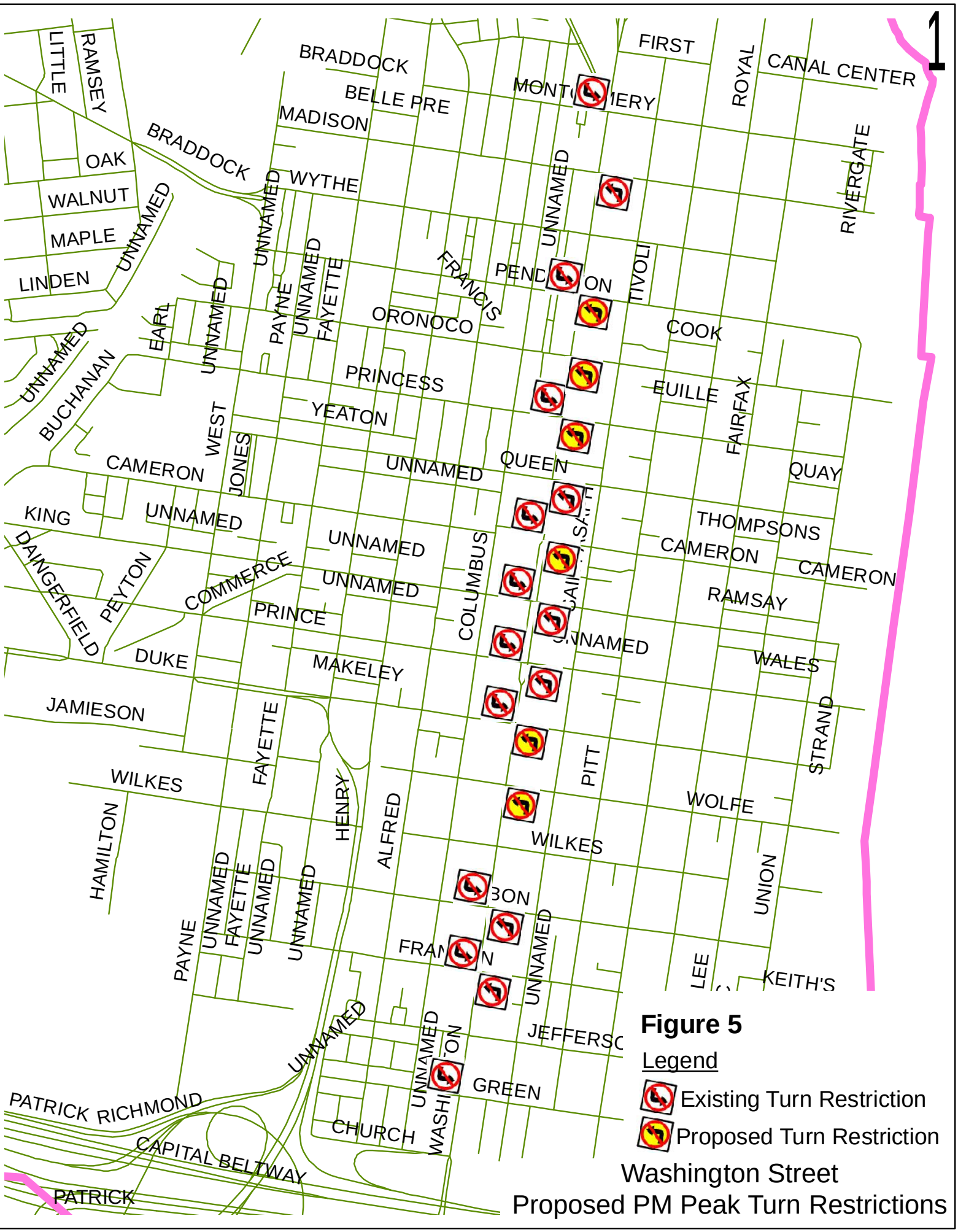


Figure 4

Washington Street
Existing PM Peak Turn Restrictions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LITTLE
RAMSEY
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MADISON
FIRST
ROYAL
CANAL CENTER
OAK
WALNUT
MAPLE
LINDEN
WYTHE
UNNAMED
RIVERGATE
FRANCIS
PENDLETON
TIVOLI
ORONOCO
COOK
EARL
PAYNE
FAYETTE
BUCHANAN
PRINCESS
EUILLE
FAIRFAX
YEATON
WEST
JONES
CAMERON
QUEEN
QUAY
KING
THOMPSONS
DAINGERFIELD
PEYTON
COMMERCE
COLUMBUS
RAMSAY
PRINCE
DUKE
MAKELEY
WALES
JAMIESON
STRAND
WILKES
HENRY
ALFRED
PITT
WOLFE
HAMILTON
UNION
FRANKLIN
LEE
KEITH'S
JEFFERSON
GREEN
PATRICK RICHMOND
CHURCH
CAPITAL BELTWAY
PATRICK
Figure 5
Legend
Existing Turn Restriction
Proposed Turn Restriction
Washington Street
Proposed PM Peak Turn Restrictions

Alternative 2 – Lane Control Signals with Shifting Double Yellow Line

A lane in the non-peak direction of travel would be removed during HOV hours and used as a dedicated left turn lane for both directions of travel.

During the AM peak, there would be a northbound HOV lane, two northbound through travel lanes, a northbound/southbound dedicated left turn lane (shared as required), a single southbound through lane, and a southbound parking lane, as shown in Figure 6.

During the PM peak, there would be a southbound HOV lane, two southbound through travel lanes, a northbound/southbound left turn lane (shared as required), a single northbound through lane, and a northbound parking lane.

This alternative would require the addition of midblock lane use control signals to designate lane use to designate the shifting use of the center lane. The proposal would also use four-section flashing yellow arrow (FYA) signal heads, with protected only movements for the left turns in the non-peak direction of travel during HOV hours.

Advantages

This alternative gives a dedicated left turn lane for both northbound and southbound traffic during HOV hours, with the ability to provide a protected only left turn movement for left turns in the non-peak direction of travel during HOV hours. The solution would be permissible under existing Manual of Uniform Traffic Control Devices (MUTCD) standards.

Disadvantages

This potential alternative is the most complex of the proposed alternatives. From a driver acceptance perspective, this solution is the most likely to cause driver error due to the use of lane control signals that vary three times a day, as well as pavement markings that would consist of three sets of double yellow lines on the roadway. Since lanes would shift during the day and vary the lane from which left turns are made, the placement of the 4-section FYA signal head would have to be placed on a lane line and not centered over a travel lane. There is a three block stretch of divided roadway between Prince Street and Cameron Street that would not fit into the proposed solution. The non-peak direction of travel will be limited to one through lane, which could potentially cause complications if there is double parking or if a bus cannot pull to the curb lane to pick up or discharge passengers. The lane use control signs and associated mast arms and support poles would be extensive (a minimum of nine sets of signs) and are not easily integrated into the historic character of Old Town.

Evaluation

While practical in theory, this proposed alternative will deviate from typical lane configurations and is likely to cause an increase in driver error. Shifting of lanes during peak periods will increase the likelihood of head on collisions if the lane use control signals are ignored during the peak periods. While the left turn yield on green problem would be solved, it is likely that the overall number of crashes would go up along the corridor due to the complexity associated with the lane configurations varying by time of day. The additional infrastructure required to implement this alternative (predominantly the lane control signs) is likely to encounter resistance. This alternative is not recommended.

Washington St

Proposed Lane Configuration During AM Peak

Shifting Double Yellow Line

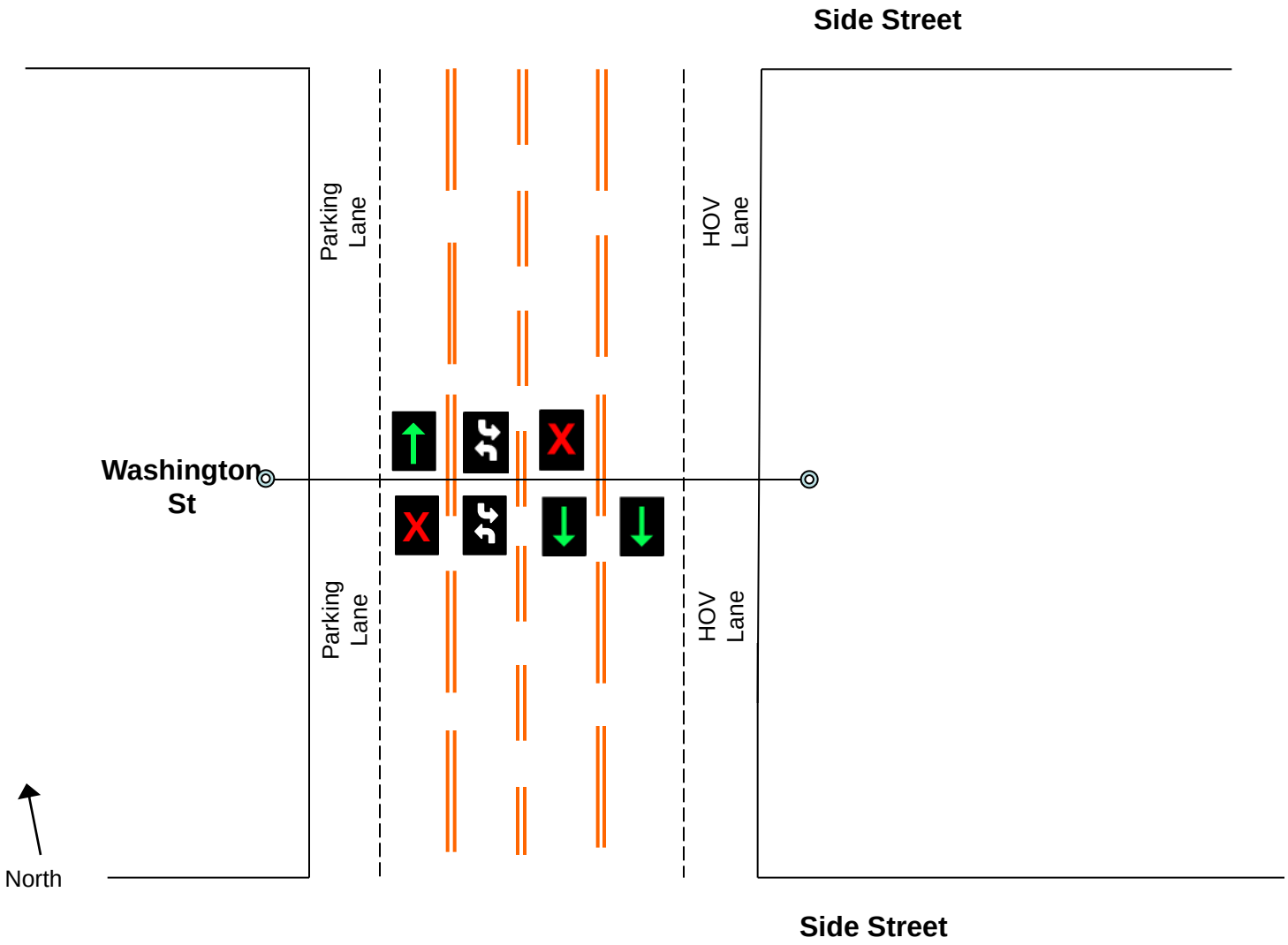


Figure 6

Alternative 3 - Allow left turns on green arrow only during HOV hours
This proposed alternative would allow left turns only on a green arrow during HOV hours for left turns in the non-peak direction of traffic (see Figures 7 & 8). This solution would have a protected lagging left turn phase at the end of the mainline signal cycle to clear vehicles desiring to turn left from the non-peak direction of traffic. Left turns in the peak direction of traffic (assuming a turn prohibition is not in place) would have a permitted only left turn movement. A four-section flashing yellow arrow (FYA) signal head would be installed on each approach immediately adjacent to the leftmost through signal head. Outside of HOV hours, the left turns would operate in a permitted only mode. The lane existing lane configuration on Washington Street would not change.

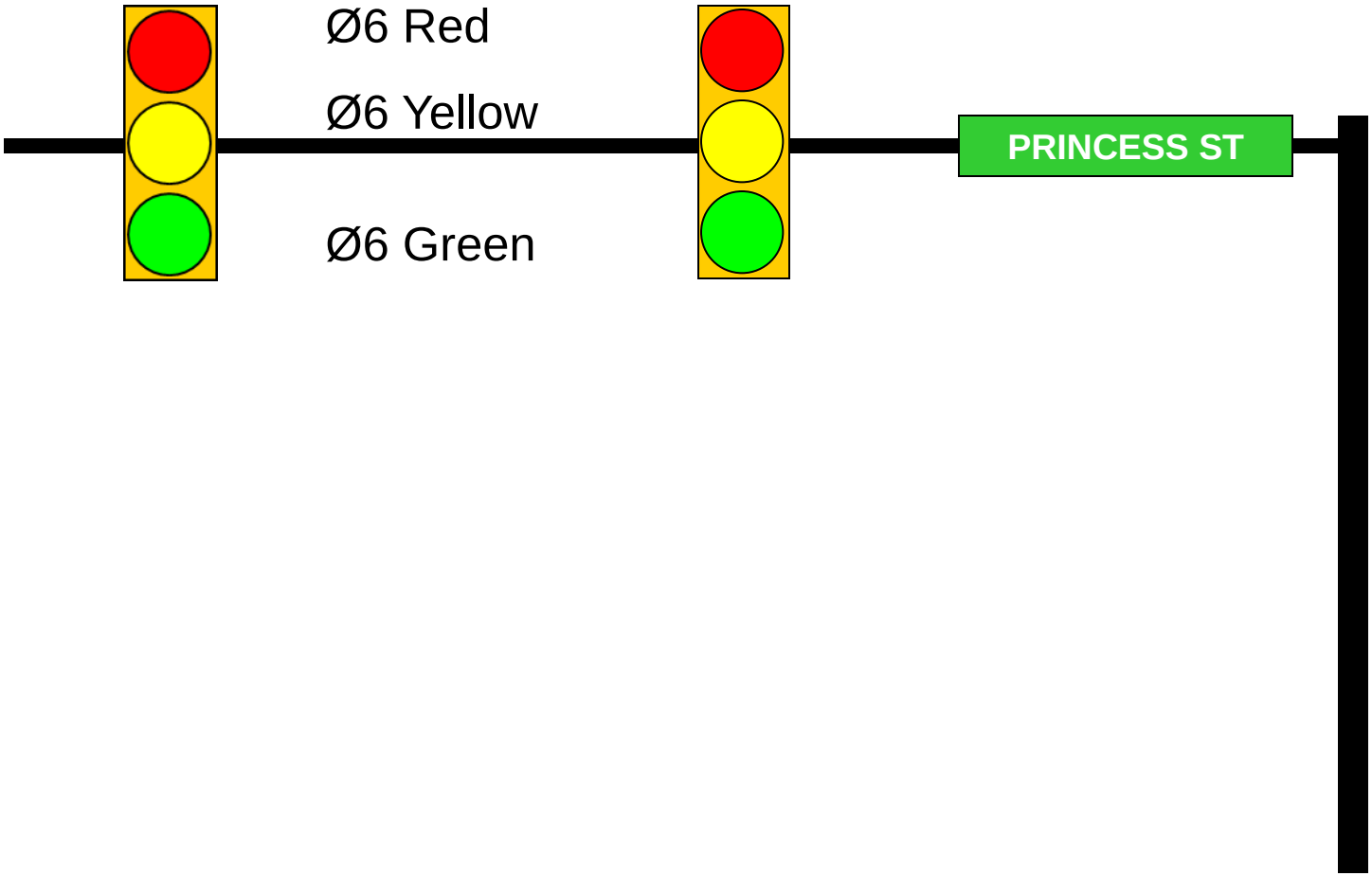
Advantages
This proposed alternative would continue to allow left turns, but during HOV hours would provide a protected movement at the end of each cycle to allow motorists to safely turn left. The FYA signal head would display a red arrow at all other times to prohibit left turns during HOV hours when the potential for queuing and limited sight distance is the greatest. This alternative would have the least overall impact to drivers travelling in the non-peak direction of travel desiring to turn left and would adequately address the safety concern with left turn failure to yield crashes during HOV hours.

Disadvantages
Having a protected only left turn movement without a dedicated left turn lane (the left turn lane would be shared with the through movement with this solution) is prohibited by the Manual of Uniform Traffic Control Devices (MUTCD) Section 4D-17, Paragraph 06.
The signal head configuration proposed is not MUTCD compliant. The signal head configuration would essentially be a 7-section signal head (see Figure 8). A waiver from the FHWA would be required to implement this proposed alternative.

This alternative converts the leftmost off-peak travel lane into a defacto turn lane during HOV hours (as soon as one car desires to turn left, the left lane in effect becomes a turn lane). There are complications with what signal indication to show on the 4 section FYA head to the peak hour direction of traffic if there is a left turn prohibition during HOV hours. A potential solution would be a dynamic left turn prohibition sign, but a dynamic sign would add weight and potentially put the mast arm pole over capacity. This alternative is costly (loops would need to be cut and new signal heads installed), and would have a long lead time due to the need to get FHWA approval and the time needed to retrofit the existing traffic signals. This solution would likely be introduced at only one or two intersections initially due to the costs and the need to get FHWA approval, which would not solve the left turn failure to yield crashes during HOV hours at several intersections with above average crash rates.

Evaluation
This alternative potentially has promise as a long term solution. The unorthodox signal head configuration would be unique and may result in some driver confusion initially. However, it is important to recognize that the issue being studied is unique to this corridor and lane configuration, and may require an unconventional solution. Implementation at one of the two highest crash locations should be considered to gauge the effectiveness of the solution. If successful, the crash issue would be addressed without inconveniencing or restricting left turning motorists.

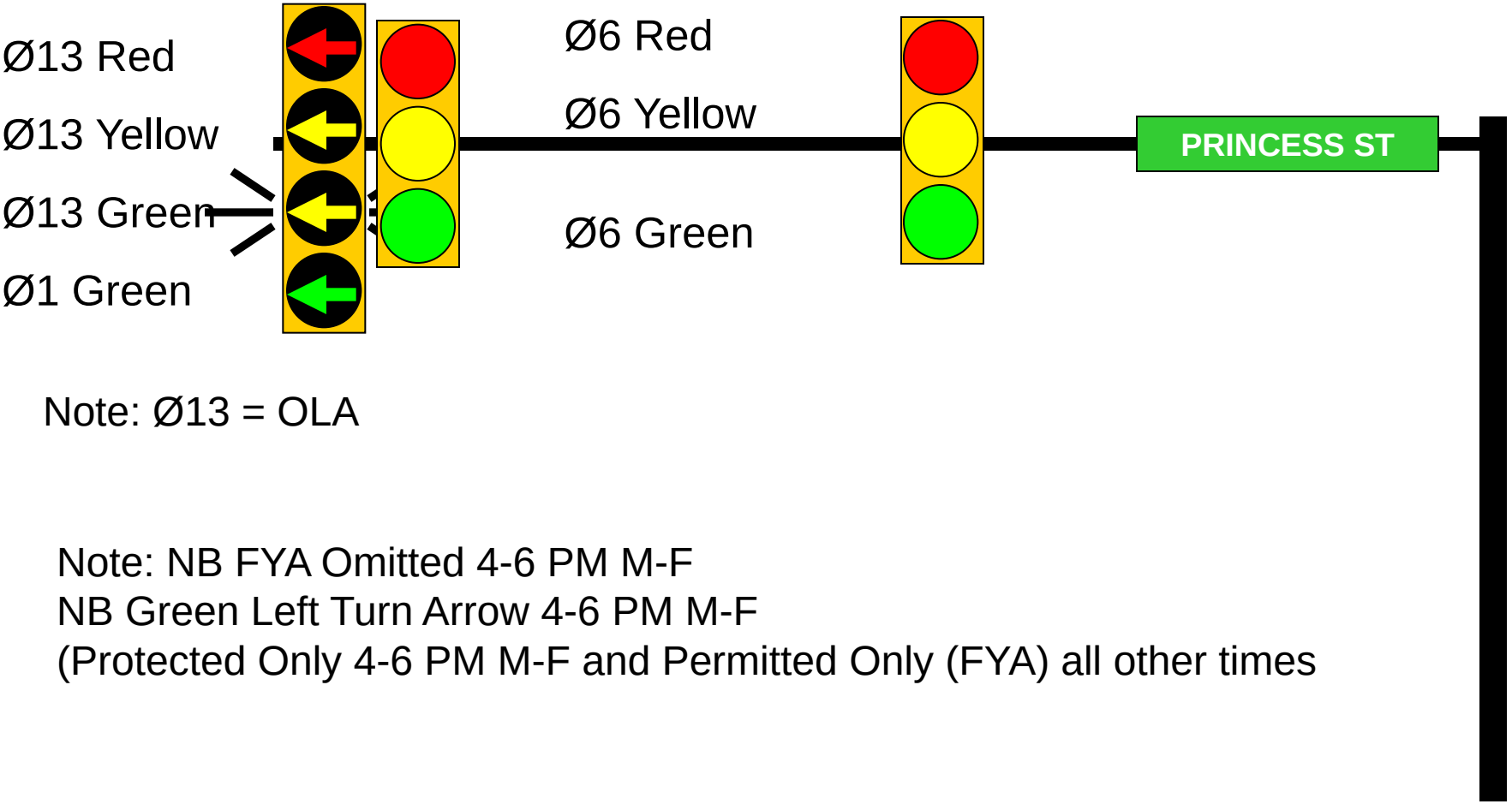
Existing Signal Head Wiring for NB Approach (To Washington, DC)



Note: Not to Scale

Figure 7

Proposed Signal Head Wiring for NB Approach (To Washington, DC)



Note: Ø13 = OLA

Note: NB FYA Omitted 4-6 PM M-F
NB Green Left Turn Arrow 4-6 PM M-F
(Protected Only 4-6 PM M-F and Permitted Only (FYA) all other times

Note: Not to Scale

Figure 8

Alternative 4 - Move HOV Lane from curb lane to inside lane adjacent to median/double yellow line

Move the HOV lane from the curb lane (outer lane) to the innermost lane adjacent to the double yellow line. During HOV hours, the innermost lane would become the HOV lane and the curb lane (which is a parking lane outside of HOV hours) would be used as a regular travel lane.

Advantages

Moving the HOV lane from the curb lane to the lane adjacent to the double yellow line would solve the sight distance problem caused by queued vehicles. Free flowing HOV vehicles would be in the center of the roadway, visible to vehicles turning left.

Disadvantages

During non-HOV hours, the curb lane is a parking lane. Frequently at the beginning of the HOV period, there are vehicles who have failed to adhere to the no parking restrictions in place during HOV hours, effectively blocking the curb lane for travel. Having a parked vehicle in conflict with a high volume general purpose traffic lane will increase the probability of sideswipe same direction crashes as a large number of vehicles have to switch lanes. There will be difficulty with the initial transition and both the south end of the corridor during the AM peak and at the north end of the corridor during the PM peak as traffic shifts from two available lanes to three available lanes. Currently, the pavement markings direct traffic to the two inner lanes when travelling northbound. Because the curb lane is used for parking during non HOV hours, it is not possible to shift the pavement markings to initially direct traffic into the two outer lanes. There are similar issues in the southbound direction on how the shift of the general purpose travel lanes over to the outer lanes would be accomplished during HOV hours. During the northbound HOV lane termination at the northern end of the corridor, there may be issues with balanced lane utilization at the intersection of George Washington Parkway and Abingdon Road. Balanced lane utilization is critical at this intersection during the AM peak to maximize throughput of traffic and to minimize queuing into Old Town. At intersections where left turns are permitted, the left turning vehicles would potentially block through HOV traffic until a gap allowed the left turn to occur, increasing HOV lane travel times. Buses would also be affected by this solution. Buses will now be in a regular travel lane as opposed to the HOV lane, thereby increasing travel time for the buses and further congesting the general travel lanes. Bus timetables and schedules would likely have to be revisited under this scenario.

Evaluation

The lack of a viable way to shift the general purpose lanes to the two outer lanes when the roadway cross section expands to three lanes is a critical flaw in this alternative. The effects on buses would also be pronounced. This alternative is not recommended.

Alternative 5 - Eliminate the HOV Lanes on Washington Street
Eliminate the HOV Lanes on Washington Street which currently operate in the northbound direction between 7 AM and 9 AM and in the southbound direction between 4 PM and 6 PM.

Advantages
Eliminating the HOV lanes on Washington Street would help improve the safety of the left turning maneuvers. The unsafe conditions are created by the conflicts between left turning vehicles from the off-peak direction on Washington Street and fast moving vehicles traveling on the HOV lanes. The vehicles on the HOV lane are often moving when vehicles on the adjacent vehicles are stopped due to congested conditions downstream. The speed differential between vehicles on the general purpose lanes and the HOV lane creates unsafe conditions for the left turning maneuvers. The elimination of the HOV lanes would eliminate the speed differential.

Disadvantages
The elimination of the HOV lanes would result in increased usage of single occupancy vehicles. This will result in deterioration of traffic conditions not only within the Washington Street corridor but throughout the City and the region. HOV lanes help with the formation of carpools and vanpools. HOV lanes also help transit vehicles provide faster and more reliable service. The elimination of the HOV lanes will be a disincentive to form carpools or vanpools, or to utilize transit services.

Evaluation
Because the elimination of the HOV lanes would result in increased usage of single occupancy vehicles and deterioration in traffic conditions, this alternative is not recommended.

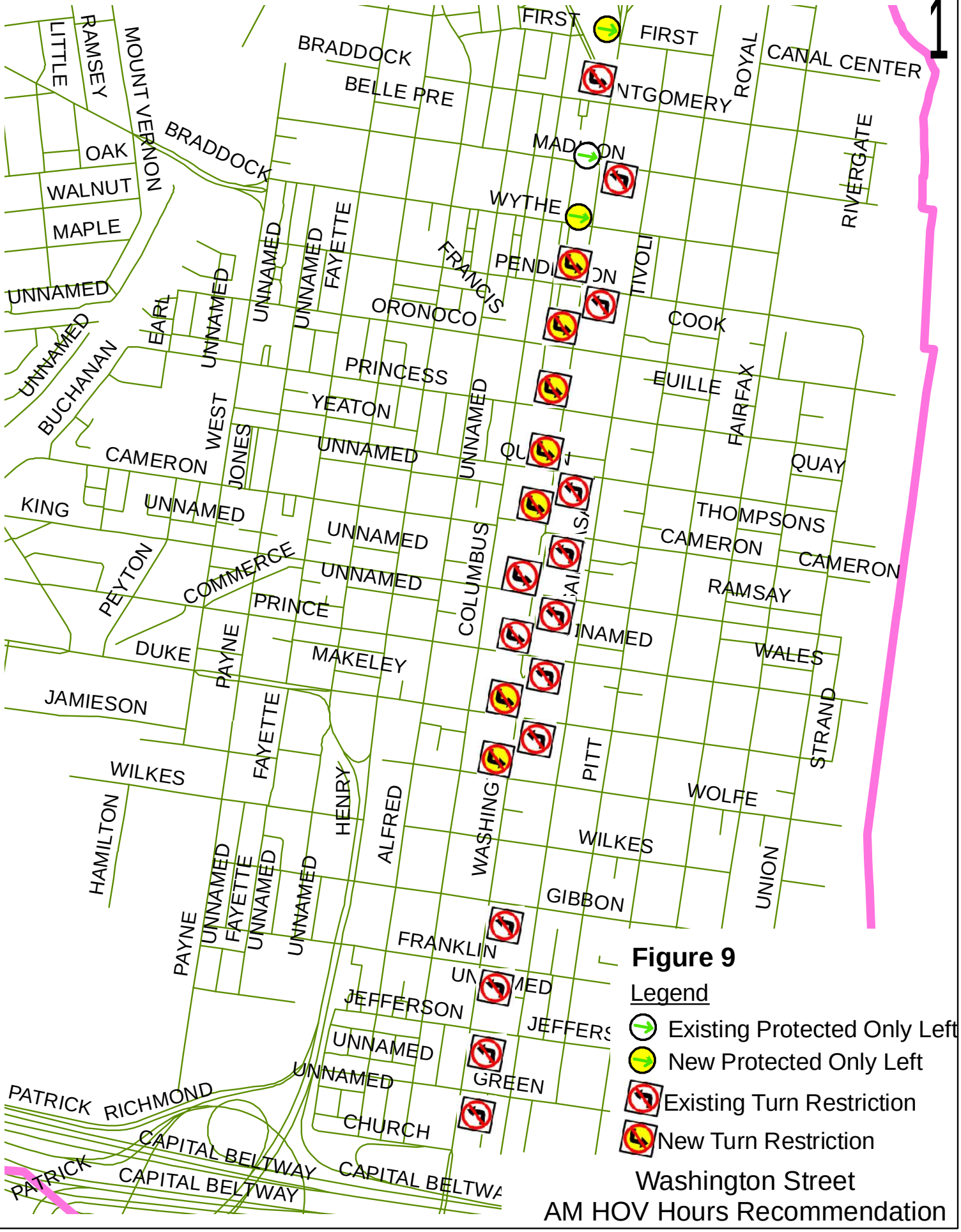
Recommendations

The two solutions with the most merit are the left turn restrictions during HOV hours and the left turn on green arrow only during HOV hours. The left turn restriction is the more restrictive option, and will initially require targeted police enforcement to prove effective. However, initial installation costs are low, and the turn restrictions could be implemented quickly. The less restrictive option, adding signal heads on Washington Street to allow a lagging protected only left turn, maintains mobility but would be costly, would require a long lead time for FHWA approval and signal modification, and would initially be restricted to one or two intersections to demonstrate the effectiveness of the lagging left before committing to installation at all seven intersections with high crash rates. Assuming driver acceptance, either solution should ultimately prove effective in eliminating the left turn failure to yield crashes experienced along the Washington Street corridor during HOV hours.

The left turn restrictions during HOV hours is the recommended alternative due to its quick implementation time frame and overall lower cost. If the turn restriction is implemented but does not prove to be a viable long term solution, the protected left turn phase should be considered as a secondary option.

In addition, it is recommended that the left turn signal at Washington and First be modified to a four-section FYA head (from the current doghouse five-section protected/permitted configuration), with protected only movements from 7 to 9 AM Monday through Friday and protected/permitted movements at all other times. This change has the potential to eliminate several left turn failure to yield crashes per year during HOV hours. It is also recommended that both the northbound and southbound left turns at Washington and Wythe be modified from permissive only to a 4-section FYA left turn signal head, with a protected only mode from 7-9 AM Monday through Friday for southbound left turns, with a permissive (FYA) mode at all other times, and a protected only mode from 4-6 PM Monday through Friday for northbound left turns, with a permissive (FYA) mode at all other times. This change has the potential to eliminate several left turn failure to yield crashes per year during HOV hours.

Figures 9 & 10 show the implementation recommendations during the AM and PM HOV hours, respectively.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OAK
BRADDOCK
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PENDLETON
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FAIRFAX
YEATON
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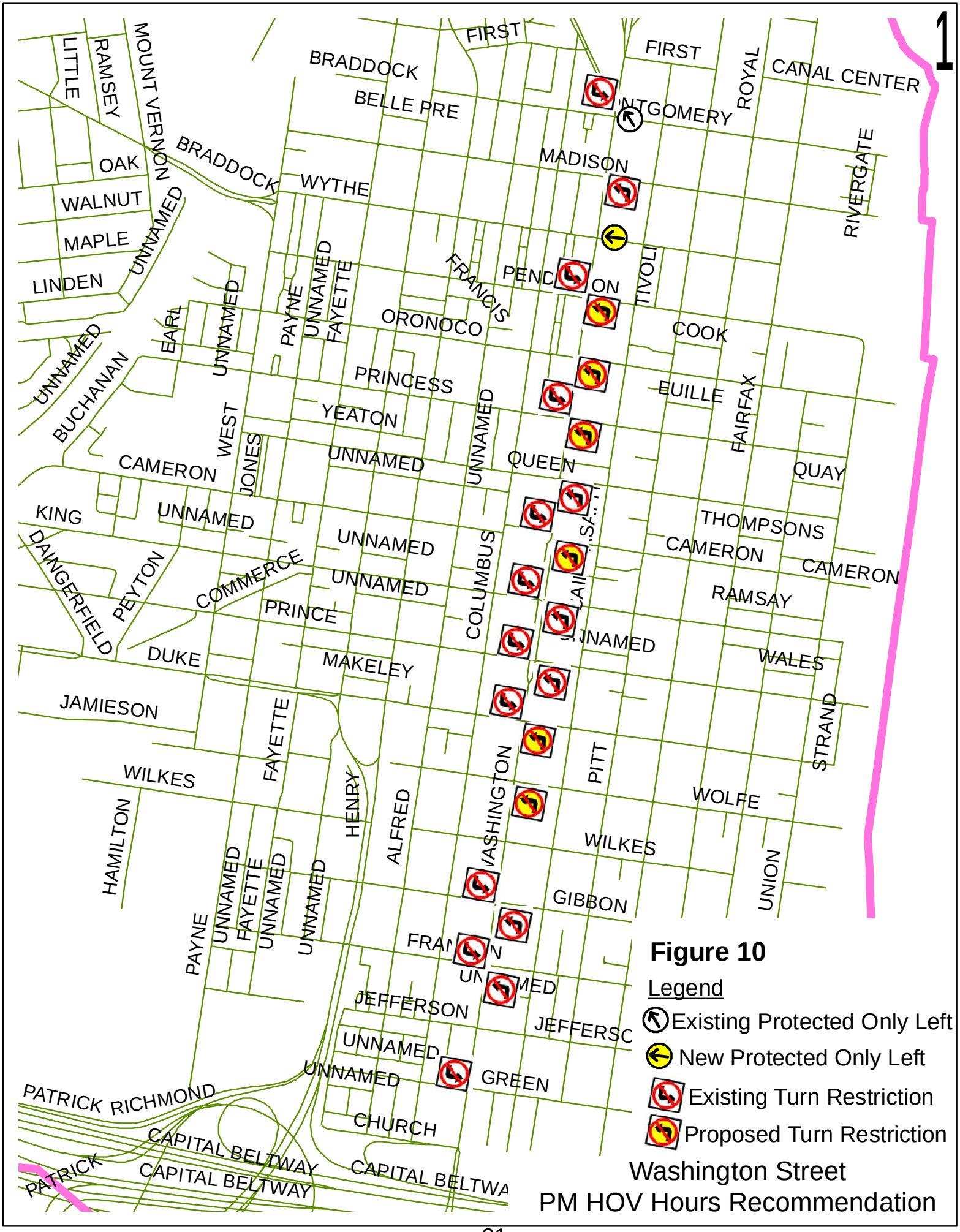
CAPITAL BELTWAY
CAPITAL BELTWAY
CAPITAL BELTWAY
PATRICK
Figure 9
Legend
Existing Protected Only Left
New Protected Only Left
Existing Turn Restriction
New Turn Restriction
Washington Street
AM HOV Hours Recommendation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CAPITAL BELTWAY
CAPITAL BELTWAY
CAPITAL BELTWAY
PATRICK
Figure 10
Legend
Existing Protected Only Left
New Protected Only Left
Existing Turn Restriction
Proposed Turn Restriction
Washington Street
PM HOV Hours Recommendation

Appendix A

Washington Street Corridor Crash Data

2008 – 2010

Appendix A	**Crash Data 2008 -2010**			2008 Crashes			2009 Crashes		
Intersection	Turn Restrictions	Dedicated Turn Lanes	Left Turn Protected?	Total	Left Turn Fail to Yield	Left Turn during HOV	Total	Left Turn Fail to Yield	Left Turn during HOV
Green	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	2	1	0	2	0	0
Jefferson	NB No Left 7-9 AM M-F	None	No	2	0	0	1	1	0
Franklin	NB No Left SB No Left 4-6 PM M-F	None	No	4	0	0	5	1	1
Gibbon	NB No Left 7-9 AM 4-6 PM SB No Left 4:30-6 PM M-F	None	No	4	1	0	9	0	0
Wilkes	None	None	No	6	1	0	5	0	0
Wolfe	None	None	No	9	1	1	4	3	2
Duke	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	14	4	1	10	4	1
Prince	NB No Left SB No Left	None	N/A	3	0	0	9	3	0
King	NB No Left SB No Left	None	N/A	5	0	0	2	0	0
Cameron	NB No Left 7-8:30 AM M-F SB No Left 4-6 PM M-F	None	No	5	3	2	10	6	2
Queen	NB No Left	None	No	3	0	0	6	1	1
Princess	SB No Left 4-6 PM M-F	None	No	5	3	3	14	12	7
Oronoco	None	None	No	6	2	1	9	4	3
Pendleton	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	8	3	2	9	3	1
Wythe	None	NB and SB	No	9	5	3	8	3	3
Madison	NB No Left	SB	7-9 AM M-F Only	5	0	0	3	0	0
Montgomery	NB No Left onto Montgmry SB No Left Turn	NB	Yes	4	0	0	5	0	0
First	None	SB	Prot/Perm 24/7	3	2	1	4	3	2
TOTALS				97	26	14	115	44	23

Appendix A	2010 Crashes			Total Crashes				
Intersection	Total	Left Turn Fail to Yield	Left Turn during HOV	Total	Left Turn Fail to Yield	Left Turn during HOV	% of All Crashes Left Turn Fail to Yield	% of All Crashes Left Turn during HOV Hours
Green	1	1	1	5	2	1	40%	20%
Jefferson	6	0	0	9	1	0	11%	0%
Franklin	4	1	0	13	2	1	15%	8%
Gibbon	5	0	0	18	1	0	6%	0%
Wilkes	4	1	1	15	2	1	13%	7%
Wolfe	4	2	2	17	6	5	35%	29%
Duke	7	0	0	31	8	2	26%	6%
Prince	5	0	0	17	3	0	18%	0%
King	3	0	0	10	0	0	0%	0%
Cameron	0	0	0	15	9	4	60%	27%
Queen	3	0	0	12	1	1	8%	8%
Princess	15	12	6	34	27	16	79%	47%
Oronoco	4	4	3	19	10	7	53%	37%
Pendleton	7	3	2	24	9	4	38%	17%
Wythe	9	5	4	26	13	10	50%	38%
Madison	2	0	0	10	0	0	0%	0%
Montgomery	5	0	0	14	0	0	0%	0%
First	5	3	3	12	8	6	67%	50%
TOTALS	89	32	22	301	102	59	34%	20%
3 Year Avg. (All Intersections)				100	34	20	Highlights: >15% over avg. or >5 left turn	
Per Intersection (3 Year Aggregate)				16.7	5.7	3.3	crashes over avg. or >3 HOV crashes over avg.	

Appendix A	Total Crashes			
Intersection	NB Left Turn Fail to Yield	SB Left Turn Fail to Yield	NB Left Turn HOV	SB Left Turn HOV
Green	2	0	1	0
Jefferson	0	1	0	0
Franklin	0	2	0	1
Gibbon	1	0	0	0
Wilkes	1	1	0	1
Wolfe	3	3	2	3
Duke	3	5	1	1
Prince	0	3	0	0
King	0	0	0	0
Cameron	6	3	3	1
Queen	0	1	0	1
Princess	24	3	13	3
Oronoco	2	8	1	6
Pendleton	3	6	2	3
Wythe	11	2	8	2
Madison	0	0	0	0
Montgomery	0	0	0	0
First	0	8	0	6
TOTALS	56	46	31	28
	55%	45%	53%	47%

Appendix B

Crash Rates and Crash Rate Methodology for:

Washington Street Corridor
Route 1 Corridor (Four comparison intersections)
Duke Street Corridor (Two comparison intersections)

2008 – 2010

Appendix B – Crash Rates 2008-2010

Assumptions:

1. Traffic data from the AM and PM peak hours was used to develop estimated 24 hour intersection traffic volumes. The AM and PM peak entering intersection traffic volumes were added together, and a K factor of 0.16 was assumed to convert the peak hour volumes to 24 hour traffic volumes.

Methodology for selecting comparison intersection locations

Based on the conditions for left turning vehicles on Washington Street, the following criteria were used to develop a list of comparison intersections within the city to provide a crash data comparison to the Washington Street Corridor overall and left turn crash rates.

1. Intersection was required to be signalized.
2. Relatively low mainline left turning volumes (preference given to locations with less than 100 left turning vph)
3. High opposing mainline traffic volumes, especially during peak hours, with a minimum of 2 lanes of opposing traffic
4. Permissive Only (preferred) or Protected/Permitted left turn signal operation (Intersections with Protected Only left turn movements were eliminated from consideration)
4. Intersections with a Shared through/left turn lane were given preference, but intersections with dedicated left turn lanes were also considered.

Based on the above criteria, the following intersections were selected for comparison purposes:
1. Route 1 & Howell - Signalized, low mainline left turn volumes, high opposing mainline traffic volumes with two lanes of opposing traffic, protected/permitted mainline left turn signal phasing, dedicated northbound left turn lane.
2. Route 1 & Custis – Signalized, low mainline left turn volumes, high opposing mainline traffic volumes with two lanes of opposing traffic, permissive only left turn signal phasing, shared through/left turn lane
3. Route 1 & Swann - Signalized, low mainline left turn volumes, high opposing mainline traffic volumes with two lanes of opposing traffic, permissive only left turn signal phasing, shared through/left turn lane
4. Route 1 & Hume - Signalized, low mainline left turn volumes, high opposing mainline traffic volumes, permissive only left turn signal phasing, shared through/left turn lane
5. Duke Street & Paxton Street – Signalized, low to moderate mainline left turn volumes, high opposing mainline traffic volumes with three lanes of opposing traffic, protected/permitted mainline left turn signal phasing, dedicated eastbound and westbound left turn lanes.
6. Duke Street & Reynolds Street - Signalized, low to moderate mainline left turn volumes, high opposing mainline traffic volumes with three lanes of opposing traffic, protected/permitted mainline left turn signal phasing, dedicated eastbound and westbound left turn lanes.

Appendix B Crash Rates 2008 - 2010

Intersection	Turn Restrictions	Dedicated Turn Lanes	Left Turn Protected?	Total Crashes: Total	Total Crashes: Left Turn Fail to Yield	Total Crashes: Left Turn during HOV	SB Left Turn AM Peak	NB Left Turn PM Peak	Est. 24 Hour Entering Volume	Intersection Crash Rate	Crash Rate for AM Peak SB Left	Crash Rate for PM Peak NB	Overall Left Turn Crash Rate
Green	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	5	2	1	1	26	36056	0.127	0.00	17.56	7.69
Jefferson	NB No Left 7-9 AM M-F	None	No	9	1	0	10	11	31981	0.257	0.00	0.00	4.17
Franklin	NB No Left SB No Left 4-6 PM M-F	None	No	13	2	1	14	One Way	33356	0.356	32.62	N/A	13.92
Gibbon	NB No Left 7-9 AM 4-6 PM SB No Left 4:30-6 PM M-F	None	No	18	1	0	0	12	35738	0.460	No Left Turns Recorded	0.00	5.04
Wilkes	None	None	No	15	2	1	4	30	31881	0.430	114.16	0.00	1.35
Wolfe	None	None	No	17	6	5	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Duke	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	31	8	2	8	26	35981	0.787	57.08	17.56	28.51
Prince	NB No Left SB No Left	None	N/A	17	3	0	0	One Way	34313	0.452	No Left Turns Recorded	N/A	438.36
King	NB No Left SB No Left	None	N/A	10	0	0	0	0	35738	0.256	No Left Turns Recorded	No Left Turns Recorded	0.00
Cameron	NB No Left 7-8:30 AM M-F SB No Left 4-6 PM M-F	None	No	15	9	4	9	46	35113	0.390	50.74	29.78	23.48
Queen	NB No Left	None	No	12	1	1	61	One Way	33869	0.324	7.49	N/A	1.37
Princess	SB No Left 4-6 PM M-F	None	No	34	27	16	3	35	33550	0.925	456.62	169.60	34.31
Oronoco	None	None	No	19	10	7	10	17	34581	0.502	273.97	26.86	20.87
Pendleton	NB No Left 7-9 AM M-F SB No Left 4-6 PM M-F	None	No	24	9	4	21	15	37431	0.586	65.23	60.88	29.89
Wythe	None	NB and SB	No	26	13	10	68	29	40219	0.590	13.43	125.96	9.36
Madison	NB No Left	SB	7-9 AM M-F Only	10	0	0	22	One Way	40838	0.224	0.00	N/A	0.00
Montgomery	NB No Left onto Montgmry SB No Left Turn	NB	Yes	14	0	0	One Way	78	38781	0.330	N/A	0.00	0.00
First	None	SB	Prot/Perm 24/7	12	8	6	341	No Street	41456	0.264	8.03	N/A	1.42
TOTALS				301	102	59	572	325	610881	**0.425**	**19.96**	**40.74**	**7.03**
				100.33	34	20							
				16.7	5.7	3.3							

Appendix B Crash Rates 2008 - 2010

Comparison Intersections	Turn Restrictions	Dedicated Turn Lanes	Left Turn Protected?	Total Crashes: Total	Total Crashes: Left Turn Fail to Yield	Total Crashes: Left Turn during HOV		PM Peak Hour NB Left Turn	Est. 24 Hour Entering Volume	Intersection Crash Rate	Crash Rate for AM Peak SB Left Turns	Crash Rate for PM Peak NB Left Turns	Overall Left Turn Crash Rate
Rte 1													
Howell	None	NB and SB	Prot/Perm	7	1	N/A		77	42881	0.149	No SB Lefts	0.00	0.95
Custis	None	None	Perm	9	0	N/A		19	42744	0.192	No SB Lefts	0.00	0.00
Swann	None	None	Perm	8	0	N/A		10	41850	0.175	No SB Lefts	0.00	0.00
Hume	None	None	Perm	6	0	N/A		29	42263	0.130	No SB Lefts	0.00	0.00
Rte 1 Totals				30	1	N/A		135	169738	**0.161**		**0.00**	**0.54**

							AM Peak EB & WB Left Turn	PM Peak EB & WB Left Turn		Intersection Crash Rate	Crash Rate for AM EB & WB Left Turns	Crash Rate for PM EB & WB Left Turns	Overall Left Turn Crash Rate
Duke													
Paxton	None	EB and WB	Prot/Perm	15	5	N/A	130	155	32506	0.421	0.000	2.95	2.56
Reynolds	None	EB and WB	Prot/Perm	17	7	N/A	92	261	38444	0.404	0.000	1.75	2.90
Duke Totals				45	12	N/A	222	416	70950	**0.412**	**0.000**	**2.20**	**2.75**

NOTES:
Intersection Crash Rate = Crashes per million entering vehicles
AM Peak Left Turn Crash Rate = Crashes per million AM Peak Hour left turning vehicles in specified direction
PM Peak Left Turn Crash Rate = Crashes per million AM Peak Hour left turning vehicles in specified direction
Overall Left Turn Crash Rate = Crashes per million mainline left turning vehicles