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Washington, District of Columbia

Final Report

April 2012

Summary of Evaluation and Recommendations

District Department of Transportation Bicycle Facility Evaluation

Washington, District of Columbia

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Section 1 Executive Summary

Executive Summary

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 use of 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., 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 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.

Section 2 – Study Facilities provides more detailed descriptions and illustrations of these facilities.

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, 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. Table 1 summarizes the methods used and the data collected for each facility. Further explanation of these methods is provided in Section 3 ¿Study Methodology .

Table 1 Facility Evaluation Summary

Type of Analysis	16th / U/ New Hampshire	Pennsylvania Avenue	15th Street	Data Collected for Analysis
BICYCLE FACILITIES				
Volume Analysis	ã	ã	ã	¶ Bicycle counts
Highway Capacity Manual 2010 Multi-Modal Level of Servic		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Pavement condition
Danish Bicycle Level of Servi		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Pavement condition ¶ Land use information
Bicycle Environmental Qualit Index		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Land use information
Bicycle Corridor Travel Tim		ã	ã	¶ Signal timing data
Crash Analysis	ã	ã	ã	¶ Crash data
Survey Analysis	ã	ã	ã	¶ User intercept surveys ¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video

Type of Analysis	16th / U/ New Hampshire	Pennsylvania Avenue	15th Street	Data Collected for Analysis
MOTOR VEHICLE FACILITIES				
Volume Analysis	ã	ã	ã	¶ Motor vehicle counts
Highway Capacity Manual 2000 Arterial Level of Service	ã	ã	ã	¶ Motor vehicle counts ¶ Pedestrian counts ¶ Lane geometry and cross section ¶ Speed data ¶ Signal timing and phasing
Travel Time Analysis			ã	¶ Drive time data
Survey Analysis	ã	ã	ã	¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video
PEDESTRIAN FACILITIES				
Highway Capacity Manual 2010 Multi-Modal Level of Service		ã	ã	¶ Motor vehicle counts ¶ Pedestrian counts ¶ Lane geometry and cross section ¶ Speed data
Survey Analysis	ã	ã	ã	¶ User intercept surveys ¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video

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 for each facility.

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.

A complete summary of the intersection analysis is provided in Section 4 – Evaluation of the Intersection of 16th Street NW/U Street NW/New Hampshire Avenue NW. The analysis yielded the following findings:

- Bicycle volumes increased after installation of the bicycle facilities. Between April 2010 (before the bicycle facilities were installed) and April 2012 (after the bicycle facilities were installed), there was a 133 percent increase in the number of bicyclists traveling on New Hampshire Avenue during the a.m. peak hour and a 185 percent increase during the p.m. peak hour.
- Motor vehicle volumes remained approximately constant after installation of the bicycle facilities. There was a one percent decrease between May 2009 (before the bicycle facilities were installed) and April 2012 (after the bicycle facilities were installed).
- Motor vehicle intersection level of service (LOS) remained the same before and after the bicycle facilities were installed. Reduced green time for the motor vehicle signal phases increased delay and the volume-to-capacity (v/c) ratio only slightly 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 bicyclist use the bicycle 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. 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 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).

- 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. The number of crashes per year (adjusted for the increase in bicyclist volumes) remained approximately the same before and after installation of the bicycle facilities. 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 contraflow bike lanes make cycling safer and easier on New Hampshire. The bicycle signal and bike box elicited generally positive responses regarding safety and ease, although significantly lower than the response to the contraflow lanes. 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.

Based on these findings, the team makes the following 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:
  - o Provide a green bike signal that operates concurrently with green time on U Street. For consistency with the MUTCD meaning of a green ball for autos (i.e., allows through Í Ï Ö Å Í Å Î Ô Á Î Ä Ô Õ Ò Î Ó Å Ø Ã Å Ð Ô Á Ó Í Ï Ä É Æ É Å Ä BIKES Â Ù Ó CROSS 16TH ST ON GREEN ō should be installed to make it clearer that the bike signal Ä Ï Å Ó Î õ Ô Á Ì Ì Ï × Ð Ò Ï Ô Å Ã Ô Å Ä Í Ï Ö Å Í Å Î Ô Á Ì Ì Ô È Å × bike lanes and boxes would also reinforce this message.
  - o Provide a three second solid yellow bike signal before the all-red bike signal.
  - o 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 Ō Â Å Æ Ï Ò Å ō Ã Ï Î Ä É Ô É Ï Î Ó 8
  - o Install a flashing yellow right-turn arrow for eastbound and westbound right turning vehicles.
  - o Implement a flashing yellow arrow indication for the westbound left-turning movement Ä Õ Ò É Î Ç É Ô Ó Ð Å Ò Í É Ó Ó É Ö Å TURNING VEHICLES YIELD TO BIKES Ã É Ç Î Á Ì Ì Á
  - o Prohibit eastbound left-turns to minimize conflicts with bicyclists.
  - o 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/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/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.

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.

A complete summary of the analysis of the center median bicycle lanes is provided in Section 5 – Evaluation of Pennsylvania Avenue NW from 3rd Street NW to 15th Street NW. This analysis yielded the following 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.
- 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 Ō ! ÖÅ Ò ÁÇ Å Ō before facility installation Ô Ï Ō (É Ç È 1 Õ Á Ì É Ô Ù Ō after. The BEQI scores (out of Ó Ô Á Ì 100) improved from approximately 45 (out of 100) 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 10-15 mph is LOS E or F between 3rd Street and 9th Street, 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, and more Ô È Á Î È Á Ì Æ Ï Æ Ã Ù Ã Ì É Ó Ô Ó - Ã Ï Å Ð Ë Ó Å Ä Ó Å Ø Ð Å Ê Å Î Ã Å Ä Î Å Ç Ó Ô Ã Ù Ã Ì É Ó Ô Ó Ò Å Ð Ï Ò Ô Å - Ã Ï Å Ø Ð Å Ê Å Î Ã É Î Ç Ô Ð Î Ã Ï Î É Î Ç Í Ï Ô Ï 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). Compared to the data in the few published studies available on cyclist compliance with bicycle-specific traffic signals, this is a high violation rate, and is very high compared with motorist compliance.
- 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, and that the center bike lanes provide a useful connection for getting around Washington, D.C. on a bicycle.
- .ÅÁÒÌÙ ÔÈÒÅÅ ÉÎ ÆÏÕÒ ÒÅÓÉÄÅÎÔÓ ÉÎÄÉÃÁÔÅÄ ÔÈÁÔ 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 (note that 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.

Based on these findings, the team makes the following 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, and would 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, Ō7 !4) (%2%ō ÏÒ Ō34/0 (%2%ō ÐÁÖÅÍÅÎÔ ÍÁÒËÉÎÇÓ Ð (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

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. 15th Street is one-way northbound for motor vehicles north of Massachusetts Avenue, and is a two-way street south of Massachusetts Avenue. Before installation of the cycle track, bicyclists shared the roadway with vehicle traffic and there were no accommodations for southbound cyclists north of Massachusetts Avenue (15th Street is one-way northbound for motor vehicles).

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.

A complete summary of the analysis of the two-way cycle track is provided in Section 6 ̧Evaluation of 15th Street NW from E Street NW/Pennsylvania Avenue NW to V Street NW. This analysis yielded the following 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.
- 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* õÓ ÕÒÂÁÎ ÓÔÒÅÅÔÓ ÍÅÔÈÏÄ
- 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 "ÉÃÙÃÌÅ ,/3 ! ÁÎÄ "8 4ÈÅ ÍÏÄÅÌ ÐÒÅÄÉÃÔÓ ÔÈÁÔ ÌÉÔÔÌÅ ÓÁÔÉÓÆÉÅÄ 15th Street after installation ÆÁÃÉÌÉÔÉÅÓ ÏÎ ρυ
- 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.

¶ The number of crashes involving bicyclists remained similar 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. In addition to comprehension, violations of the pedestrian signal by cyclists are high, especially by southbound cyclists.

¶ Red-light running by cyclists is high, with over 40 percent of cyclists observed disobeying signals. Compared to the data in the few published studies available on cyclist compliance with bicycle-specific traffic signals, this is a high violation rate, 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.

¶ Motorist attitudes are generally favorable toward the cycle track. The like that it provides ÓÅÐÁÒÁÔÅ ÓÐÁÃÅÓ ÆÏÒ ÃÁÒÓ ÁÎÄ ÂÉÃÙÃÌÅÓħ ÁÎÄ Í Ì
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.

Based on these findings, the team makes the following 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 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 signal progression for southbound cyclists north of Massachusetts Avenue to the extent possible. 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.

RECOMMENDATIONS FOR FUTURE BICYCLE FACILITIES

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

Data Collection and Monitoring

This research study provides a comprehensive analysis of the study facilities over the first one to two years after installation. However, 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).

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 oneway 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 have 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 ÔÈÁÔ ÄÏÅÓÎõÔ ÒÅ-bi-direction travel), one-way bicycle facilities on paired couplets is generally preferred.

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/right turning vehicles in advance of intersections, have not yet been implemented in Washington, DC. 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.

Green Colored Pavement

The Federal Highway Administration (FHWA) [illegible] 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 Manual on Uniform Traffic Control Devices (MUTCD), this interim approval gives agencies authority to install colored pavement along bicycle facilities, subject to several conditions (Reference 2).

However, 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).

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 (see Photo 1) 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 of cycle tracks along transit routes, but may be necessary to maintain ADA compliance for transit service.

Photo 1 Example Transit Stop Designed to Accommodate Bikes (Portland, Oregon)

http://www.flickr.com/photos/theoverheadwire/4331455737/sizes/m/in/set-72157601072534715/

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 the District 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 developed 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.

Section 2
Study Facilities

STUDY FACILITIES

16th Street NW / U Street NW / New Hampshire Avenue NW

16th Street/U Street/New Hampshire Avenue is a six-leg intersection. DDOT installed bicycle boxes, bicycle signals, and contra flow bicycle lanes in August 2010 to facilitate cyclist travel on New Hampshire Avenue. New Hampshire Avenue is a low-volume roadway connecting Florida Avenue on the north to Dupont Circle on the south, making it a naturally attractive route for cyclists. However, New Hampshire Avenue is restricted to one-way travel for one block on either side of U Street, with travel only allowed in the direction away from U Street, to prevent the use of New Hampshire Avenue by through traffic. This configuration also simplifies the traffic signal phasing and reduces cycle lengths.

As a result of the one-way restrictions, cyclists desiring to use New Hampshire Avenue were forced to travel against traffic on the approach to 16th Street/U Street and to cross the intersection in two stages ÖÉÁ ÔÈÅ ĐÅÄÅÓÔÒÉÁÎ ÃÒÏÓÓ×ÁÌËÓ8 $$/4õÓ ÉÍĐÒÏÖÅÍÅÎÔ travel along New Hampshire Avenue safer, more convenient, and legal. Figure 1 shows the location of the intersection improvements, Figure 2A provides pavement marking details, and Figure 2B ¿ Figure 2D show pictures of the new facilities.

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

- *Bicycle boxes* were installed on the northbound and southbound approaches on 16th Street (as shown in Figure 1 and Figure 2D). 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.
- *Bicycle signals* were installed on the northwest and southeast corners of the intersection (as shown in Figure 1 and Figure 2C). 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 in Figure 1 and Figure 2B). 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 1 and Figure 2C). 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.

Pennsylvania Avenue NW from 3rd Street NW to 15th Street NW

DDOT installed bicycle lanes in the center median of Pennsylvania Avenue from 3rd Street to 15th Street in June 2010. The lanes have no physical separation from general traffic apart from flexible bollards located near intersections. For this analysis, the corridor was divided into two study segments (1) 6th Street to 10th Street and (2) 10th Street to 15th Street. Figure 3A shows the Pennsylvania Avenue project limits.

This section of Pennsylvania Avenue connects the White House on the west to the Capitol on the east. It is both a high-volume street and an important bicycle connection through the downtown core. Prior to the bicycle lane installation, this section of Pennsylvania Avenue generally had an eight-lane cross-section and was used by 1,800 vehicles during the weekday peak hour. This lane configuration, combined with the high volume of vehicular traffic, made it difficult for most bicyclists to comfortably travel along Pennsylvania Avenue.

To improve cyclist mobility, DDOT installed five-foot bicycle lanes in each direction with three-foot buffers on either side within the center median. Figure 3B shows the typical pavement marking details for the bicycle lanes, buffers, and intersection bicycle approaches. Figure 4A shows a picture of the constructed median bicycle lanes and buffers.

A flush median is provided at intersections to accommodate bicyclists and pedestrians. Bicyclists wait behind the median in the bicycle lanes during red signal phases. The approaching bicycle lane splits at intersections to provide a bicycle turn lane and a bicycle through lane. The turn lane uses the six feet that are allocated to bike lane buffers at mid-block locations and places turning bicyclists between the through cyclists in each direction. The through cyclists are controlled by a traffic signal for through motorists on Pennsylvania Avenue, while turning bicyclists are expected to act as pedestrians and use the crosswalks. Figure 4B is a picture of the bicycle signs for turning and through bicyclists at an intersection, and Figure 4C is a picture of the bicycle lane approaches at an intersection.

Figure 5A and Figure 5B display the typical lane configurations and cross-sections for Pennsylvania Avenue between 6th Street and 10th Street, while Figure 5C and Figure 5D display the typical lane configurations and cross-sections between 10th Street and 15th Street. The cross-section varies along Pennsylvania Avenue, so the figures portray the typical cross-section found along the segment of interest.

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 4A, Figure 5A, and Figure 5C). 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 4B).

¶ *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.

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DDOT installed a cycle track (a separated two-way bicycle facility between the sidewalk and parked vehicles) on 15th Street from E Street/Pennsylvania Avenue to V Street. For this analysis, the corridor was divided into three study segments: (1) E Street/Pennsylvania Avenue to New York Avenue, (2) H Street to Massachusetts Avenue, and (3) Massachusetts Avenue to V Street. There is no cycle track on 15th Street between New York Avenue and H Street because cyclists are able to ride through a park section adjacent to the White House where private vehicular traffic is not permitted. Figure 6A shows the 15th Street project limits.

15th Street is a two-way street south of Massachusetts Avenue and a one-way northbound street north of Massachusetts Avenue. Before the cycle track installation, bicyclists shared the roadway with vehicular traffic, and there were no accommodations for southbound bicyclists north of Massachusetts Avenue. DDOT installed the two-way cycle track both to allow for southbound bicycling along the corridor and to provide a separated facility to increase the comfort of cyclists riding in both directions.

The two-way cycle track was installed in two phases. In November 2009, DDOT installed a one-way southbound cycle track between Massachusetts Avenue and U Street, and in November 2010, DDOT expanded the facility to a two-way cycle track between E Street/Pennsylvania Avenue and V Street. The current two-way cycle track is eight feet wide with a three-foot buffer between the cycle track and vehicular traffic or parked vehicles, and is located on the west side of the roadway. There are white, flexible channelizing posts installed within the three-foot buffer to further delineate the dedicated cyclist space to motorists. Figure 6B is a picture of the constructed two-way cycle track with buffer, and Figure 6C shows the typical pavement marking details for the cycle track.

At intersections along 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. This design was implemented by prohibiting on-street parking in the intersection vicinity. The design is intended to make cyclists more visible to motor vehicles making left turns from 15th Street onto intersecting roadways.

At intersections along the two-way section of 15th Street, no buffer is provided between the two cycle track directions. Dashed striping and shared lane markings are used through intersections to alert motorists to the presence of cyclists and to guide cyclists through the intersections. Figure 6D shows the cycle track configuration approaching an intersection in the one-way section, and Figure 6E shows the pavement markings provided through the intersections.

Figure 7A and Figure 7B display the typical lane configurations and cross sections for 15th Street between E Street/Pennsylvania Avenue and New York Avenue, Figure 7C and Figure 7D display the typical lane configurations and cross sections between H Street and Massachusetts Avenue, and Figure 7E and Figure 7F display the typical lane configurations and cross sections between Massachusetts Avenue and U Street. The cross section varies along 15th Street, so the figures portray the typical cross section found along the segment of interest.

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 6B). 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 6E).
- *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 6B).
- *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.

Section 3
Study Methodology

STUDY METHODOLOGY

Several types of evaluation were conducted for each location to determine the effect of the bicycle facilities. Table 2 summarizes the evaluations performed and data used for each facility. Data used for the analyses were collected by DDOT and Kittelson & Associates, Inc. (KAI) for conditions before and after bicycle facility installation. A short description of the evaluations is provided below, with subsequent sections providing the evaluation results.

Table 2 Facility Evaluation Summary

Type of Analysis	16th / U/ New Hampshire	Pennsylvania Avenue	15th Street	Data Collected for Analysis
BICYCLE FACILITIES				
Volume Analysis	ã	ã	ã	¶ Bicycle counts
Highway Capacity Manual 2010 Multi-Modal Level of Servic		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Pavement condition
Danish Bicycle Level of Servi		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Pavement condition ¶ Land use information
Bicycle Environmental Qualit Index		ã	ã	¶ Motor vehicle counts ¶ Lane geometry and cross section ¶ Speed data ¶ Land use information
Bicycle Corridor Travel Tim		ã	ã	¶ Signal timing data
Crash Analysis	ã	ã	ã	¶ Crash data
Survey Analysis	ã	ã	ã	¶ User intercept surveys ¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video
MOTOR VEHICLE FACILITIES				
Volume Analysis	ã	ã	ã	¶ Motor vehicle counts
Highway Capacity Manual 2000 Arterial Level of Servic	ã	ã	ã	¶ Motor vehicle counts ¶ Pedestrian counts ¶ Lane geometry and cross section ¶ Speed data

Type of Analysis	16th / U/ New Hampshire	Pennsylvania Avenue	15th Street	Data Collected for Analysis
				¶ Signal timing and phasing
Travel Time Analysis			ã	¶ Drive time data
Survey Analysis	ã	ã	ã	¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video
PEDESTRIAN FACILITIES				
Highway Capacity Manual 2010 Multi-Modal Level of Service		ã	ã	¶ Motor vehicle counts ¶ Pedestrian counts ¶ Lane geometry and cross section ¶ Speed data
Survey Analysis	ã	ã	ã	¶ User intercept surveys ¶ Surrounding neighborhood surveys
Video Analysis	ã	ã	ã	¶ Study area video

Volume Analysis

DDOT anticipated that installing bicycle facilities could influence both vehicular and bicycle volumes. Before-and-after traffic volumes were analyzed to determine trends along the study roadways.

DATA COLLECTION

Volume data were collected for motorized vehicles and bicycles both before and after the bicycle facilities were installed. For projects completed in multiple stages (e.g., 15th Street cycle track), volume data were collected before facility installation, after phase one of the project was completed, and after phase two was completed.

Synchro reports for 16th Street/U Street/New Hampshire Avenue, Pennsylvania Avenue, and 15th Street are available in Appendices A1, B1, and C1, respectively. The reports contain the motorized vehicle volumes used in the volume analysis. Appendices A2, B2, and C2 contain the bicycle volume data used in the analysis for 16th Street/U Street/New Hampshire Avenue, Pennsylvania Avenue, and 15th Street, respectively.

Highway Capacity Manual Multi-Modal Level of Service

A *Highway Capacity Manual* (HCM) 2010 multi-modal level of service (MMLOS) evaluation was completed for the Pennsylvania Avenue and 15th Street corridors (Reference 3). This type of level-of-service (LOS) evaluation assesses the quality of service experienced by all roadway users: pedestrians, bicyclists, drivers, and transit riders. MMLOS was calculated for each roadway segment (i.e., street sections between signalized intersections) for conditions before and after installation of the final phase of the bicycle facilities.

There are many factors that affect MMLOS, which vary depending on the type of user being evaluated. In general, bicycle LOS calculations consider cross-section dimensions, intersection crossing distance, number of driveways and access points, motorized vehicle volumes and speeds, heavy vehicle presence, on-street parking, and pavement condition.

The factors associated with motor vehicle LOS are the number of stops made by vehicles and the presence of left-turn lanes.

Pedestrian LOS is based on pedestrian density; sidewalk width and horizontal separation from the street; presence of street trees, occupied on-street parking, or other physical barriers; motorized vehicle volumes; conflicts with turning vehicles at signalized intersections; average wait time at signals; and ability to cross the street between signalized intersections

MMLOS also provides a method for evaluating transit LOS. Transit LOS was not evaluated for either 15th Street or Pennsylvania Avenue because there is no transit service provided on 15th Street and because the bicycle facilities did not affect transit service (or pedestrian access to transit service) on Pennsylvania Avenue. The analyses performed for this study were meant to provide insight into changes resulting from the bicycle facilities, so no transit MMLOS evaluation was required on either study corridor.

The MMLOS methodology develops LOS scores for each type of user, which correspond to traditional LOS letters as follows for the pedestrian and bicycle methodologies:

A = <2.00	D = 3.50 – 4.25
B = 2.00 – 2.75	E = 4.25 – 5.00
C = 2.75 – 3.50	F = > 5.00

DATA COLLECTION

The data required for the MMLOS evaluation include motor vehicle, bicycle, and pedestrian counts, speed data, and lane geometry and cross-section information. DDOT and KAI collected data for the facilities for conditions before and after the final phase of installation of the bicycle facilities. *Appendices B3 and C3 contain data for the MMLOS evaluation for Pennsylvania Avenue and 15th Street, respectively.*

Danish Bicycle Level of Service

A cumulative logit regression model was developed for the Danish Road Directorate to determine the level of bicyclist satisfaction related to bicycle facilities along road segments (between intersections) using data from Denmark. The model predicts the percentage split among six levels of satisfaction, and a LOS letter is calculated using the splits. Descriptions of the specific variables used in the Danish Bicycle LOS model are available in the report "Pedestrian and Bicycle Level of Service on Roadway 3ÅÇÍÅÎÔÓ" (Reference 4). The factors applied in the model include motor vehicle volumes, average speeds, land use type, cross-section dimensions, presence of sidewalks, medians, bus stops, and vegetation, number of travel lanes, pedestrian and bicycle volumes, and the number of parked vehicles. The variables with the largest effect on bicyclist satisfaction are the type and width of the bicycle facility and the distance to motor vehicles in the nearest drive lane and pedestrians. The Danish bicycle LOS model was incorporated into this evaluation because it accounts for bicycle facility types such as cycle tracks that are not accounted for in the HCM MMLOS model due to a current lack of such facilities in the United States.

DATA COLLECTION

The Danish Bicycle LOS method requires motorized vehicle counts, speed data, and cross-section, pavement condition, and land use information. The data used as part of this evaluation were collected before and after the final installation of the bicycle facilities. *Appendices B4 and C4 contain Danish Bicycle LOS analysis data for Pennsylvania Avenue and 15th Street, respectively.*

Bicycle Environmental Quality Index

Bicycle Environmental Quality Index (BEQI) indicator values were determined by the San Francisco Department of Public Health Environmental Health Section using survey responses from bicycle experts and members of the bicycle community. Survey respondents ranked the importance of an indicator variable for bicycle quality and the relative importance of the indicator response categories within each indicator variable. A discussion of the specific variables included in the model is available in the reports "ÂÉÃÙÃÌÅ %ÎÖÉÒÏÎÍÅÎÔÁÌ 1ÕÁÌÉÔÙ)ÎÄÅØ" (Reference 5) and "Bicycle Environmental Quality Index (BEQI), Draft Report ςππω" (Reference 26). The information used in the model includes the presence of a marked bicycle facility, connectivity, driveway cuts, traffic calming, bicycle signs, lighting, vegetation, and bicycle parking, along with bicycle facility width, pavement type, posted speed, motorized vehicle volumes, and cross-section, line-of-sight, and land use information.

The maximum BEQI score, calculated based on the variables listed above, is 100 points. The following levels of quality are identified, based on the number of points achieved

- 100 – 81: Highest quality, many important bicycle conditions present
- 80 – 61: High quality, some important bicycle conditions present
- 60 – 41: Average quality, bicycle conditions present but room for improvement
- 40 – 21: Low quality, minimal bicycle conditions
- 20 – 0: Poor quality, bicycle conditions absent

DATA COLLECTION

The data used for the BEQI evaluation were collected before and after the final installation of the bicycle facilities. *Appendices B5 and C5 contain BEQI analysis data for Pennsylvania Avenue and 15th Street, respectively.*

Bicycle Corridor Travel Time (Signal Progression)

KAI completed a bicycle progression analysis to assess Â É Ã Ù Ã ability to travel along Pennsylvania Avenue and 15th Street without impedance due to signal timing constraints. Note that signal timing changes were not generally within the scope of the initial design; the signal progression analysis serves instead to assess how well the existing signal timing works for cyclists and to identify potential opportunities for improvement.

The progression analysis was completed for traffic conditions along Pennsylvania Avenue and 15th Street after the installation of the cycle facilities, using the signal timing parameters given in Synchro files provided by DDOT.

For each time period (weekday a.m. and weekday p.m.), a progression analysis was completed in both directions (eastbound and westbound for Pennsylvania Avenue, northbound and southbound for 15th Street) for bike speeds of 10 miles per hour (mph) and 15 mph.

For analysis purposes, the Pennsylvania Avenue corridor was split into two sections: (1) 3rd Street to 9th Street and (2) 9th Street to 15th Street. The 15th Street corridor was split into three sections (1) between Lower E Street and I Street, (2) between I Street and Rhode Island Avenue, and (3) between Rhode Island Avenue and V Street. The progression analysis for each section began at the start of a green signal.

Bike acceleration start-up times were not considered in this analysis. Because the speed of a bicycle is difficult to keep constant, it is assumed that travel times are averages and that a two to three second