District Department of Transportation

Bicycle Facility Evaluation






District Department of Transportation

Washington, District of Columbia
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Bicycle Facility Evaluation
Washington, DC

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District Department of Transportation

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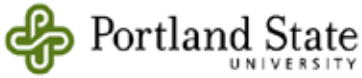

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INTRODUCTION AND BACKGROUND

In recent years, Washington, D.C. has emerged as one of the foremost cities for bicycling in the United States. Bicycling in the District has grown considerably as the District Department of Transportation (DDOT) has actively pursued construction of bicycle facilities on its roadways. One reason for this success is DDOT's willingness to try new and innovative bicycle treatments, particularly in high-visibility locations with engineering challenges.

Innovative bicycle facilities were installed at three locations in Northwest D.C. and were designed to provide increased safety, comfort, and convenience for cyclists. Facilities include dedicated road space, signal control, and signs and pavement markings. The treatments at the three locations (Figure 1) consist of:

- **New Hampshire Avenue NW/U Street NW/16th Street NW intersection treatments**: bicycle boxes, bicycle signals, and contra-flow bicycle lanes were installed at this six-leg intersection to facilitate cyclist travel on New Hampshire Avenue.
- **Pennsylvania Avenue NW center median bicycle lanes (3rd Street to 15th Street):** buffered bicycle lanes were installed in the center median of Pennsylvania Avenue, with flexible bollards placed near intersections.
- **15th Street NW two-way cycle track (E Street to V Street):** a two-way cycle track was installed between the sidewalk and parked vehicles on 15th Street.

After these treatments were installed, DDOT sought to understand how well they work for cyclists, motorists, and pedestrians in terms of safety, level of service (LOS), behavior, and attitude. This report provides a comprehensive multimodal evaluation of these facilities for the purposes of (1) identifying recommended modifications to the constructed installations, and (2) providing guidance for the design and operation of future bicycle facilities within the District.

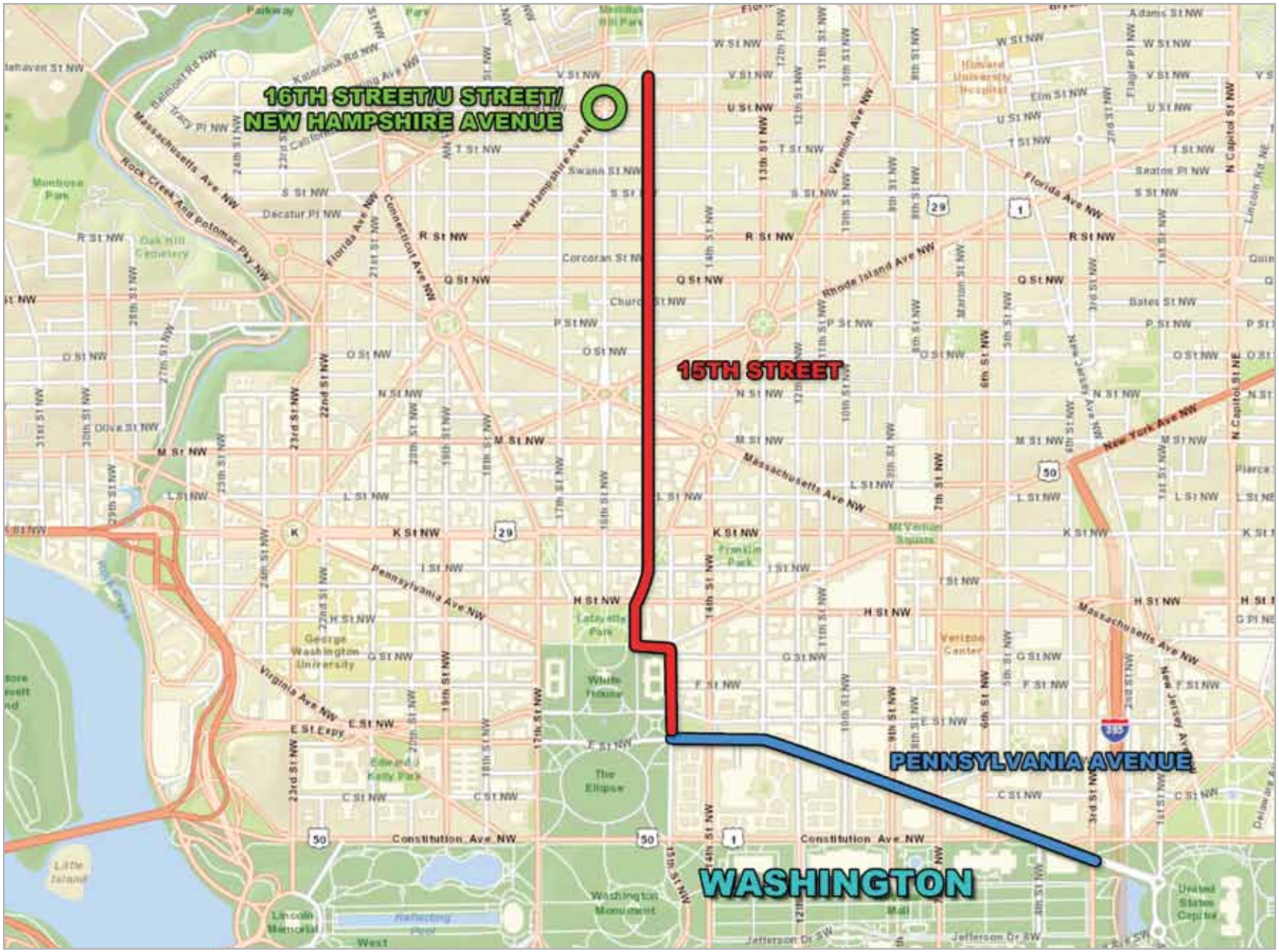
In general, the following areas were evaluated for conditions before and after the installation of the bicycle facilities:

- **Facility Use:** analysis of bicyclist and motor vehicle volumes.
- **Efficient Operations:** analysis of the level of service experienced by bicyclists, pedestrians, and drivers.
- **Convenience:** analysis of the corridor travel times experienced by bicycles and motor vehicles.
- **Comfort:** analysis of user intercept and surrounding neighborhood surveys concerning attitudes towards the new facilities.
- **Safety:** analysis of bicyclist, pedestrian, and driver compliance with traffic laws; interactions between modes; and crash history before and after facility installation.

The analysis employed a wide range of methods to understand the impact of these facilities on cyclists, motorists, and pedestrians. Tables 1 to 3 summarize the methods used and the data collected for each facility.

Clockwise from top: Bicycle facilities at the entrance onto U Street from New Hampshire Avenue; Pennsylvania Avenue at 4th Street; and 15th Street at S Street.

Figure 1. Map of the study areas.



Top: Pennsylvania Avenue at 3rd Street. **Bottom:** Intersection of 16th Street and U Street looking up New Hampshire Avenue.

Table 1. Bicycle facilities evaluation summary.

Type of Analysis	16th Street/ U Street/ New Hampshire Avenue	Pennsylvania Avenue	15th Street	Data Collected for Analysis
Volume Analysis	●	●	●	Bicycle counts
Highway Capacity Manual 2010 Multimodal Level of Service		●	●	Motor vehicle counts Lane geometry and cross section Speed data Pavement condition
Danish Bicycle Level of Service		●	●	Motor vehicle counts Lane geometry and cross section Speed data Pavement condition Land use information
Bicycle Environmental Quality Index		●	●	Motor vehicle counts Lane geometry and cross section Speed data Land use information
Bicycle Corridor Travel Time		●	●	Signal timing data
Crash Analysis	●	●	●	Crash data
Survey Analysis	●	●	●	User intercept surveys Surrounding neighborhood surveys
Video Analysis	●	●	●	Study area video

Table 2. Motor vehicle facilities evaluation summary.

Type of Analysis	16th Street/ U Street/ New Hampshire Avenue	Pennsylvania Avenue	15th Street	Data Collected for Analysis
Volume Analysis	●	●	●	Motor vehicle counts
Highway Capacity Manual 2010 Arterial Level of Service	●	●	●	Motor vehicle count Pedestrian counts Lane geometry and cross section Speed data Signal timing and phasing
Travel Time Analysis			●	Drive time data
Survey Analysis	●	●	●	Surrounding neighborhood surveys
Video Analysis	●	●	●	Study area video

Pennsylvania Avenue at 11th Street.

Table 3. Pedestrian facilities evaluation summary.

Type of Analysis	16th Street/ U Street/ New Hampshire Avenue	Pennsylvania Avenue	15th Street	Data Collected for Analysis
Highway Capacity Manual 2010 Multimodal Level of Service		●	●	Motor vehicle counts Pedestrian counts Lane geometry and cross-section Speed data
Survey Analysis	●	●	●	User intercept surveys Surrounding neighborhood surveys
Video Analysis	●	●	●	Study area video

16th Street and U Street bike box sign.

STUDY FACILITIES

16TH STREET NW / U STREET NW / NEW HAMPSHIRE AVENUE NW

New Hampshire Avenue is a low-volume diagonal street that cuts through the D.C. grid network and is a DDOT priority route for bicycle travel. The approach legs to its intersection with 16th Street and U Street are one-way for vehicles traveling away from the intersection (on both sides). Contra-flow bicycle lanes were installed to permit bicycle movements toward the intersection and encourage the use of New Hampshire Avenue as a through corridor for cycling. However, because vehicles are not permitted to drive across the intersection on New Hampshire Avenue, provisions were needed to allow bicyclists to negotiate the intersection. DDOT installed bicycle signals and bicycle boxes to permit cyclists to travel across the intersection in two stages.

The primary changes made to the 16th Street/U Street intersection and New Hampshire Avenue approaches include the following:

- *Bicycle boxes* were installed on the northbound and southbound approaches on 16th Street (as shown Figure 2). The bicycle boxes are located between the crosswalks and the vehicular stop bars. They provide an area for bicyclists crossing 16th Street on the green bicycle phase to queue in front of motor vehicles before crossing U Street. The bicycle boxes are meant to make bicyclists more visible to drivers, thereby reducing conflicts and crashes.

Figure 2. Southbound cyclists on 16th Street.

- *Bicycle signals* were installed on the northwest and southeast corners of the intersection (as shown in Figure 3). Bicyclists receive their own signal phase to allow bicyclists to travel from the New Hampshire Avenue contra-flow bicycle lanes to the 16th Street bicycle boxes without having to cross the intersection using the pedestrian crosswalks. No motor vehicle movements run concurrently with the bicycle signal phase.
- *Bicycle detection* is provided in the contra-flow bicycle lanes on New Hampshire Avenue so that bicycles are detected by the signal controller as they approach the intersection.
- *Shared lane markings* have been added to New Hampshire Avenue for cyclists traveling in the same direction as vehicular traffic (as shown Figure 4). The shared lane markings help improve cyclist positioning in the roadway and inform drivers of the potential presence of bicycles.
- *Contra-flow bicycle lanes* are provided on New Hampshire Avenue for bicyclists traveling in the opposite direction as the vehicular traffic (as shown in Figure 3). The contra-flow bicycle lanes legalize the movement of cyclists in the opposite direction of motor vehicle traffic on New Hampshire Avenue and notify drivers of the likely presence of cyclists.

Figure 3. Southbound approach on New Hampshire Avenue.

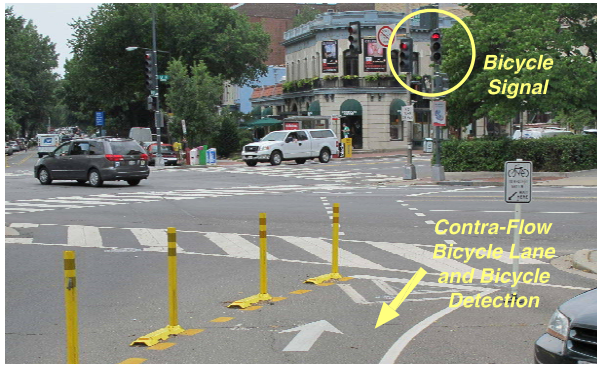


Figure 4. Looking north on New Hampshire Avenue.

PENNSYLVANIA AVENUE NW FROM 3RD STREET NW TO 15TH STREET NW

Bicycle lanes were installed in the center median of the Pennsylvania Avenue NW roadway (with no grade or barrier separation) between 3rd Street and 15th Street. Pennsylvania Avenue is a high-volume street that connects the White House to the Capitol Building, and it is also an important bicycle corridor. The eight-lane street has high vehicle speeds and volumes, including many buses and trucks and a lack of dedicated bike facilities, which created uncomfortable conditions for bicycling.

The bicycle lanes are five feet wide with three-foot buffers on each side. At intersections, the approaching bicycle lane splits to provide a turn lane and a through lane. Turning bicyclists wait in the middle (between the through bicycle lanes) while through cyclists follow the traffic signal for through motorists. To complete turning movements, cyclists wait for the pedestrian signal and cross in the crosswalk.

The following primary changes were made to the Pennsylvania Avenue corridor:

- *Bicycle lanes* were constructed in the center median of the roadway with buffers on either side (as shown in Figure 5). The bicycle lanes are meant to provide added safety and comfort for bicyclists traveling along Pennsylvania Avenue.
- *Bicycle signs* were added for turning and through cyclists in the traversable median (as shown in Figure 6).
- *Left-turn and U-turn restrictions* were instituted to reduce potential conflicts between cyclists and turning vehicles at locations where left-turns had previously been permitted. New restrictions were added at 3rd Street and 15th Street, while intersections with existing restrictions and missing signs (including 4th Street, 6th Street, 7th Street, 9th Street, 10th Street, and 14th Street) had new signs posted.
- *Signal timing changes* were made at intersections on Pennsylvania Avenue that provided protected left-turns. The new signal timing separates the left-turn phase from the adjacent through phase (e.g., the westbound through movement receives a red signal indication whenever the westbound left movement receives a green indication). This is because the same signal indication controls both through bicyclists and through motorists (i.e., the same signal head controls both through bicyclists and through motorists), and a concurrent movement would place through bicyclists in conflict with left-turning motor vehicles.

Figure 5. Looking east from the 6th Street Intersection.

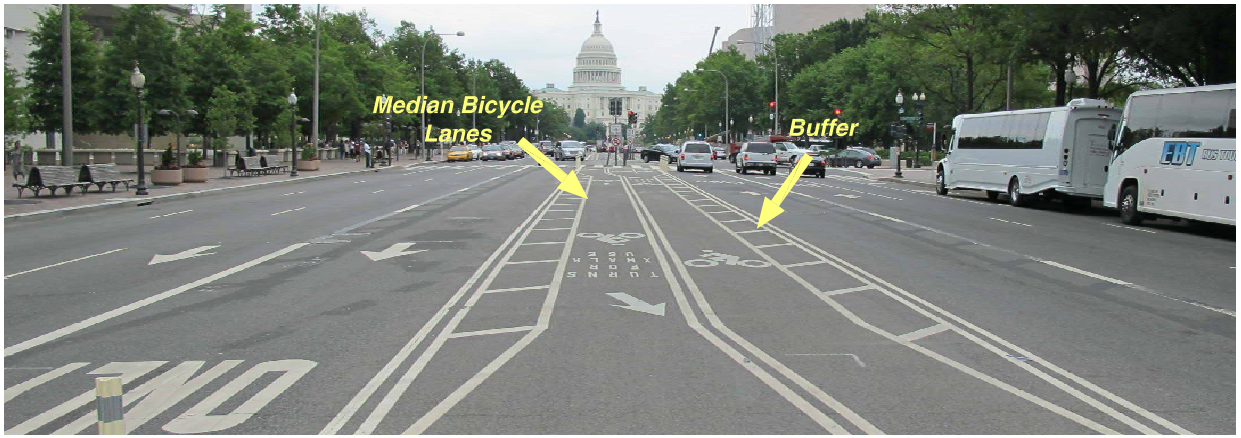


Figure 6. Westbound signals and signage at the 9th Street Intersection.

15TH STREET NW FROM E STREET NW/ PENNSYLVANIA AVENUE NW TO V STREET NW

DDOT installed a two-way cycle track on 15th Street NW between E Street/Pennsylvania Avenue and V Street (except in the section between New York Avenue and H Street). The cycle track is located on the west side of the street between the sidewalk and parked vehicles. Before installation of the cycle track, bicyclists shared the roadway with vehicle traffic; there were no accommodations for southbound cyclists north of Massachusetts Avenue (15th Street is one-way northbound for motor vehicles), and between Pennsylvania Avenue and New York Avenue, and again between H Street and Massachusetts Avenue, 15th Street is two-way.

The cycle track is eight feet wide with a three-foot buffer between it and vehicle traffic or parked cars. White, flexible channelizing posts were installed in the buffer to further delineate the dedicated cyclist space to motorists. At intersections on the one-way section of 15th Street, the approaching cycle track is diverted away from the sidewalk, creating a seven-foot buffer between the two directions of bicycle traffic and increasing cyclist visibility to left-turning motorists (as shown in Figure 7).

The following primary changes were made to the 15th Street corridor:

- *Cycle tracks* were constructed on the west side of the roadway with a buffer (as shown in Figure 8). The cycle track was designed to provide added safety and comfort for bicyclists traveling along 15th Street by separating all cyclists from vehicular traffic.
- *Shared lane markings* were added through intersections to indicate the likely presence of bicyclists to motorists and indicate the need for turning motorists to yield to cyclists (as shown in Figure 9).
- *STOP FOR PEDESTRIAN* markings were added at mid-block crosswalks and T-intersections to indicate to bicyclists to yield to crossing pedestrians (as shown in Figure 8).
- *Bicycle signs* were added for way-finding and to direct bicyclist turning movements.
- *Left-turn restrictions* were instituted to reduce potential conflicts between cyclists and left-turn vehicles at locations where left-turns had previously been permitted. Left turns were eliminated at some signals, while others remained using protected left-turn phases.
- *Signal timing changes* were made to accommodate bicyclists. In addition to the protected left-turn phases at intersections mentioned above, additional time was provided for bicyclists to enter the intersection prior to motor vehicle movement.

Figure 9. Southbound cycle track across R Street intersection.

Figure 7. Cycle track approach at Church Street Intersection.

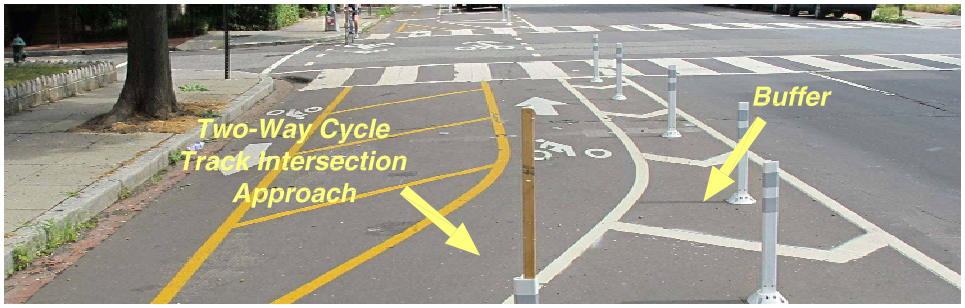


Figure 8. Two-way cycle track near F Street intersection.

FACILITY FINDINGS AND RECOMMENDATIONS

Overall, the analysis found that the bicycle treatments improved conditions for cycling without negatively impacting other modes in the vicinity of the investment. Due to the unique and independent conditions at each facility, key findings are provided separately. In addition, this section presents a set of general recommendations for future bicycle facilities within the District of Columbia.

16TH STREET NW/U STREET NW/NEW HAMPSHIRE AVENUE NW

Key Findings

- **Motor vehicle intersection LOS remained the same before and after the bicycle facilities were installed.** Reduced green time for the motor vehicle signal phases only slightly increased delay and the volume-to-capacity (v/c) ratio during the p.m. period, but resulted in somewhat larger impacts during the a.m. peak.
- **Few cyclists are using the bike box and bike signal as intended to cross the intersection.** The video revealed that fewer than 20 percent of bicyclists use the bike signal to cross the intersection. This percentage is consistent for southbound and northbound travel. Over 40 percent of bicyclists cross the intersection via crosswalks (usually first crossing U Street, then 16th Street) rather than using the bicycle facility. The cyclist intercept survey confirmed these findings (Table 4). More than three-quarters of surveyed cyclists indicated that it was not worth the time to wait for the signal with the present signal timing.
- **Few cyclists are using the bike box as intended, although it may still achieve its purpose.** The video revealed that 82 percent of bicyclists stopped in the crosswalk rather than waiting in the box. However, video evidence showed that fewer than 15 percent of cyclists using the bike box encountered a motor vehicle stopped in the box, suggesting that the bike box may be effective at providing separation between bicyclists and motorists and providing cyclists with space to maneuver.
- **Cyclists using the bike signal often encounter motor vehicles, but are able to navigate through.** Four of the 32 southbound bicyclists (13 percent) observed using the signal experienced interactions with late motorist eastbound left-turns from U Street (who turned left on red). Despite this, most bicyclists that do use the bike signal (42 out of 48) were able to cross the intersection without stopping, either by crossing diagonally or proceeding during the 16th Street green. Note that a small percentage of bicyclists (19 out of 298) used the bike signal to cross the intersection diagonally (without first traveling to the box).

Table 4. 16th Street/U Street/New Hampshire Avenue cyclist survey: self-described path through intersection compared to observed path.

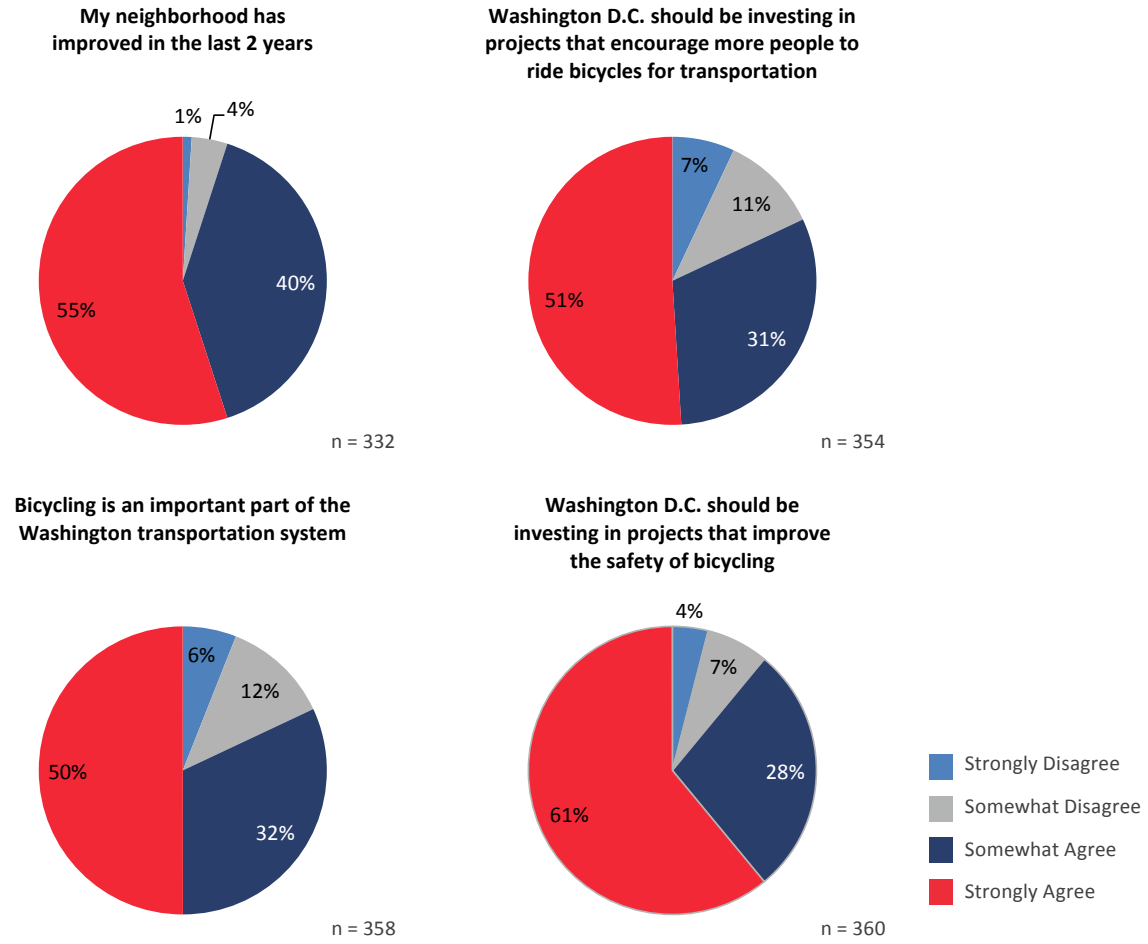
	A. Crossed 16th Street, entered the bike box, then crossed U Street	B. Crossed the intersection diagonally	C. Used the crosswalks: crossed 16th Street then crossed U Street	D. Used the crosswalks: crossed U Street then crossed 16th Street	Other
Self-described path of survey respondents, NB Cyclists (n[1]=42)					
	Total of A, B, and C: 50%[2]			45%	5%
Video Review (n=122)	44%	2%	2%	51%	--
Self-described path of survey respondents, SB Cyclists (n=113)					
	40%	10%	7%	35%	9%
Video Review (n=176)	51%	9%	5%	35%	--

[1] n = Number of cyclists

[2] Due to a survey error, NB cyclists were asked a different version of the question that included wording about waiting for the bicycle signal. If responses are best matched, combining A, B, and C responses totals 50 percent, D totals 45 percent, and other responses total 5 percent.

- **More bicycle crashes per year were observed at the intersection after installation of the bicycle facilities.** There were 5 bicycle crashes at the intersection during the first 13 months after implementation, compared to a total of 4 bicycle crashes during the previous 4 years. The low number of total crashes and limited length of time observed for the after period (13 months) is too short to draw definitive conclusions; however, this increase in crashes indicates that crash patterns should continue to be monitored, particularly as operational changes are made to the intersection to improve bicyclist compliance.
- **Perceptions of the facility are generally positive from both cyclists and motorists.** Cyclists reported enthusiastic agreement that the contra-flow bike lanes make cycling safer and easier on New Hampshire Avenue (Figure 10). The bike signal and bike box elicited generally positive responses regarding safety and ease, although positive responses to contra-flow lanes were significantly higher. Motorists did not indicate that the new bicycle facilities caused any problems in terms of added congestion, delay, or parking challenges.
- **Residents responding to the survey support more investments in bicycle facilities.** Many area residents do not believe bicycling in Washington, D.C. is safe, but a strong majority support investments in encouraging bicycling for transportation and improving the safety of bicycling.

Figure 10. 16th Street/U Street/New Hampshire Avenue resident survey: general opinions on the neighborhood, bicycling, and investment.



Preliminary Recommendations

- Restrict trucks making eastbound right turns onto New Hampshire Avenue from U Street due to the new reduced turning radius.
- Increase the street cross-section width at the southwest New Hampshire intersection entrance to make room for the future bike lane. Supplement the increased width with a permanent barrier between motorists and bicyclists.
- Paint the bike boxes and dashed bike lanes leading to the bike boxes green. The green may increase the share of cyclists stopping in the box, rather than in the crosswalk, where conflicts with pedestrians can occur.
- The stop bars on 16th Street are not recommended for modification. They are currently located approximately 10 feet back from the crosswalks, providing an angled bicycle box area between the stop bar and crosswalks. They are recommended to remain in approximately the same position under any reconstruction plan to allow unimpeded bicycle access to the bike boxes.
- The dashed bike lanes crossing 16th Street should be located as close as possible to the crosswalk to increase visibility of cyclists to turning motorists (subject to other geometric design constraints).
- Consider adding medians (with bike openings) on both 16th Street approaches to increase pedestrian safety by providing a refuge from turning vehicles.

- Add a push-button for cyclists and/or improved bicyclist detection, or alter the signal timing to provide a green bike phase every cycle (see signal phasing modifications below).
- Near-side bicycle signal heads should be mounted lower for improved visibility. Consider installing smaller lenses (e.g., 4-inch) for the near-side bicycle signal heads. Small, low-mounted near-side bike signal heads are used successfully in northern Europe in similar situations.
- Modify signal phasing to reduce delay for all users and more closely reflect the way that cyclists currently use the intersection:
  - Provide a green bike signal that operates concurrently with green time on U Street. For consistency with the Manual on Uniform Traffic Control Devices (MUTCD) meaning of a green ball for motorized vehicles (i.e., allows through movement and turns except as modified by signing/striping/etc.), signing (e.g., BIKES CROSS 16TH ST ON GREEN 🚲) should be installed to make it clearer that the bike signal does not allow protected movement all the way through the intersection. Green painted bike lanes and boxes would also reinforce this message.
  - Provide a three-second solid yellow bike signal before the all-red bike signal.
  - Eliminate the exclusive bike phase; bicycles would receive the same amount of green time that U Street currently receives, which would reduce cyclist delay considerably. Furthermore, the time currently used by the exclusive bicycle phase would be returned to 16th and U Streets, which should improve motorized vehicle operations to close to "before" conditions.
  - Install a flashing yellow right-turn arrow for eastbound and westbound right turning vehicles.
  - Implement a flashing yellow arrow indication for the westbound left-turning movement during its permissive phase and install a TURNING VEHICLES YIELD TO BIKES sign.
  - Prohibit eastbound left-turns to minimize conflicts with bicyclists.
  - Consider adding a short leading pedestrian/bicycle interval in advance of the U Street green indication. The length of any leading pedestrian/bicycle interval should be limited to avoid encouraging aggressive cyclists to cross the full intersection diagonally during the lead phase. Note that a leading pedestrian/bicycle interval would require eliminating the leading westbound left-turn phase as there is no dedicated left-turn lane.
  - Temporarily use NEW TRAFFIC PATTERN AHEAD signs on the New Hampshire Avenue intersection approaches to inform bicyclists about the changed bicycle signal phasing.
- An alternative to the recommended signal timing modifications would be to implement an exclusive bicycle and pedestrian phase to allow cyclists to cross the intersection diagonally during the bicycle green phase. The length of the exclusive phase should be based on the needed pedestrian clearance interval for perpendicular crossing (using a walking speed of 3.5 feet per second). Pedestrians will also be allowed to cross during the U Street and 16th Street green phases (similar to the exclusive pedestrian phase at 7th Street and H Street in Chinatown). This alternative has the benefit of eliminating conflicts between cyclists and motor vehicles, but will likely require a longer cycle length with longer delays for both motorists and cyclists compared to the preferred alternative.

Top: Cyclists get a head start at 16th Street and U Street southbound. **Bottom:** Cyclists wait on detector loops at 16th Street and U Street southbound.

PENNSYLVANIA AVENUE NW FROM 3RD STREET NW TO 15TH STREET NW

Key Findings

- **Bicycle volumes increased by approximately 200 percent after the bicycle facilities were installed.** Bicycle counts were taken between 6th Street and 7th Street and between 14th Street and 15th Street during the a.m. and p.m. peak hours in April 2010 and June 2011. All locations and time periods experienced significant bicycle volume growth after installation of the bicycle facilities (Figure 11).
- **Arterial LOS was similar for motor vehicles on Pennsylvania Avenue before and after the bicycle facilities were installed.** The study segments remained at LOS E or better during both the a.m. and p.m. peak hours, even after left turns were restricted and through movement green time was reduced on Pennsylvania Avenue at several intersections. The minimal change partially reflects the extensive work done prior to installation to adjust corridor signal timing.
- **The corridor experienced decreased motorized vehicle volumes after the bicycle facilities were installed.** Between October 2009 and June 2011, there was a 21.3 percent decrease in volumes between 6th Street and 10th Street during the p.m. peak hour and a 14.7 percent decrease in volumes between 10th Street and 15th Street during the p.m. peak hour. The reason for the decrease is not entirely clear, but may have resulted from the different times of year that the counts were taken and/or driver route choice changes due to the turn restrictions.
- **Danish Bicycle LOS and Bicycle Environmental Quality Index (BEQI) analyses all show significantly improved operations for cyclists with the median bike facilities.** The Danish Bicycle LOS improved from LOS E before the bicycle facilities were installed to LOS C after installation. The BEQI index indicated that the bicycling environment went from being "Average" before facility installation to "High Quality" after installation. The BEQI scores (out of 100) improved from approximately 45 before installation to 70 after installation.
- **Signal timing for bicycles generally works well between 10th Street and 15th Street, but results in large delays to cyclists between 3rd Street and 9th Street.** The speed-based LOS experienced by bicycles, based on existing signal timing and cyclist travel speeds of 10 to 15 mph, is LOS E or F between 3rd Street and 9th Street and LOS A to D between 10th Street and 15th Street.
- **The frequency of bicycle crashes experienced along Pennsylvania Avenue increased after the bicycle facilities were installed.** There were 16 bicycle crashes on the corridor during the first 14 months after implementation, compared to a total of 9 bicycle crashes during the previous 4 years. This represents an increase in crash frequency, even when taking into account the observed tripling of cyclist volume on the corridor. The low number of total crashes and limited length of time observed for the after period (14 months) is too short to draw definitive conclusions; however, DDOT should continue to monitor crash patterns to identify potential safety improvements along the corridor.
- **No collisions were directly observed in the video data and relatively few were self-reported in the cyclist surveys.** Video observations revealed occasional instances of cyclists and pedestrians navigating around one another at intersection crosswalk medians; more than half of cyclists reported experiencing "near-collisions" with pedestrians. About half of cyclists reported experiencing "near-collisions" with turning motor vehicles, although there were none observed in the six hours of video analyzed.
- **Cyclists understand how they are supposed to behave at the intersections, but frequently do not comply.** All surveyed cyclists understood that they should follow the through-traffic motor vehicle signal. However, the video data revealed a high violation rate. In the observed data, an average of 42 percent of cyclists arriving on a red signal violated the signal, though this varied substantially by intersection and by cross street volume. This is a high violation rate compared to the data in the few published studies available on cyclist compliance with bicycle-specific traffic signals and is very high compared to motorist compliance.

Figure 11. Bicycle volumes increased following bicycle facility improvements on Pennsylvania Avenue.

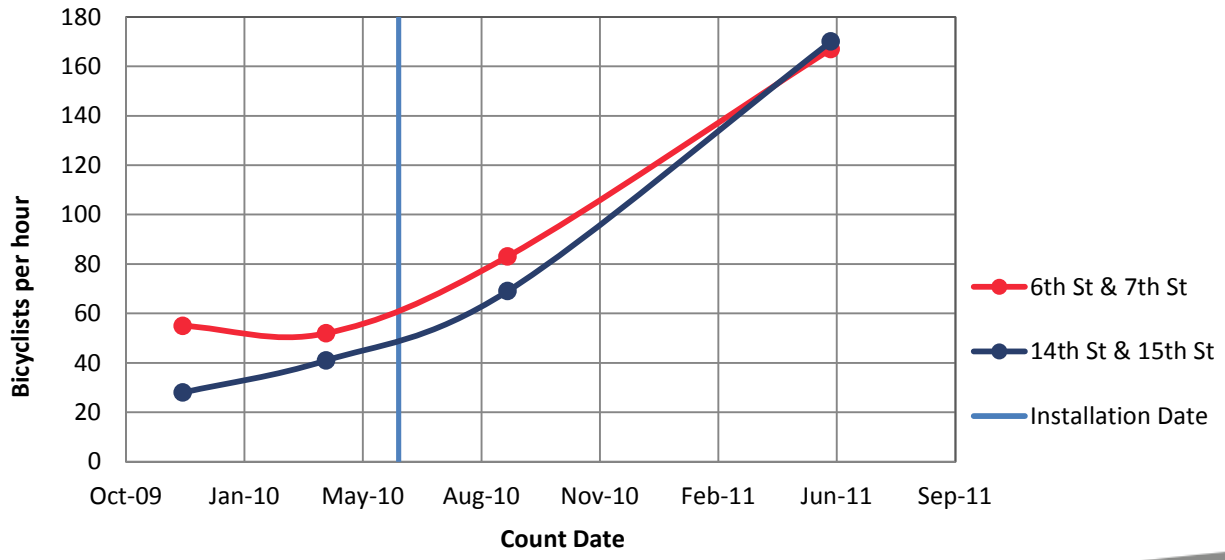
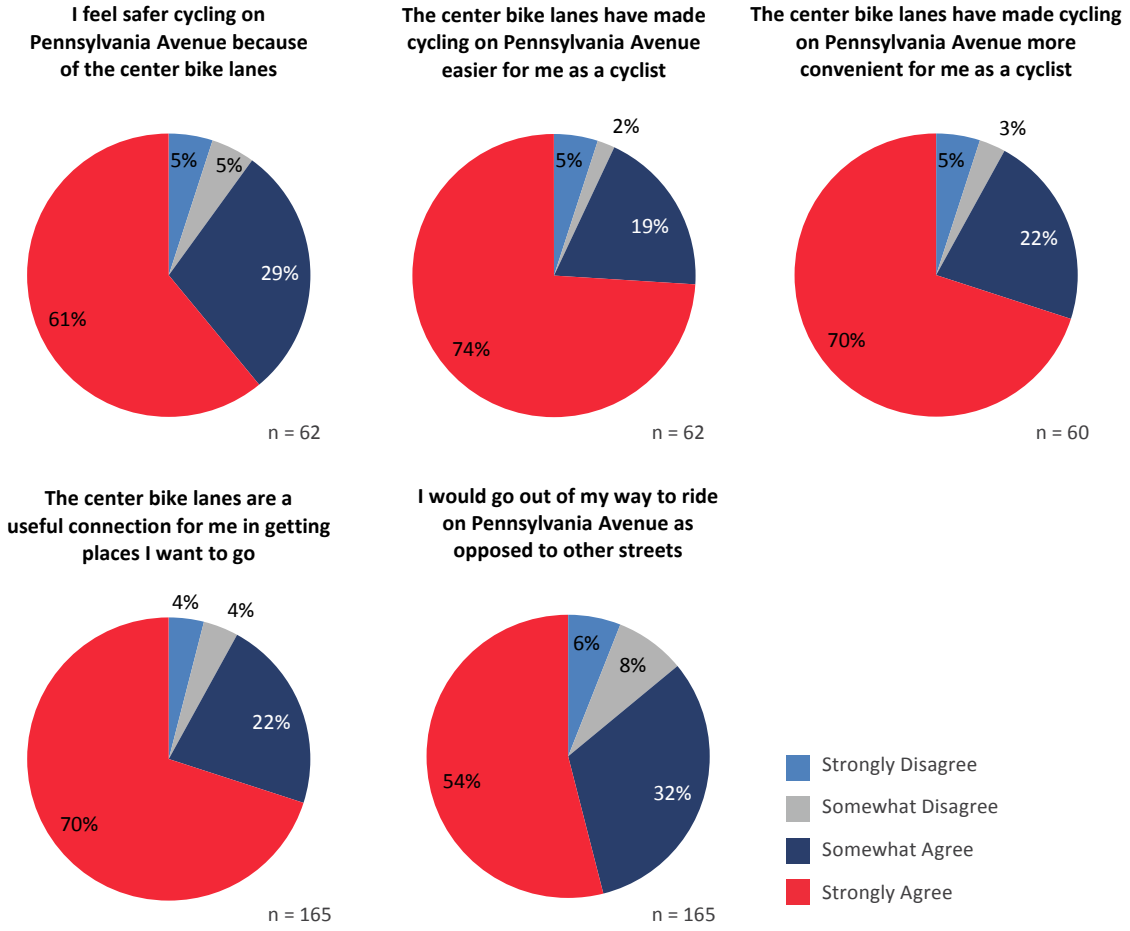


Figure 12. Pennsylvania Avenue cyclist survey: sense of safety and ease.



- **Most cyclists stopping at red lights stop in the crosswalk or median area rather than behind the white stop bar.** This pattern could result in potential collisions with left-turning vehicles and blocking pedestrians trying to use the crosswalk.
- **Cyclists overwhelmingly indicated that they felt riding a bicycle on Pennsylvania Avenue with the center bike lanes is safer and easier** (Figure 12) and that the center bike lanes provide a useful connection for getting around Washington, D.C. on a bicycle.
- **Nearly three in four residents indicated that they "support" the center bike lanes and believe them to be a valuable asset to the neighborhood.** They also support investment in encouraging cycling and improving the safety of cycling, although there was a greater amount of differing opinions for this facility than for the other facilities evaluated.
- **Motorists support the separation between bikes and cars provided by the center bike lanes, but have some concerns.** About half the respondents indicated that restrictions on U-turns are a major inconvenience along the route. U-turns were always prohibited, but several missing signs were replaced when the bicycle facility was installed. Nearly half of respondents indicated that signals, signs, and street markings do not make it clear who has the right-of-way at intersections.
- Pedestrians find there are fewer cyclists riding on sidewalks now. While pedestrian responses indicate that there may now be some competition for space at medians along Pennsylvania Avenue, only one respondent reported being involved in a collision with a cyclist in the center bike lanes.

Preliminary Recommendations

- Improve legibility of signals, signs, and markings. Only 56 percent of drivers indicated it was clear who has the right-of-way at intersections. Bicycle signals clarifying the separation of bicycle movements from left-turns could help improve legibility.
- Add bicycle signals to create independent vehicle and bicycle through phases. Since the bicycle lane is positioned to the left of the vehicle left-turn lane, the lanes must operate with different signal phases. Through motorists, who drive to the right of the left-turn lane, do not conflict with turning vehicles, but currently must wait since they share a signal head with bicyclists. Adding a bicycle signal and bicycle through phase would permit independent operation of the through bicycle and vehicle phases and increase green time for through vehicles. These additions would also make it easier to adjust signal timing to accommodate both cyclist and motor vehicle progression.
- Resize and reposition bicycle signs. The bicycle signs create a sight distance obstruction and could be made smaller. In the longer term, taller signal poles would allow the signs to be placed higher to increase visibility.

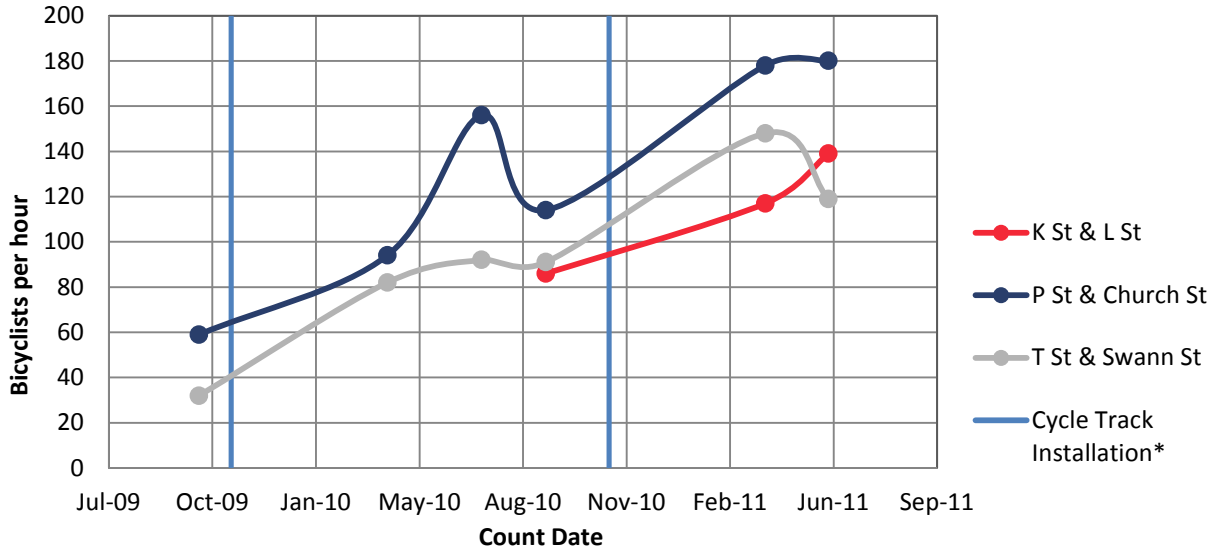
- Consider additional pavement markings to reduce pedestrian/bicyclist conflicts. For instance, WAIT HERE or STOP HERE pavement markings prior to the stop bar in the cycle track (between the stop bar and the bike symbol) could be used to encourage cyclists to stop at the proper location. Similarly, bike stencils in the crosswalk where the cycle track crosses the crosswalk (similar to those used at driveways along 15th Street) could help to indicate the presence of the cycle track to pedestrians.
- Include cyclist progression analysis as an explicit performance measure in future signal re-timing along Pennsylvania Avenue. In particular, eastbound bicyclists experience poor progression in the a.m. peak period and westbound cyclists experience poor progression in both peak periods.
- DDOT should consider a cyclist education and enforcement campaign to encourage compliance with traffic signals.

15TH STREET NW FROM E STREET NW/ PENNSYLVANIA AVENUE NW TO V STREET NW

Key Findings

- **The data indicate that more bicyclists began using 15th Street after the one-way cycle track was installed** and, in general, even more began traveling along the corridor after the two-way cycle track was installed. After the two-way cycle track was installed, there was a 205 percent increase in bicycle volumes (from before conditions) between P Street and Church Street during the p.m. peak hour, and there was a 272 percent increase in bicyclist volumes (from before conditions) between T Street and Swann Street during the p.m. peak hour (Figure 13).
- **Motor vehicle counts show that volumes have remained relatively constant on 15th Street before and after the bicycle facilities were installed.** Between September 2007 (before the bicycle facilities were installed) and July 2011 (after the two-way cycle track installation), there was a 4.0 percent increase in motor vehicle volumes between E Street and New York Avenue, a 10.1 percent increase in motor vehicle volumes between H Street and Massachusetts Avenue, and a 1.2 percent decrease in motor vehicle volumes between Rhode Island Avenue and U Street.
- **Motor vehicle operations show only minor changes before and after the bicycle facilities were installed.** Most segments remained at LOS D or E based on the Highway Capacity Manual 2000's urban streets method.
- **Overall, the bicycle facilities did not significantly change motor vehicle travel speeds along 15th Street.** Analysis of travel time runs done both before and after installation of the cycle tracks showed no significant difference in corridor travel time for motor vehicles.
- **The Danish Bicycle LOS analysis indicates that bicyclists experienced a better LOS after the new facilities were installed.** Before installation, 15th Street was rated as having Bicycle LOS D and E on the three study segments; after installation, 15th Street was rated as providing Bicycle LOS A and B. The model predicts that nearly all bicyclists will indicate being at least "a little satisfied" with the facilities on 15th Street after installation.
- **The BEQI index analysis ranked 15th Street as having "average" quality bicycle facilities before the cycle track installation and "high" to "highest" quality bicycle facilities after installation.** Before installation, 15th Street received scores of approximately 45 out of 100. After installation, 15th Street received scores of approximately 75 out of 100.
- **Bicyclists experience less delay on 15th Street between Lower E Street and I Street than between I Street and U Street.** Bicyclists riding at 15 mph between Lower E Street and I Street can achieve LOS D or better based on average travel speed, but bicyclists traveling between I Street and U Street generally experience significant signal delay.

Figure 13. Bicycle volumes increased following bicycle facility improvements on 15th Street.



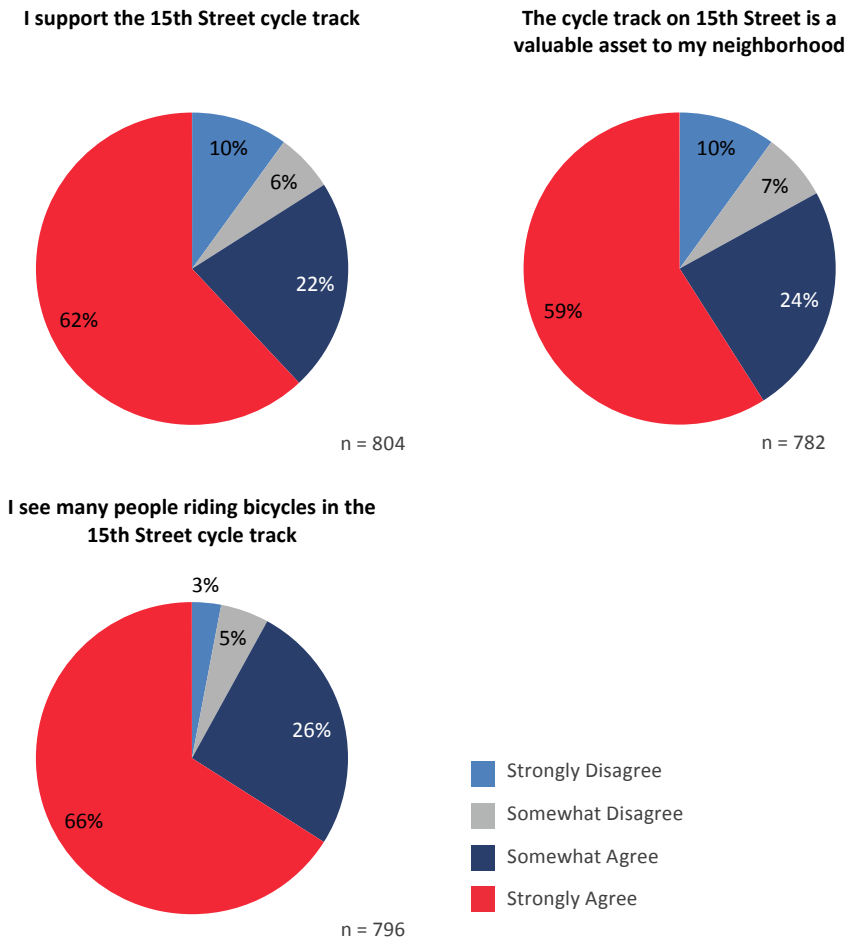
* The one-way and two-way cycle tracks were installed in November 2009 and November 2010, respectively.

- **Little difference was measured in the number of crashes involving bicyclists after the bicycle facilities were installed** after accounting for the substantial increase in bicyclist volume. Thirteen crashes involving cyclists occurred in the first 14 months after installation of the two-way cycle track, compared to 20 crashes over the 4 years prior to cycle track implementation. As cyclist volumes approximately doubled over this same time period, this represents no significant change in crashes per cyclist. One year of data after installation does not provide conclusive information for the crash patterns occurring along the corridor. However, it appears that crashes involving bicyclists remain a relatively rare event along 15th Street. It is recommended that crash reports continue to be evaluated in future years.
- **There are potential issues with the existing design, which uses the pedestrian signal to control cyclist movements.** According to the survey responses, many cyclists (approximately 20–30 percent) watch the through motor vehicle green, which could result in conflicts with left-turning vehicles during the protected left-turn phase (Figure 14). Issues with comprehension may contribute to the high rate of violations of the pedestrian signal by cyclists, especially by southbound cyclists.
- **Red-light running by cyclists is high, with over 40 percent of cyclists observed disobeying signals.** This is a high violation rate compared to the data in the few published studies available on cyclist compliance with bicycle-specific traffic signals and is very high compared with motorist compliance. Violation rates differed considerably by intersection and are highest at intersections with (1) low volumes of conflicting traffic and/or (2) high levels of signal delay.
- **Cyclists encounter many pedestrians and, during congested periods, it is not uncommon for cross traffic to block the intersection.** Generally, cyclists navigate around pedestrians and stopped traffic without needing to resort to emergency actions to avoid collisions. This appears to be a convenience, rather than safety issue, due in part to very low turning vehicle speeds.
- **Cyclists overwhelmingly feel that riding on 15th Street with the cycle track is much safer and easier now**, that it is a useful connection, and that they would go out of their way to ride on the cycle track as opposed to other streets.
- **Residents support investments that encourage people to bicycle for transportation and improve the safety of bicycling.** Over 80 percent of residents support the cycle track and view it as a valuable asset to the neighborhood (Figure 15).
- **Motorist attitudes are generally favorable toward the cycle track.** They like that it provides separate spaces for cars and bicycles, and most do not find that traffic congestion has gotten worse. However, just under half of motorists find waiting for a green arrow to make a left turn to be a major inconvenience, and about two-thirds find turning off 15th Street into alleys to be difficult with the cycle track.
- **Pedestrians indicated that they are encountering fewer cyclists on sidewalks**, although some do not feel cyclists are yielding to pedestrians in the crosswalks.

Figure 14. 15th Street cyclist survey: signal selection. **Top:** Intersection of 15th and S Street. **Bottom:** Intersection of 15th Street and U Street.

The Whitehouse Plaza area along the 15th Street cycle track.

Figure 15. Street resident survey: support for cycle track.



Preliminary Recommendations

- Add bicycle signal heads to control bicycle traffic for both northbound and southbound movements, rather than using pedestrian signals. Many cyclists do not understand that they should use the pedestrian signals as their traffic control. Installing bicycle signals at these intersections, which will require additional or modified Federal Highway Administration (FHWA) experimentation requests, will improve signal control clarity and potentially reduce crash risks.
- Consider installing a flashing yellow left-turn signal for motorists. A flashing yellow arrow for left-turning motorists may help convey through bicycle priority and reduce risk of crashes. Implementing this as an experimental treatment at one or more intersections would allow a review of its effectiveness before full corridor implementation.
- Consider using green colored pavement at unsignalized conflict areas (e.g., driveway crossings), in addition to the existing stencils, to alert motorists of the presence of the bicycle facility.
- Green pavement might also be appropriate through intersections to provide a visual cue to motorists to watch for potential conflicts and not block the intersection while waiting to turn.
- Improve pavement conditions for southbound cyclists through repaving, widening, and/or removing the gutter.
- Improve, to the extent possible, signal progression for southbound cyclists north of Massachusetts Avenue. Traffic signals on the one-way portion of 15th Street are timed for one-way northbound traffic, which results in frequent stops for southbound cyclists. Signals should be retimed to accommodate bicycle traffic in both directions, although this must be balanced with the need to maintain northbound progression for motor vehicles, and potentially cross-street progression.
- Add pedestrian islands to crossings north of Massachusetts Avenue. Providing storage for crossing pedestrians will reduce conflicts between cyclists and pedestrians standing in the cycle track.
- Consider using a green bike box at the intersection of Pennsylvania Avenue/15th Street for eastbound cyclists to provide cyclists with a clearly marked location to wait.
- DDOT should consider a cyclist education and enforcement campaign to encourage compliance with traffic signals.

Segways use the bike lane at Pennslyvania Avenue and 15th Street.

RECOMMENDATIONS FOR FUTURE BICYCLE FACILITIES

Based on the above analysis and a review of national best practices, the research team identified several general recommendations for the design and operation of bicycle facilities within D.c.

DATA COLLECTION AND MONITORING

This research study provides a comprehensive analysis of the study facilities over the first one to two years after installation. DDOT should continue to monitor the performance of these and other facilities over time. Frequent analysis bicycle volume data and crashes will allow DDOT to continue to monitor the effectiveness of these facilities in meeting goals to both (1) increase bicycle ridership and (2) provide a safe bicycling environment.

In particular, continued monitoring of crash data is necessary to fully understand the effects of the bicycle facilities on safety, as too little data were available to draw strong conclusions about safety impacts within this report. Moreover, recent research suggests that the safety effects of bicycle facilities may not be fully apparent for several years, and that user behaviors may continue to change years after a facility is installed (Reference 1).

Automated bicycle counters can provide continuous information on facility use.

CONTRA-FLOW BICYCLE FACILITIES

Observation of contra-flow bicycle facilities in Washington, D.C. has shown that the use of two-way bicycle facilities on one-way streets poses challenges for signal progression and use of signal equipment.

Signal progression is meant to help vehicles and bicycles progress with reduced delay at intersections and works best on one-way facilities and facilities with heavy travel in one direction. However, when users are traveling in both directions, one direction inevitably experiences increased delays while the other is able to progress more efficiently. While signal timing can be coordinated to balance these results, two-way cycle tracks located on one-way streets inevitably pose challenges for signal timing.

Installation of two-way bicycle facilities on one-way streets also has the potential to require more significant signal modifications. The 15th Street results show that the use of signs indicating that bicyclists should use the pedestrian signals is not effective. Bicyclists should use either the motor vehicle signal indications or bicycle-specific signals depending on intersection specifics. This may require installation of additional poles to accommodate two-way bicycle travel on one-way streets.

While there are unique situations where a two-way bicycle facility on a one-way street works well (such as along 15th Street north of Massachusetts Avenue where there is no parallel southbound street that does not require significant out-of-direction travel), one-way bicycle facilities on paired couplets is generally preferred.

New signal pole and signal head installed to control contra-flow movement on a two-way cycle track along a one-way street.

BICYCLE SIGNALS

There are advantages and challenges associated with installing bicycle signals versus using vehicle signals to control bicycle movements.

If bicycle signals are used, there is more flexibility in signal timing for the vehicle and bicycle movements. For example, on Pennsylvania Avenue, the same signal indications control both through vehicle and through bicyclist movements at intersections. As a result, the through vehicles receive a red indication during protected left-turns (even when there are no conflicting movements) to prevent conflicts between left-turning vehicles and through cyclists. The installation of bicycle signals would allow through vehicles to progress through the intersection with left-turning vehicles while through cyclists remained stopped. The use of bicycle signals would allow for more efficient signal operations and decrease delay for vehicles.

Depending on intersection capacity and intersection-specific operations, the operational benefit associated with bicycle signals may not be large enough to justify the capital and maintenance costs of the bike signals. Intersections with protected bicycle movements also require more complicated signal timing.

To help bicyclists understand the traffic control that applies to them, the application of bike signals should be consistent along a particular facility.

MIXING ZONES

Mixing zones, where cyclists in a cycle track merge with left- or right-turning vehicles in advance of intersections, have not yet been implemented in Washington, D.C. However, anecdotal evidence from New York City suggests that mixing zones work best on one-way streets with one-way bicycle facilities. They are more efficient and less costly than using bicycle signals to separate through cyclists from turning vehicles, but also provide cyclists with less separation from traffic because cyclists and left-turning vehicles must navigate a weaving area near intersections.

Because cyclist surveys taken as part of the DDOT facility evaluation indicate that cyclists strongly prefer separation from vehicles, mixing zones are likely to decrease cyclist comfort when used at intersections with high turning volumes. As a result, the appropriateness of mixing zones depends strongly on turning volumes; at intersections with high volumes of turning vehicles, separating bicycle movements from turning vehicles through protected bicycle signal phases is likely to be most appropriate.

Mixing zones provide an alternative method of addressing bicycle-motorist conflicts at intersections along cycle tracks. © 2012 Google

GREEN COLORED PAVEMENT

The FHWA has given interim approval for "the optional use of green colored pavement in marked bicycle lanes and in extensions of bicycle lanes through intersections and other traffic conflict areas." While colored pavement is not yet included in the MUTCD, this interim approval gives agencies authority to install colored pavement along bicycle facilities, subject to several conditions (Reference 2).

The language within the interim approval does not provide guidance on where colored pavement is likely to be most effective. Cities within the United States have taken two primary approaches to the use of colored pavement for bicycle facilities:

- Reserve colored pavement specifically for key conflict areas (e.g., Portland). This approach is intended to indicate to both cyclists and motorists that they are entering a potential conflict zone.
- Use colored pavement along the entirety of bicycle facilities with the exception of conflict areas (e.g., New York City). This approach is intended to provide a higher level of comfort to cyclists in the bicycle facility and indicate to cyclists the presence of conflict areas where they might expect to encounter motor vehicles.

In either case, the change in pavement material is the important feature of the green paint, indicating to cyclists and vehicles that a change is taking place (i.e., entering or leaving a conflict zone).

Colored pavement at intersections make bicycle facilities more visible to turning motorists.

While this research did not examine colored pavement, we nonetheless recommend the use of colored pavement specifically for conflict areas rather than for entire bicycle facilities. There are several reasons for this recommendation. Use of colored pavement only in conflict areas:

- Indicates conflict areas effectively to both cyclists and motorists.
- Is consistent with the use of colored pavement in the bike boxes on 16th Street to enhance the visibility and use of these facilities by cyclists.
- Is consistent with the desire for more effective delineation of conflict areas at driveways and unsignalized intersections along the 15th Street cycle track.
- Reduces costs and maintenance requirements.

Note that DDOT should closely monitor the effectiveness of any colored pavement.

TRANSIT ROUTES

Typically, buses merge into bike lanes at bus stops to allow passengers to directly access the sidewalk from the bus. However, it is generally inappropriate for transit vehicles to merge into separated bicycle facilities in the same manner. As a result, the presence of separated bicycle facilities along transit routes creates design challenges whenever both transit vehicles and cyclists are located on the same side of the street. On one-way streets, placing the bicycle facility on the left side of the street solves these problems and bicycle facilities may be constructed in the median of the two-way streets (e.g., Pennsylvania Avenue).

Other solutions are needed on two-way streets or where the bike facility must be located on the right side of the roadway. For instance, the lack of an acceptable design solution to this issue led to the relocation of a transit stop on 15th Street as part of the construction of the cycle track.

Due to the rarity of separated bicycle facilities in the United States, there is no generally accepted design solution to this problem. However, the situation is akin to that of bicycle facilities along streetcar tracks where the streetcar stop uses a curb extension and the bicycle facility travels behind the transit stop adjacent to the sidewalk. This treatment is likely to add considerable expense to the construction cycle tracks along transit routes, but may be necessary to maintain compliance with the Americans with Disabilities Act for transit service.

Transit stop designs to accommodate bikes at streetcar stops could be adapted for use at bus stops along cycle tracks.

NETWORK CONNECTIVITY

Bicycle network connections should provide cyclists with comfortable routes between key destinations and along key corridors, with facilities provided so that cyclists can comfortably reach any destination they desire. The results of this analysis suggest that separated bicycle facilities have a significant role to play in creating a bicycle network within Washington, D.C. that meets this goal.

Separated bicycle facilities are most effective on roadways with high volumes and/or traffic speeds, allowing cyclists to travel comfortably along streets that would otherwise be intimidating to all but the most experienced cyclists. Conversely, separated bicycle facilities pose greater challenges on streets with transit routes, frequent driveways, and high turning volumes. While design treatments exist to address these challenges, consideration should be given to these issues before selecting an appropriate bicycle facility type for a given corridor. The National Association of City Transportation Officials (NACTO) is currently developing facility-type selection guidance as part of updates to its Urban Bikeway Design Guide (http://nacto.org/cities-for-cycling/design-guide/) to address these issues in more detail.

REFERENCES

1. R.O. Phillips, T Bjornskau, R. Hagman, and F. Sagberg, "Reduction in car-bicycle conflict at a road-cycle path intersection: Evidence of road user adaptation?", *Transportation Research Part F*, vol. 14 (2011), p. 87-95.
2. *Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14)*. Federal Highway Administration, April 15, 2011.