OVERVIEW:
Literature Review

The following information is a contextual review of bicycle facility research and implementation guides, accompanied by a selective case study survey of innovative on-street cycling implementations in both the United States and abroad. This information is intended to serve as a catalogue of ideas on which to base facility recommendations for local implementation.

Existing Documents

As U.S. federal transportation policy increasingly supports the development of alternative transportation options, planning for bicycle facilities has emerged on federal, state and local levels. With its initial release in 1981and 1991 update, AASHTO's *Guide to the Development of Bicycle Facilities* has continued to serve as the primary reference for standardized bicycle facility design and implementation.

The 1997 *New York City Bicycle Master Plan* released by the Department of City Planning offers a local context for the implementation of AASHTO recommended facilities. However, it provides few recommendations for the implementation of innovative facilities increasingly seen in use in other cities in the United States and internationally. These facilities can be used to serve cyclists more safely in locations where standardized facilities (AASHTO recommended) are not easily implementable or desirable.

Literature search

Outreach for this report focused on large metropolitan areas somewhat comparable to New York City, in addition to cities with a reputation for innovative cycling programs. Literature was received from more than 30 national bicycle programs and 10 international cycling programs.

National case studies

A review of written materials and phone interviews with local bicycle coordinators shows that the majority of bicycle facility implementation currently done in the United States centers on the installation of conventional bicycle lanes. A growing number of cities surveyed, however, have experienced successful installations of innovative facilities in recent years. These cities include Minneapolis, MN, Cambridge, MA, Portland, OR, Philadelphia, PA, and San Francisco, CA.

Nationally implemented facility innovations can be grouped into three categories: (1) intersection treatments, (2) improvements to standardized facilities and (3) new roadway accommodations. Intersection treatments used to reduce conflicts between cyclists and turning vehicles include advanced stop boxes and combination turn lanes; improvements to standardized facilities include the use of pigmented lanes and improved road marking programs; new roadway accommodations include bicycle/bus lanes, contra-flow bicycle lanes, center-median lanes and various traffic calming installations.

International case studies

Information received from other countries reflects a higher level of bicycle facility innovation and evaluation than that seen in the United States. Denmark and the United Kingdom, in particular, provided literature documenting extensive research and evaluation which expands upon U.S. facility implementations.

Successful implementation of innovative facilities in the United States provides a realistic basis upon which New York City can find innovative ways to safely accommodate cyclists on highly trafficked city streets. In addition, national testing of international bicycle facilities will likely continue as planning for cycling becomes more pervasive in the United States, particularly with increased levels of federal funding. Examples of cycling facilities used in other countries can be used to broaden the scope of innovation used in the United States to date, and supplement evaluation and safety data to guide local implementation efforts.

EXISTING DOCUMENTS

An expanding array of bicycle facility literature has been published in the decade following the 1991 Intermodal Transportation Efficiency Act (ISTEA). Moreover, with authorization of the federal 1998 Transportation Efficiency Act for the 21st Century (TEA 21), a continued national emphasis on bicycle research and implementation will occur.

Bicycle Facility Research

For the past twenty years, a major point of research and debate both in the United States and abroad has been the relative merits of separating bicyclists from motor vehicles versus integrating them into traffic flow.

A 1995 report published by the Federal Highway Administration (FHA), *Bicycle Safety-Related Reseach Synthesis*, summarizes this debate as one in which both sides used “safety” as the cornerstone of their argument:

- proponents of separation argue that bicycles and motor vehicles do not mix well because of speed differentials, operator skill, visibility and other factors;

- proponents of integration contend that seperated facilities create dangerous intersections, and that all bicyclists can be trained to ride confidently in traffic.

The nature of this debate, however, has changed over the past twenty years as much has been learned about the planning, design, operation and maintenance of bicycle facilities. In particular, the FHA’s *Research Synthesis* cites a number of case studies showing reductions in bicycle accident rates upon the implementation of bike lanes (pp.80-84). This report also cites growing evidence that the presence of bike lanes is a significant determinant of the level of bicycle use in a community:

> “In the context of the current Federal policy goal of increasing bicycle use, the issue of perceived safety and the comfort of bicyclists assumes much greater significance. Study after study reports that potential bicyclists... want a designated space in which to operate -- and that without the feeling of safety this confers on them, they simply will not ride in current traffic conditions” (p.82).

Current FHA research includes a three-year comparative analysis of bike lanes versus wide curb lanes. The study is being reviewed and should be finalized before the end of 1998. At that time, a Transportation Research Board (TRB) paper will be prepared that summarizes the results.

Overall, there has been an emerging recognition in research literature that a range of potential facilities can be used to accommodate bicyclists, and that the major issues are those of design and selection. The safety of bicyclists is influenced more by the design of a particular facility than the decision to implement that type of facility.

Implementation Guides

A number of federal, state and local guidelines have been developed for the implementation of bicycle facilities. The following pages provide a context for the *Making Streets Safe for Cycling* report by briefly describing a number of these documents.

Descriptions are organized into federal, New York State and New York City listings, paying specific attention to design guidelines and standards. These are not intended to provide an exhaustive listing of bicycle literature. Those documents listed, however, have emerged as widely referenced and recognized national guidelines and standards, or standards and reports specifically applicable to the New York City area.

Federal literature contains planning and design guidelines that are widely referenced by nearly every state (including New York). In addition, this literature offers a comprehensive review of both national and international programs, policies and design adaptations for bicycle facilities in the 1990’s.

Literature produced by New York State focuses on streamlining federal bicycle guidelines into planning for state and local projects.

New York City planning and policy documents apply coordinated state and federal guidelines to a local network. Design standards recommended in this literature generally rely on a limited number of AASHTO recommended facility types. Brief descriptions of innovative on-street facilities are contained in these documents, although none recommends implementation specific to the local network.

Federal Documents

***Selecting Roadway Design Treatments to Accommodate Bicycles*, 1994**
Federal Highway Administration (FHA)

This manual provides comprehensive guidelines for the selection of roadway design treatments to accommodate bicycles, and fills in many of the policy and planning gaps that the American Association of State Highway and Transportation Officials (AASHTO) did not address in its 1991 *Guide to the Development of Bicycle Facilities* [1] (described below). More specifically, this manual recommends design treatments and specifications for roadways to serve different types of bicyclists under various sets of traffic operational factors. Two types of design bicyclists are recognized: group A (advanced) and group B/C (basic adult and child).

Bicycle facilities recommended for implementation by the manual are limited to standard bike lanes and wide curb lanes, although shared motor vehicle/bicycle lanes (no special provision for cyclists) and roadway shoulders are also listed. Separate tables are provided for highways with urban sections, both with and without on-street parking.

Specific dimensions are suggested for the width of the recommended facility type. The manual is careful to note that these suggestions:

> "...reflect the current state of the practice in the design of bicycle-friendly roadways. Users of this manual are encouraged to treat these recommendations as 'guidelines' rather than absolute standards" (p.11).

Unfortunately, the manual provides only limited information on retrofitting existing streets for bicycles, stating that "...the recommended design treatments in the tables are most easily implemented when new construction or reconstruction is planned" (p.13).

***Guide to the Development of Bicycle Facilities*, 1991**
American Association of State Highway and Transportation Officials (AASHTO)

Uniform guidelines in the United States were established in 1981 by AASHTO, and continue to provide a national reference which most states and cities, including New York City, have adopted entirely or with minor changes as standards for the design of cycling facilities. The most recent update of the *Guide* was published in 1991, much of which is devoted to facility design.

Following a section on safe roadway conditions for facility implementation (i.e. safe drainage grates and good pavement quality), the AASHTO *Guide* describes several on and off-street facility types available to engineers and planners. On-street facility types covered by the *Guide* include bicycle lanes and wide curb lanes, in addition to the cyclists' use of shoulders and bicycle routes.

In creating the 1991 edition, notable changes were made to the 1981 AASHTO *Guide for the Development of Bicycle Facilities* based on research and experience gained during the 1980's.[2] These include:

- *Shoulders*. "Wide curb lanes and bicycle lanes are usually preferred in restrictive urban conditions and the widened shoulder will generally be more accommodating in rural circumstances" (p.13). Previously no distinction was made between rural and urban areas.

- *Wide curb lanes*. "Restriping to provide wide curb lanes may also be considered on some existing multi-lane facilities by making the remaining travel lanes and left-turn lane narrower. This should only be performed after careful review of traffic characteristics along the corridor" (p.15).

The *Guide* includes detailed cross sections and photographs of properly designed bicycle facilities. Many of its on-street design recommendations (including recommended lane widths) are referenced in detail by both the *New York State Department of Transportation Design Manual* and the *New York City Bicycle Master Plan* (see p.7 for detailed dimensions).

However, the *Guide* offers no specific guidance for selecting roadway improvements other than a general listing of topics to consider in planning. The *Guide* also offers few recommendations on the operation and maintenance of bicycle facilities.

Although the *Guide* has become the basic comprehensive reference for facility designers across the country, it is intentionally vague and

> "...not intended to set forth strict standards, but, rather, to present sound guidelines that will be valuable in attaining good design sensitive to the needs of both bicyclists and other highway users" (pp.1-2).

A revision of the AASHTO *Guide for the Development of Bicycle Facilities* is currently in progress, and is expected to be released next year.

***Manual on Uniform Traffic Control Devices (MUTCD)*, 1988, FHA**

First released in 1935, the *MUTCD* is the national manual for streets and highways that established guiding principals for the design and usage of traffic control devices, including signs, signals, pavement markings and traffic islands. Conformance with *MUTCD* standards for highway and street traffic control is required in nearly every state by statute, including New York.

Chapter 9 of the *MUTCD* contains traffic controls for bicycle facilities, including signage, markings and signals. Bicycle-use related signs are categorized as either regulatory, directional or warning, and together with pavement markings are well-covered in the *Manual*. The *Manual* does not, however, present much information on bicycle-use related signals or intersection treatments.

***National Bicycling and Walking Study*, 1992-94, FHA**

The *National Bicycling and Walking Study* was an effort by the federal government to develop a national policy on bicycling and walking. This study produced a series of 24 case studies, including several directly related to the design of on-street bicycle facilities:

- "*Traffic Calming, Auto Restricted Zones, and Other Traffic Management Techniques: Their Effect on Bicyclists and Pedestrians*" (No. 19)
- "*The Effects of Environmental Design on the Amount and Type of Bicycling and Walking*" (No. 20)
- "*Current Planning Guidelines and Design Standards Being Used by State and Local Agencies in the Design of Pedestrian/Bicycle Facilities*" (No. 24)

Report no. 24, "*Current Planning Guidelines and Design Standards Being Used by State and Local Agencies in the Design of Pedestrian/Bicycle Facilities*," is a case study of state and local programs. Emphasis is placed on state and local adaptations of AASHTO and *MUTCD* recommended guidlines, including the design of on-street roadway and signage improvements.

***Improving Conditions for Bicycling and Walking: A Best Practices Report*, 1998 FHA**

Although this report does not present specific guidelines for facility design, it is the most recent national effort to track outstanding bicycle and pedestrian projects at state and metropolitan levels of government. Its intent is to "...highlight exemplary projects and to show what has been done that can be replicated in other places." Projects described in the report formed a basis for the *Making Street Safe for Cycling* literature review.

[1] *It is important to note this manual is not meant to serve as a comprehensive guide to the design of bicycle facilities, and explicitly refers users to the AASHTO Guide for detailed specifications.*

[2] *Taken from "Bicycle Safety-Related Research Synthesis," a 1995 FHA publication.*

New York State Documents

***New York State Bicycle and Pedestrian Plan*, 1997. NYS Department of Transportation (NYSDOT)**

The *New York State Bicycle and Pedestrian Plan* fulfills the requirements of section 1025 of ISTEA, and consists primarily of broad objectives for the development of statewide pedestrian and bicycle infrastructure and program elements. One of the top ten priority actions listed in the *Plan* is the development of,

> "...a user friendly design manual, ...including provisions for on-street bicycle facilities, road shoulders, sidewalks, crosswalks, intersection design, signage, pavement markings, multi-use paths, etc." (p.iii).

Highway Design Manual
***Chapter 18: Facilities for Pedestrians and Bicycles, Revision 29,* 1996**
NYSDOT

The *Highway Design Manual* provides design guidance for pedestrian and bicycle facilities to be included in NYSDOT projects, to meet needs identified during project scoping or preparation of design approval documents. The AASHTO *Guide for the Development of Bicycle Facilities* is used as the basis for establishing the minimum requirements for the design and construction of bicycle facilities on Department projects, and is frequently referred to in the NYSDOT manual.

The *Highway Design Manual* also directly references the FHA manual *Selecting Roadway Design Treatments to Accommodate Bicycles*. It specifically states, however, that the FHA manual,

> "... is not a standard, nor is it a comprehensive guide to the design of bicycle facilities. It is intended to provide a rational and consistent method for determining widths for accommodating bicyclists on roadways... [and] should not be used as the only reference for decision making where its guidelines cannot be met" (p.18-5).

The *Highway Design Manual* does state that on-street accomodations for cyclists can usually be met through use of wide curb lanes, bike lanes, shared roadways or paved shoulders. With regard to the placement of edge stripes for wide curb lanes, it adds that,

> "...where this has the potential for encouraging the undesirable operation of two motor vehicles in one lane, it may be preferable to place the edge stripe at the edge of the travel lane, provided that a 1.2 m wide "shoulder" space (approximate) would remain between the curb face and lane stripe" (p.18-42).

***Pedestrian and Bicycle Facility Scoping Guide*, 1995**
NYSDOT

The Scoping Guide is largely a synopsis of the NYSDOT *Highway Design Manual* guidelines and criteria used to facilitate decisions about the inclusion of bicycle and pedestrian facilities as components of roadway construction and improvements. In addition to meeting design criteria, selected facilities must be consistent with the projected cost and scope of an overall project, and be necessary or desirable at the project location.

For scoping on-street bicycle facilities, this guide refers to minimum design standards and guidelines from AASHTO and the NYSDOT *Highway Design Manual*, and also recommends use of wide curb lanes, standard bike lanes, shared lanes and roadway shoulders.

New York City Documents

***New York City Bicycle Master Plan*, May 1997**
BND Program, Transportation Division
NYC Department of City Planning

The *New York City Bicycle Master Plan* was released by the NYC Department of City Planning as a comprehensive policy document for bicycling in New York City. The *Plan* contains specific recommendations for an on-street network, bridge access, off-street and greenway facilities, access to mass transit, and design guidelines. It was released in conjunction with a series of maps depicting a 900-mile on and off-street network for the five boroughs.

The *Plan* directly refers to both the AASHTO *Guide to the Development of Bicycle Facilities* and the *MUTCD* signage guidelines for facility design. Recommendations for on-street accommodation of bicyclists emphasize the installation of bike lanes, although the use of wide curb lanes, shoulders and shared roadways are also noted.

Recommended bicycle lane widths are consistent with both AASHTO and NYSDOT guidelines:

- <u>overall</u>; 4-foot minimum bicycle lane width requirement for all situations;
- <u>with parking</u>; 5-foot bicycle lane on an urban street between a motor vehicle lane and parking lane (no bicycle lane recommended *between* a curb and a parking lane);
- <u>with parking</u>; 12-foot minimum curb lane for combined bicycle travel and motor vehicle parking;
- <u>no parking</u>; 4-foot minimum bicycle lane between motor vehicle lane and the curb face;
- <u>no parking</u>; 4-foot minimum bicycle lane between traffic lane and roadway shoulder (on a highway without curb or gutter);
- <u>no parking</u>; 12-foot minimum and 14-foot (or more) preferred wide curb lane accommodating both cyclists and motor vehicles.

The *Plan* also briefly describes AASHTO recommended movements for cyclists at intersections. Cyclists proceeding straight through intersections are typically allowed to cross the path of motorists turning right, and intersection design that encourages these crossings in advance of the intersection in a merging fashion are preferable to those that force the crossing in the immediate vicinity of the intersection. Left-turning cyclists are generally permitted to turn either as a vehicle (in traffic) or as a pedestrian (following crosswalks).

Finally, the *Plan* briefly highlights selected innovative on-street facilities:

Pigmented bicycle lane: used to reinforce the exclusivity of use of the bicycle lane by cyclists, reduce vehicle speeds by creating the impression of a more narrow roadway, and discourage motor vehicle parking in the bike lane.

Center median bike lane: a lane adjacent to the center median of a roadway (far left side of a travel direction). Use of these lanes can sometimes reduce the number of conflicts between bicycles and motor vehicles, as bicyclists are not forced to cross the path of right-turning vehicles.

Shared bike/bus lane: recommended as a 14 to 16-foot wide curb lane on roadways with peak bus headways of 1.5 to 2 minutes, limited right-turn movements, prominent sign and pavement markings and consistent enforcement.

Contra-flow lane: a one or two-way bicycle lane located adjacent to a one-way motor vehicle lane. This alternative allows cyclists to ride against oncoming traffic and is therefore contrary to the "rules of the road." These lanes are often recommended to provide direct access on routes that have few intersections, where cyclists can merge into typical traffic flow, and where a substantial number of cyclists are already using the roadway in a contra-flow direction. The design of contra-flow lanes may include some form of physical separation or buffer zone.

"Bicycle-exclusive" signal phase: adjusts timing of motor vehicle signal to allow adequate time for cyclists to cross two or more lanes of traffic. Signal phase is activated by pushbuttons or metal detection loops embedded in the pavement.

Advanced stop line/box: bicycle-only stop line or box placed in front of motor vehicles at signalized intersections to give cyclists a head start to make turning movements across multiple lanes of traffic.

Separated or raised bicycle lane: "on-street" bicycle lane physically separated from motor vehicle lanes through the installation of unit paver safety strips or rubberized curbs, or construction of bike lane on a slightly raised path on a mountable curb.

Curb separated bicycle lane on Sixth Avenue
Source: NYCDOT

In 1980, a curb separated bicycle lane was installed on Sixth Avenue in Manhattan, and removed within several months. This installation is cited by the *Masterplan* as a lesson on the "... importance of designing a site specific facility." By locating a new, protected right-of-way on one of the city's most heavily used pedestrian corridors, the lane became more a refuge for street vendors than cyclists.

Traffic calming devices: changes to the physical street geometry and design used to reduce the amount and speed of motor vehicle traffic. These include speed tables (elongated speed bumps), traffic circles, chicanes (navigable barriers), bicycle boulevards (on which barriers prevent through movement of motor vehicles but allow clear bicycle access), and slow streets (a concentration of various traffic calming devices heavily signed to prioritize non-motorized traffic).

***Bicycle Blueprint,* 1993**
Transportation Alternatives

In 1993, Transportation Alternatives (a local cycling advocacy group) released its *Bicycle Blueprint: A Plan to Bring Bicycling Into the Mainstream in New York City*. This plan presented a comprehensive bicycling agenda, including recommendations for improvements to the physical infrastructure, "on the job" cycling, security, accident prevention and bicycle education.

Specific and extensive suggestions for short and long-term on-street design improvements contained in the *Blueprint* (pp.37-38) include:

- Pigmented and texturized bike lanes;
- Painted lines delineating bike lanes several inches wider than regular lane stripes (e.g. 4-inch v. 6-inch wide);
- Replacement of diamond markings with bicycle profile stencils;
- Upgrade of existing signage (additional signs and signs directing cyclists to bicycle lanes from adjacent streets);
- Bike lanes continued through intersections using dashed lines ("pegga tracking");
- 5-foot or wider lanes between sidewalks and parking lanes;
- 5-foot or wider lanes next to center islands or medians on two-way routes;
- 5-foot or wider curbside lanes displacing on-street parking lanes;
- Bicyclist waiting areas in front of motor vehicle stop lines (e.g. advanced stop box);
- Slightly raised bicycle lanes across intersections without traffic lights (speed hump);
- Grade separated curbside bicycle lanes (with mountable curb);
- Curbside or median bike lanes with no grade separation from motor vehicle lanes, with a line of paving stones or other tactile visual and boundary markers.

In addition to design suggestions, the *Blueprint* also offers a list of specific recommendations for improvements to the street network. More general proposals included in the plan are pilot traffic calming projects, experimentation with lower speed limits, a gradual elimination of taxi cruising, and the removal of street surface hazards, including temporary steel construction covers and raised or lowered catch-basin covers problematic for cyclists.

***Bikeway Planning and Policy Guidelines for New York City*, May 1978**
NYC Department of Transportation (NYCDOT)

New York City's first comprehensive report on bicycle planning included broad policy recommendations and a skeletal framework for what later became the BND's recommended 550-mile on-street network. This 1978 document was released two years prior to uniform AASHTO guidelines, and recommended a minimum bicycle lane width of 3 1/2 feet, and a preferred width of 4 feet or more.

LITERATURE SEARCH

In the past decade, information on national and international bicycle planning and design guidelines, including on-street facility innovations, has been well-documented. Few attempts, however, have been made to incorporate innovative facilities into the NYC bicycle network.

Scope of the literature search

The literature search performed for this report does not provide a comprehensive update of bicycle policies and programs well-documented in other reports. Rather, it is a selective case study review of national and international on-street innovative cycling facility *implementations*. Ultimately, experience learned from cycling implementations in other places will be used to make recommendations for similar facilities in New York City.

Although this study focuses on innovative facilities in other U.S. cities, it is also an attempt to catalogue innovations seen in other parts of the world. National testing of international cycling facilities is likely to continue as planning for cycling becomes more pervasive in the United States, particularly with increased levels of funding available through TEA 21. Larger international cities (including London and Munich) experience high volume traffic conditions similar to those found in New York City.

The literature reviewed in this report was collected by reaching out to a wide number of national and international cycling programs. Outreach focused on large metropolitan areas somewhat comparable to New York City, in addition to cities with a reputation for innovative cycling programs.

Implementation in the U.S.

Written information was received from over 30 United States city-based cycling programs; phone interviews were conducted with 18 state and local bicycle program coordinators and planners (Appendix C).

Information received from these sources show that the majority of current on-street (Class II) bicycle facility planning work being done in the United States is the implementation of standardized bicycle lanes (5 to 6 feet wide) on streets where one or more lanes of motor vehicle travel or parking had been removed or narrowed. Examples of innovative on-street (Class II) facilities, the focus of this report, were less prevalent. In addition, these types of facilities rarely received formal, written evaluation.

International research

The international literature seach conducted for this study reached out to a total of 12 countries. The best responses were those from countries with well-established cycling programs and high levels of ridership, including Germany, Great Britain, Denmark, Finland, Japan and The Netherlands.

Many facilities about which written information was received were implemented as part of larger, national campaigns to promote cycling and walking as alternatives to automobile use. This national prioritization of improved cycling facilities was often reflected through a broad range of facility implementations, extensive evaluation of those facilities and overall safety research.

International case studies contained in this report are meant to compliment the survey of national case studies in two ways: (1) to broaden the scope of facility innovation seen in the U.S. to date and (2) to supplement evaluation and safety data not yet available for national implementation of comparable facilities.

United States

As network and policy planning for bicycles in the United States has expanded, a number of cities have implemented innovative on-street facilities. These facilities are used to serve cyclists more safely in locations where standardized facilities (AASHTO recommended) are not easily implementable or desirable.

Facility implementations focused almost exclusively on creating safe interaction between cyclists and vehicular traffic, without significant disruption to overall traffic flow.

Following is a brief description of many of these prototype facilities, listed first by facility type and then by city (also see pp. 7-8 for descriptions of facility types given by the *New York City Bicycle Master Plan*). Facilities are grouped into three categories:

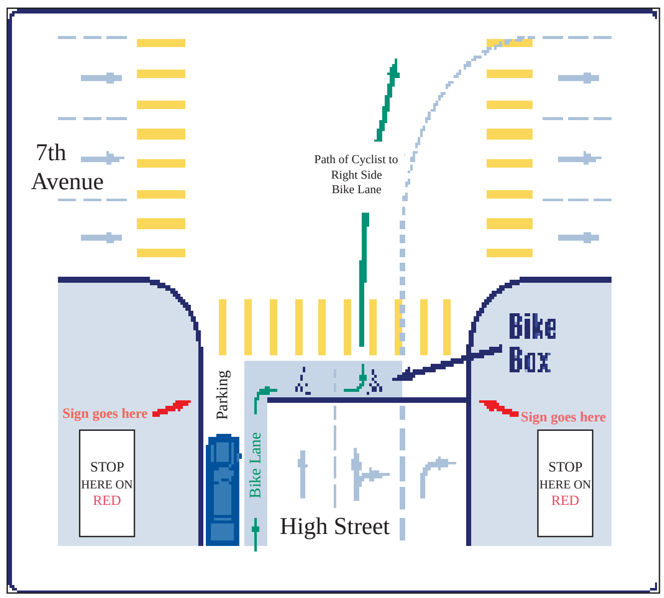
- **Intersection treatments**
- **Improvements to standaridized facilities**
- **New roadway accommodations**

Evaluation, enforcement and public awareness issues specificly linked to innovative facility implementation are also noted.

INTERSECTION TREATMENTS

Advanced stop box

Eugene, OR
In Eugene, an advanced stop box, or "bike box," was installed in spring of1998 on High Street at Seventh Avenue, a busy intersection in downtown Eugene. An advanced stop box is similar to an advanced stop line, and allows cyclists to wait ahead of motor vehicles at signalized intersections to create safe and effective through movements.



Bicycle box design at High Street, Eugene OR
Source: City of Eugene web site

Eugene's bike box on High Street (a one-way street) allows cyclists to move from a left-side bike lane with parking into a protected zone at the head of the middle traffic lanes when the signal is red. Then, when the signal changes to green, cyclists can proceed through the intersection ahead of motor vehicles and safely switch to the through bike lane on the right-hand side of the street after the intersection.

The box is not meant to be used when the signal is green. Signs indicate that traffic, except bikes, should stop prior to the box at a red signal ("stop here on red except bikes").

Using the bike box, cyclists are placed ahead of other traffic and have the right-of-way as they ride through the intersection. Because cyclists generally are able to accelerate quickly through the intersection and because vehicles are not allowed to turn on red at that intersection, the new safety box is not expected to significantly delay or inconvenience motorists.

Before the bike box was in place, cyclists continuing through the intersection (using the left-side bike lane) were forced to make a left turn at the following intersection. Cyclists wishing avoid this left turn had to either find a gap and cross two lanes of through traffic, or dismount and use the crosswalk with pedestrians.

Preliminary evaluation of this facility by the City of Eugene's bicycle program has found that the box creates a safe bicycle route for commuters, which is "exactly what [it] is intended to provide." A description of the box and accompanying diagram can be accessed through the City's web site at www.ci.eugene.or.us.

Formal evaluation of this facility is currently being performed by the University of North Carolina Highway Safety Research Center (HSRC). Cyclists traveling through the intersection have been videoptaped before and after placement of the box. One measure of effectiveness is to ascertain if cyclists use the box and if the box is used correctly. Another is whether motor vehicles encroach into the box. Conflicts between bicycles and motor vehicles will also be examined. This evaluation will be completed near the end of 1998, and published after FHA review.

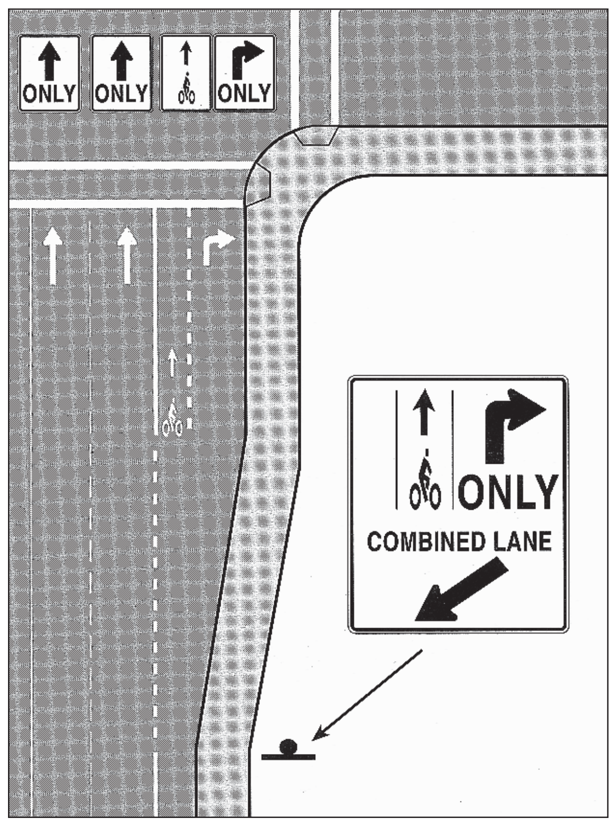
Cambridge, MA
Cambridge recently installed a bike box at an atypical intersection where cyclists need to access a left-side bike path entrance from a right-side bicycle lane. The box allows cyclists stopped at the intersection to move in front of traffic to make a quick left turn onto the path without confusing or conflicting with motor vehicle traffic not allowed to make the turn.

This facility is described as highly successful by the city's bicycle program, but has received only informal visual evaluation. Future steps under consideration for the intersection include the addition of a dedicated bike signal to allow cyclists to make the left turn from the box more easily.

Combination turn lane

Eugene, OR
In addition to its advanced stop box, Eugene has installed a 12-foot shared right-turn lane at several intersections on 13th Street. The design is innovative in the way that it deals with limited right of way in the right turn area, which leaves insufficient room to mark a bike lane to the left of the vehicle right turn lane.

At the intersection, a 5-foot bike lane along the right side of 13th Street converts to a 5-foot bike pocket. This leaves only 7-feet for motor vehicles next to the bike pocket.



Combination turn lane configuration and signage. Source: Oregon Bicycle Master Plan

It had been assumed that motor vehicles and bicycles would tend to queue behind each other with the limited space, but this appears to happen only when trucks, buses, or other large vehicles are in the space. Cars and bicycles usually ride next to each other.

Preliminary videos recorded for an evaulation of this installation by the University of North Carolina HSRC indicate that this happens quite safely. The HSRC evaluation will be completed for FHA review at the end of 1998, after which a report will be published.

IMPROVEMENTS TO STANDARDIZED FACILITIES

Pigmented bicycle lane

Blue pigmented bicycle lane in Portland, east end of the Broadway Bridge (eastbound at Larabee). Source: City of Portland bicycle web site

Portland, OR

In an effort to reduce conflicts between bicyclists and motor vehicles, the City of Portland has installed a test of blue pigmented bicycle lanes. The test lanes are intended to increase motorists' awareness that it is illegal to drive and park in bike lanes, and of their need to yield to cyclists when crossing a bicycle lane to turn right or get into a right-turn only lane. The painted area and its accompanying signs are also intended to caution cyclists to be careful in the conflict area.

Initially, the city selected a dozen conflict areas about which motorists and cyclists had complained. From these, seven sites were chosen for evaluative testing. In each case, the conflict area had already been defined with dashed lines, in addition to signs indicating the need for motorists to yield to cyclists.

A blue color was selected based on research of European techniques to reduce conflict; blue pigmentation was found to be the most promising, cost-effective technique to delineate a conflict area.

The city has partnered with the University of North Carolina HSRC to evaluate the efffectiveness of the blue lane test areas. Each intersection was videotaped and analyzed before and after painting, and a report will be submitted for FHA approval at the end of 1998.

Portland is one of the few cities surveyed (in addition to Eugene) to have made information about its bike lane installations widely available. Approximately six pages of information about the test lanes are available from the City of Portland's Bicycle Program web site, which can be accessed through the City's web site at: www.trans.
ci.portland.or.us.

Alternate paving materials

Tucson, AZ

One of the most well-researched examples of the use of alternate paving materials for bike lanes is the Mountain Avenue demonstration project in Tucson. This project involved the construction of new bike lanes, sidewalks, street lighting and landscaping for 3 miles along Mountain Avenue, from Speedway Boulevard to Grant Road. Mountain Avenue is a collector street, linking the University campus with residential neighborhoods to the north, and receives heavy automobile, bicycle and pedestrian use.

To accommodate cyclists, the project featured 6-foot bicycle lanes (one in each direction) constructed of concrete, next to a 3-foot buffer lane constructed of dark brown precast concrete pavers. The roadway is constructed of asphalt, and the contrast created between the three lanes, bikeway, buffer and roadway, creates a clear division of space between cyclists and motorists.

A detailed evaluation of the demonstration project was performed by Tucson's Department of Transportation in 1992, which surveyed 1,035 residents living near the project to determine travel behavior, changes in corridor use patterns and general perceptions on user safety. Of the 416 respondents,

- 74% used Mountain Avenue five or more times per week;
- 86% regularly used Mountain Avenue as a motor vehicle operator;
- 87% agreed that the improved roadway is safer for bicyclists;
- 85% agreed that the improvement is safer for pedestrians;
- 73% agreed that the volume of bicycle use has increased as a result of the improvements;
- 34% agreed that the volume of motor vehicle use had increased.

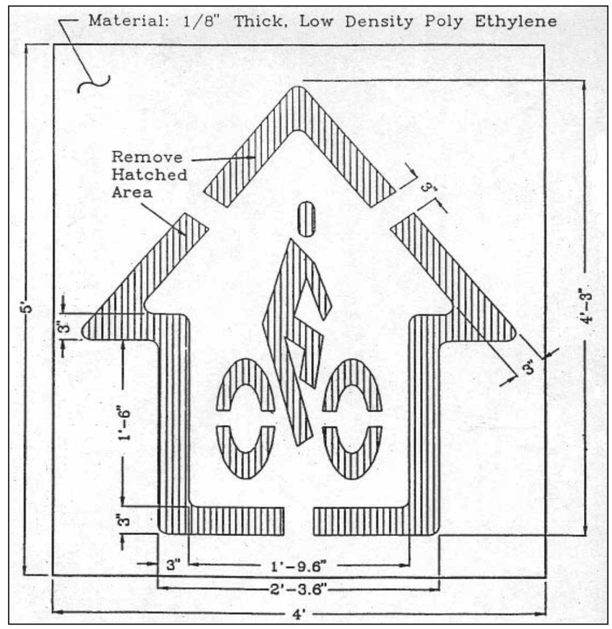
Improved striping and marking

San Francisco, CA

On streets where Class II facilities for cyclists are not continuous, San Francisco has created specialized roadway stencils to increase motorists' awareness of a shared roadway. Although stenciling does not provide an area for the exclusive use of cyclists, this program is included in the scope of the report for its role in creating specialized connectors for Class II facilities.

Green pavement stencils are placed every 200 feet on the outside traffic lane of designated streets, 11 feet from the edge of a curb with parking (3 feet if parking is not allowed). Recently, the city performed a "door zone" survey (of opened car doors) to provide justification for these dimensions. Priority placement for stencils is on segments of Class II routes where bike lanes are discontinuous.

San Francisco's stencils are intended to delineate the right-hand travel corridor that bicyclists will likely use, reinforce the correct direction of travel, and educate bicyclists and motorists of bicyclists' need to ride away from the "door zone" to minimize the risk of being struck by opening car doors, particularly on narrow roadways.



Green pavement stencil used to delineate bikeways. Source: City of San Francisco Bicycle Program

Chicago, IL

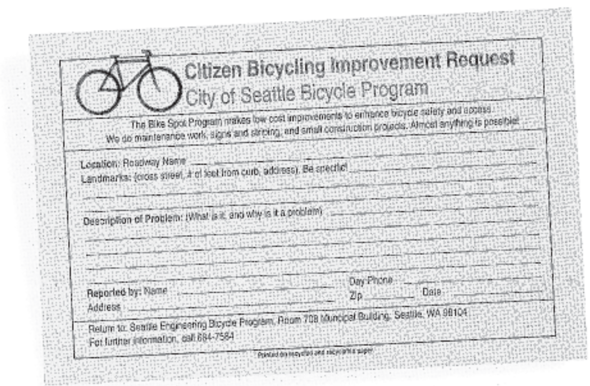
The city of Chicago plans to implement fifteen miles of new or improved bike lanes in its downtown area with several enhanced features:

- A second pavement marking line wherever the bike lane is beside parking, to distinguish the bike lane from the parking area;
- A more reflective, longer lasting and less confusing bike pavement marking;
- A special "Share the Road" pavement marking wherever a bike lane cannot be provided, to remind motorists of the priority bike route (similar to stencil pictured above);
- Taper lines and signs to advise motorists wherever two lanes of traffic narrow to one;
- Poor sections of pavement repaved before the bike lane is striped.

Spot Improvements

Seattle, WA

Beyond routine roadway maintenance, Seattle is one of the few cities with a program specifically designed to address public requests for low-cost improvements benefitting cyclists. The “Bike Spot Safety Program” solicits public information through a “Citizen Bicycling Improvement Request Form” distributed to bike shops, community centers and bicycle club publications. Individuals provide the location and nature of a roadway problem, as well as their name, address and phone number.



Citizen Bicycling Improvement Request
City of Seattle Bicycle Program

The Bike Spot Program makes low cost improvements to enhance bicycle safety and access.
We do maintenance work, signs and striping, and small construction projects. Almost anything is possible!

Location: Roadway Name
Landmarks: (cross street, # of feet from curb, address). Be specific!

Description of Problem: (What is it, and why is it a problem)

Reported by: Name
Address
Day Phone
Zip
Date

Return to: Seattle Engineering Bicycle Program, Room 708 Municipal Building, Seattle, WA 98104
For further information, call 684-7584

Printed on recycled and recyclable paper

Source: FHA Best Practices Report (1998)

When the form is received by the city’s bicycle program, staff assess the request and call the person who filled out the form to let them know that: (a) the problem will be fixed; (b) the problem needs further investigation; or (c) the problem is something that the bike spot program cannot address. In all cases, the citizen knows about how long it will take to respond to their request.

After a field check is performed (if necessary) and a work improvement is approved, a work instruction is sent electronically to the appropriate City crew who do the work, and then notify the bicycle program that the work has been completed. Bicycle program staff then call the citizen who originally made the request to complete the loop.

Seattle’s Bicycle Program regards Bike Spot Safety as,

> “...the single most important program we administer. Citizens appreciate the quick turn-around on the initial phone call. The program is popular with elected officials and other decision makers since it generates thank you letters and phone calls. Finally, it helps the City defend itself against liability claims since we can demonstrate that we have a safety program that quickly responds to maintenance concerns.”

The program works with existing maintenance programs that pay for many of the bike spot projects (e.g. pothole requests). However, new facilities are directly paid by the bike spot program at a cost of approximately $500,000 to $700,000 per year.

NEW ROADWAY ACCOMMODATIONS

Bicycle/bus lane

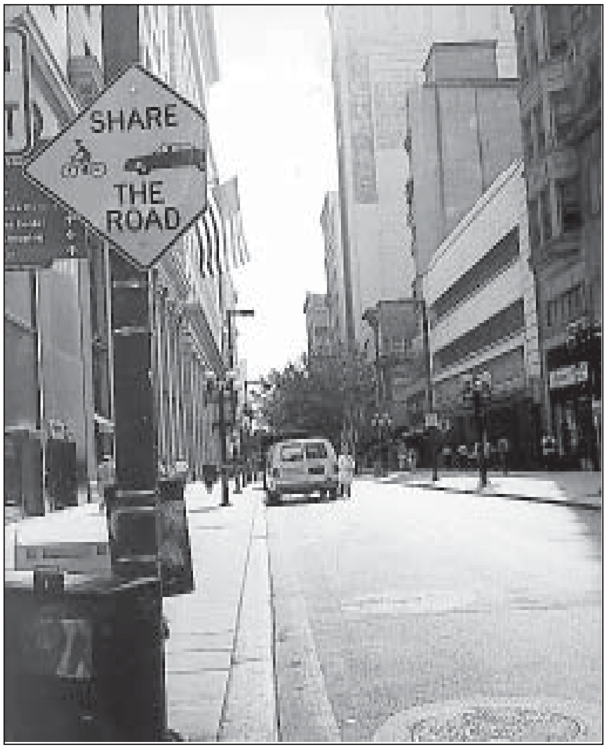
Philadelphia, PA

Philadelphia is implementing an 11-foot bicycle/bus lane in its Center City district. The shared lane will run from 6th to 18th Streets on Chestnut Street (one-way) as part of an effort to reintroduce motor vehicle traffic to a former pedestrian mall.

Currently there are two lanes on Chestnut Street on which vehicle traffic is prohibited from 6am to 7pm. This restriction does not apply to delivery trucks, service trucks, buses and hotel shuttles with permits. Delivery trucks are able to stop and unload in the left lane, the right lane is dedicated to bus traffic, and bicyclists travel where space is available.

Wide and distinctively paved sidewalks on the street will be narrowed to create three lanes. A right-hand 11-foot shared bicycle/bus lane will be next to a center 10-foot motor vehicle lane, then a left-hand 7-foot parking lane.

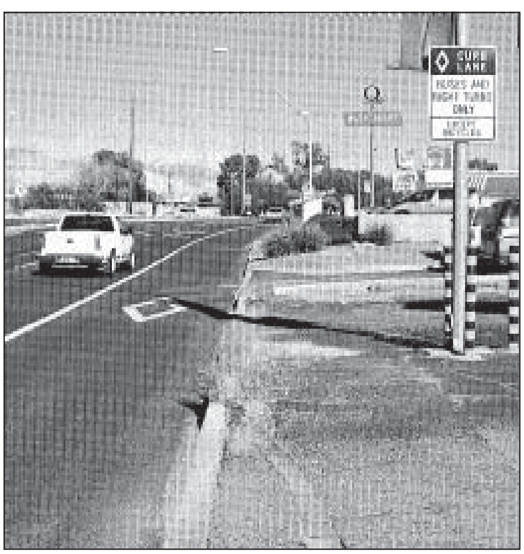
These lane widths are consistent with lane widths on an increasing number of bike lane streets in Philadelphia striped with 7-foot parking lanes and 10-foot travel lanes. Transportation planners have cited the beneficial traffic- calming effect created by the narrowed travel and parking lanes, in addition to more mangeable pedestrian crossing distances.



Current (July 1998) configuration on Chestnut street, Philadelphia (to be converted to bicycle/bus use).

Tucson, AZ

Tucson began implementing bicycle/bus lanes in 1986. The lanes accommodate cyclists and the fixed route transit system (Sun Tran), and are also utilized as right turn lanes for vehicles. No accidents have been reported as a result of these lane installations.



Tanque Verde Rd. bicycle/bus lane (in Tucson).

A Bicyclist Advisory Committee (with members appointed by the mayor and city council) has played an active role in the operation of the lanes by the transit authority, providing training information for bus drivers about cyclists in the roadway.

Contra-flow bicycle lane

Minneapolis, MN

In the past several years, Minneapolis has installed some of the most innovative on-street contra-flow bicycle lanes in the country. One such lane exists on Hennepin Avenue, a commercial street which runs through Minneapolis' central business district .

The Hennepin Avenue bicycle lane runs for a total of 10 blocks, beginning as a one-direction contra-flow lane.

Contra-flow lane on Hennepin Avenue at 2nd Street, looking south (lane begins at 1st Street).

After 2 blocks, the lane widens to beome a 10-foot wide *bi-directional* bicycle lane with a 1-foot buffer on each side, and continues for approximately 10 blocks. The lane is located between a 12-foot south bound (contra-flow) bus lane and three lanes of north bound automobile traffic (variable widths). The bicycle lane is seal coated in a red quartz; traffic and bus lanes are treated with black seal coat. One lane of automobile traffic was removed to create the bicycle lane.

Bi-directional contra-flow bicycle lane on Hennepin Avenue between 4th and 5th Streets, looking south.

Primarily because Hennepin Avenue is a highly trafficked route (25,000 cars/day), initial concerns were raised about the safety of the new bicycle lane. Of particular concern was the high percentage of northbound automobile traffic making left turns on 5th and 3rd Streets to access a nearby freeway, requiring drivers to look in two directions for oncoming cyclists.

Left-turn treatment on Hennepin Avenue at Washington Avenue, looking north.

Instead of prohibiting vehicle turns along the bicycle path, however, signs were installed to alert motorists to cycling movements ("Left turns yield to bikes"), giving cyclists the right-of-way.

The Hennepin Avenue bike lane is seen as a successful installation by city officials, improving conditions for cyclists without resulting in increased bicycle or vehicle accidents or negatively impacting high volume traffic flows.

However, the Hennepin Avenue lane has been met with mixed review from some cyclists, who cite abrupt endpoints which leave them mid-traffic at intersections. In addition, cyclists uncomfortable riding in traffic may prefer to use Nicollet Mall, a pedestrian street parallelling Hennepin Avenue one block east.

Additional contra-flow bicycle lanes are scheduled for implementation in downtown Minneapolis in Summer 1998, on Marquette and 2nd Avenues. These streets make up a one-way pair located two and three blocks east of Hennepin Avenue (past Nicollet Mall).

Similar to Hennepin Avenue, these contra-flow lanes will be located between a southbound (contra-flow) bus lane and three northbound motor vehicle lanes. Each bicycle lane, however, runs in one direction only (with buses).

Presidio, San Francisco, CA

A recent demonstration project run by the National Park Service at the Presidio is a bi-directional (contra-flow) bicycle lane with special signage. The bicycle lane is a 1000-foot long test facility on a one-way park street. The right-hand bicycle lane is 5-feet; the bi-directional left lane is also 5-feet. A 4-foot striped and reflectorized buffer separates that lane from motor vehicle traffic.

Signs posted along the route indicate special turning allowances for bicycles, exempting them from motor vehicle restrictions with the statement, "except for bicycles." Park police were initially uncomfortable with the lane, in part because of its location at a conversion from a two to a one-way street. The demonstration, however, has not resulted in any increase in bicycle or motor vehicle accidents.

Madison, WI

Madison has a 12-block contra-flow bike lane on University Avenue (from Bassett St. to Babcock Dr.), which was created from a converted contra-flow bus lane in 1984. The lane is central to the University of Wisconsin campus in Madison, and is used by over 3,000 commuters each day. No real increases in accident rates, however, have occurred along the avenue.

To help prevent conflicts between cyclists and left-turning vehicles (across the bicycle lane) at several of the avenue's busiest intersections, advanced red lights have been installed for the bike lane. These halt contra-flow bicycle movements while a longer green light allows cars to make left turns (to keep automobile traffic moving through the intersection). Regulatory signs for motorists have also been installed at several of these intersections which read, "Left turn yield on green to bikes."

Arthur Ross, the Bicycle Coordinator for the City of Madison, recommends the use of contra-flow lanes in special circumstances, particularly on streets with few crossings (outside of a traditional street grid).

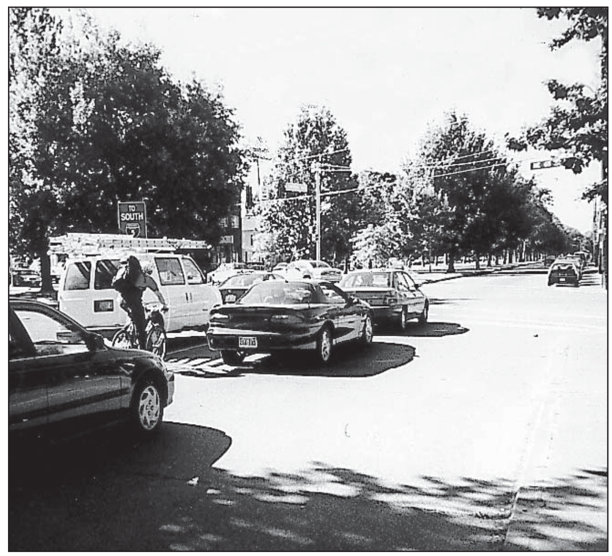
Seattle, WA

Seattle currently has two 5-foot contra-flow bicycle lanes. Each lane runs a length of two blocks, and was implemented in the late 1970's to create site-specific access.

Contra-flow bicycle lane on N. 34th St. at Evanston Ave., facing east.

Although no extensive evaluation of these lanes has been performed, neither has resulted in increased bicycle or motor vehicle accidents. Peter Lagerwey, the Bicycle and Pedestrian Coordinator for the City of Seattle, recommends the use of contra-flow lanes as access connectors (to other on-street facilities or destinations) for a length of one to three blocks. These lanes are also recommended for use on blocks without on-street parking, with a minimum number of driveway crossings.

Center-median bicycle lane



Center-median lane located on Ravenna Blvd. at NE 65th (Seattle) places cyclists between a vehicle left-turn lane and through lane at major intersections.

Seattle, WA

Seattle has had a center median bicycle lane since the late 1970's. The lane runs for approximately two miles, and is located next to a 100-foot wide median. The lane is widely considered a success, although the unusual circumstances of its placement have not led to recommendations for similar lanes elsewhere in the city.

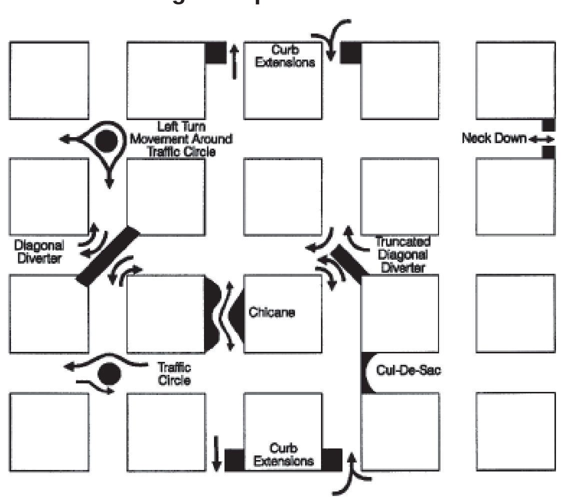
As with Seattle's contra-flow lanes, Peter Lagerwey recommends center median lanes for use on continuous roadways with few turning movements. Intersections where motor vehicles make left turns through the median should be handled similarly to intersections where cyclists using a right-side bicycle lane face right turning motor vehicles (AASHTO recommended). To accommodate a left turn:

- the center median (left side) bike lane ends before the intersection;
- a short space exists where cyclists merge right as vehicles move into the far left turning lane;
- a dedicated through bike lane picks up again through the intersection (to the right of the vehicle turning lane).

Traffic-calming techniques

Traffic-calming implementations are used to reduce the amount and speed of vehicle traffic, generally benefitting both pedestrians and cyclists. Examples of traffic-calming techniques include traffic circles, raised crosswalks (speed tables), and chicanes (obstacles that interrupt roadway alignment), and are described in the *New York City Bicycle Master Plan* (referenced on p.8).

Traffic-calming examples:



Source: NYC Bicycle Master Plan

A number of traffic-calming programs have been successfully implemented throughout the United States, including those in Seattle, WA and Cambridge, MA. Although traffic calming often creates safer traffic conditions, some facilities pose potential hazards for cyclists without careful installation. Speed bumps and raised reflectors or rumble strips, in particular, can deflect a bicycle wheel, causing a cyclist to lose control. Placement of these facilities which leaves an open path along the edge of a roadway for cyclists to use, or the use of speed tables instead of bumps (with a more gradual incline) could create safer conditions for cyclists. In addition, proper maintenance of these facilities is needed to ensure that roadway barriers do not increase the amount of debris collected on the sides of roadways where cyclists typically ride.

For these reasons, specific examples of traffic calming installations sought for this literature review were those (1) specifically used to accommodate cyclists on a roadway or (2) evaluated specifically for cyclists.

Bicycle boulevard
Palo Alto, CA

A bicycle boulevard is a street upon which bicyclists have precedence over automobiles, through the installation of barriers which prevent through movement of motor vehicles. It is important to note that these facilities do not deny or reduce access to residents and their cars, but simply prevent them from being used as a cut-through by commuters or other users.

The Bryant Street Boulevard in Palo Alto is a 3-mile residential street that parallels two major arterials and connects south Palo Alto to the Downtown north city limits. The first 2 miles of Bryant Street were converted into a bicycle boulevard in 1982. In 1992, the city extended the boulevard 1.25 miles north to the city limit, first with temporary barriers (6 months), then with permanent fixtures.

Improvements to Bryant Street included:

- Elimination of nine (of thirteen) stop signs to reduce travel time for bicyclists;
- Two street closures passable only by bicycles installed to create a discontinuous route for motor vehicles;
- Two pedestrian/bicycle bridges over natural (creek) barriers;
- Traffic signals for bicyclists installed at Embarcadero Road, a major arterial, to provide protected crossing phase for bicyclists, but not motor vehicles;

- One traffic circle installed as a traffic calming measure in the neighborhood just south of Downtown;
- Cross street traffic controlled by stop signs.

No striped bike lanes were necessary on the street, and no changes in on-street parking were made. Evaluations of the boulevard show it to be highly successful: bicycle counts exceed 600 bicyclists a day at various points along the route. Vehicular traffic volumes range from 200 to 2000 ADT at various points.

Concerns of nearby residents that traffic would be diverted from Bryant Street to adjacent streets prompted the city to put a traffic circle in one intersection to slow motor vehicles instead of block them. This compromise won the support of many local officials in addition to residents.

From its experience, the City of Palo Alto recommends the use of temporary fixtures during trial periods to improve bicycle boulevard design and gain public acceptance for it. The City also recommends residential streets flanked on both sides by arterial streets as the best candidates for bicycle boulevard installation.

International

A survey of international on-street cycling facilities was conducted for this literature review to broaden the scope of innovative facility types seen in the United States. Countries with well-established cycling programs, including Germany, Great Britain, Denmark, Finland, Japan and The Netherlands, were most responsive to requests for written materials.

Overall, information received from these countries reflects a higher level of bicycle facility innovation and evaluation than seen in the United States to date. In many countries, however, the need for facility innovation was secondary to a need to expand the network of conventional bike lanes and facilities.

Of the available case studies of innovative facilities, those contained in this report generally include specific guidelines and dimensions for implementation, as well as formal evaluation. A number of these installations were specifically designed to create safe interaction between cyclists and pedestrians in the roadway, *in addition to* safe interaction between cyclists and vehicular traffic.

As with the previous section on national case studies, a brief description of international innovations are listed first by facility type, then by country.

INTERSECTION TREATMENTS

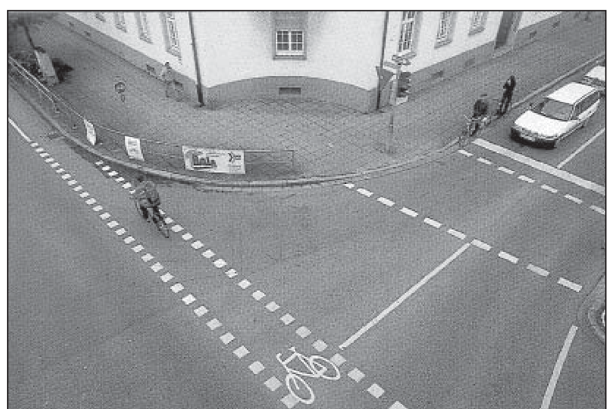
Crossing-area markings

Denmark

To draw attention to the potential conflict between cyclists and cars at signalized intersections, Denmark (and other European countries) commonly use three different types of bicycle areas at intersections: minimum, left-hand edge, international and blue surface. Bicycle pavement symbols are generally marked with each type of treatment.

Minimum cycle crossing:

The cycle crossing is marked with a broad, broken line extending to the separation between opposing traffic lanes of the intersecting roads. If the width of the roadway of the intersecting road is less than 5.5 meters (18 feet), the line should extend completely through the intersection. Only the left-hand edge of the bicycle lane should be marked, with a line of 50 cm (20 inch) long and 30 cm (12 inch) wide markings. The strokes of the line must be of equal length. The width of the cycle crossing is often the same as the bicycle lane which is interrupted.



Broken line cycle crossing at a junction in Freiburg (Germany). Source: Cities Make Room for Cyclists

Left-hand edge/international cycle crossing:

At complex junctions, both a left and right-side wide, broken demarcation line are used straight through the intersection. Where the right-hand edge of the crossing is bounded by another marking (e.g. a pedestrian area or give-way line), the broken line at the right-hand edge can be omitted.

Blue surface crossing:
Blue pigmentation is used to define the crossing area, often in combination with a broken left-side demarcation line.

Blue pigmented crossing in Odense (Denmark), used in conjunction with a left-hand broken line marking. Source: Cities Make Room for Cyclists

A blue surface (including cycle symbols) is the most visually powerful type of marking. This type is normally used at junctions where there are many cyclists and/or high safety risks for cyclists. The visibility of the other types is lower; these are used in junctions with lower volumes and accident rates. Blue surfaces at cycle crossings are used most often in Copenhagen, although the three other types of crossings have been implemented throughout Denmark.

Each type of cycle crossing is intended to increase drivers' attentiveness to cyclists and show how far it is possible to drive into the intersection without conflicting with them, especially during right-hand turns. The separation of road users from one another also helps "control" the behavior of cyclists at an intersection.

A Danish study concluded that the safety of cyclists at intersections increased with cycle crossings. Traffic accident studies showed a decrease in the number of personal injuries with the use of demarcated cycle crossings, and a 57% decrease in the number of serious injuries.

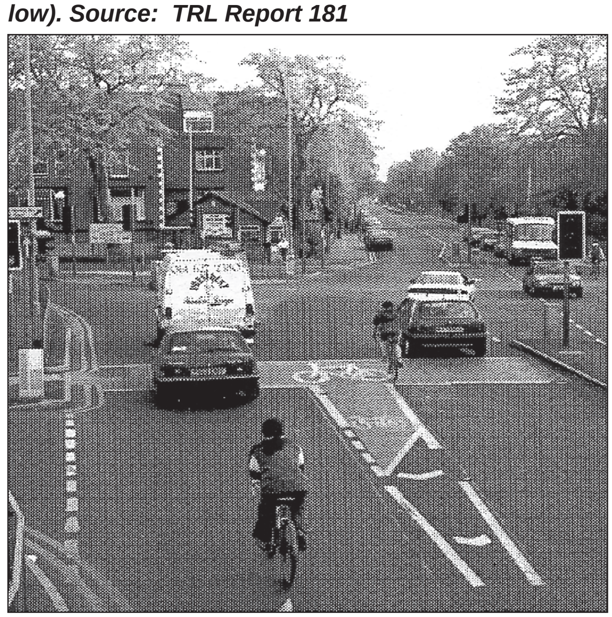
A comparison of the the different types of cycle crossings showed that the blue markings have the best effect on safety. Crossings marked with a 30 cm (12 inch) wide broken line showed no significant change in the number of accidents and personal injuries.

Advanced stop box

United Kingdom

In 1996, the Transport Research Library published a study (commissioned by the Department of Transport) on advanced stop boxes. The box allows cyclists to stop ahead of motor vehicles at signalized intersections, and includes a cycle lane approach located either (1) "nearside" (near the curb and most common) or (2) as a center lane approach:

Nearside lane (above); center lane approach (below). Source: TRL Report 181



Since the introduction of advanced cycling facilities in 1984, research work in the U.K. had established that they operated satisfactorily. This project expanded on previous reseach to:

- investigate the value of a non-nearside approach lane, with reference to the turning movements of left-turning motor vehicles versus "ahead" cyclists;
- assess the effect of different signal timings on the value of an advanced stop line.

These aims were explored with reference to the turning movements of cyclists and motor vehicles at intersections. It is important to note that because drivers in the U.K. regularly use the *left*-hand side of the roadway, turning directions should be applied to a U.S context accordingly (in the reverse).

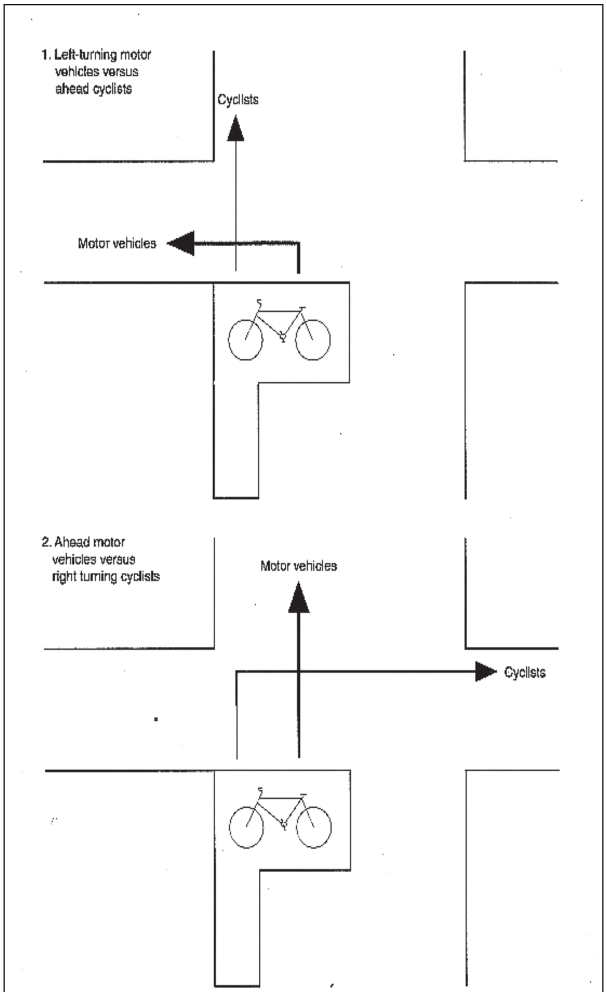


Fig. 1 Types of conflicting turning movements

Source: TRL Report 181

Video recordings were made at six sites with varying degrees of cyclist and motor vehicle flows. Sites at Manchester and Chelmsford, for example, had busy roads leading into city centers with high motor vehicle flows (665 and 661 per hour); a site at Cambridge (part of a main cycle route into the city centre) had almost as many cyclists as motor vehicles during the day.

From the film, cyclists' movements were coded approaching the junction, at the junction and making turning movements. "Conflicting turning movements" were recorded if either a cyclist or motorist was forced to do something other than a standard movement. Examples include being forced to stop, wait, brake or swerve while turning.

The results of the study were summarized under its two main aims of resesearch:

The value of a non-nearside approach lane:

- Although a large proportion of cyclists will use a nearside cycle lane approach to turn left or continue ahead, very few cyclists use the whole length of a nearside cycle lane to turn right. Instead, cyclists either tend to use part of the cycle lane and move before the reservoir, or ignore the cycle lane altogether (and remain in the all-vehicle lane).
- As vehicle flow increases, right-turning cyclists will use a nearside cycle lane less. This study suggests a threshold of 200-300 motor vehicles per hour. A central cycle lane could be an option if there are a sufficient number of cyclists making right-turns at an intersection;
- Central cycle lanes are useful at sites with more than one all-vehicle lane, a large proportion of left-turning motor vehicles and a large proportion of "ahead" cyclists;
- A central cycle lane performs the function of putting cyclists to the right of vehicles in an all-vehicle lane, usually a left-turn filter lane;
- There appears to be a relationship between the location of the cycle lane approach and the conflicting turning movements of left-turning motor vehicles versus "ahead" cyclists: more are occurring at sites with a nearside cycle lane approach than at sites with a central cycle lane approach;

- There are no apparent safety problems for cyclists entering a central cycle lane.

The effect of different signal timings:

- Cyclists benefit from advanced stop boxes when they arrive at an intersection on red, allowing them to cycle ahead of vehicles and position themselves in the reservoir;
- More cyclists arrive at an intersection when the signals are red in SCOOT mode. SCOOT (Split Cycle and Offset Optimisation Technique) is a sophisticated system where signal timings are constantly adjusted in response to traffic flows;
- Conflicting turning movements tend to occur more frequently for cyclists who arrive at the intersection when the signals are green;
- There does not appear to be a strong relationship between signal timings and the conflicting turning movements of "ahead" vehicles versus right-turning cyclists. These conflicting turning movements could be related to the way right-turning cyclists approach the stop box and their expectation of the signals at the intersection.

Additional recommended guidelines:

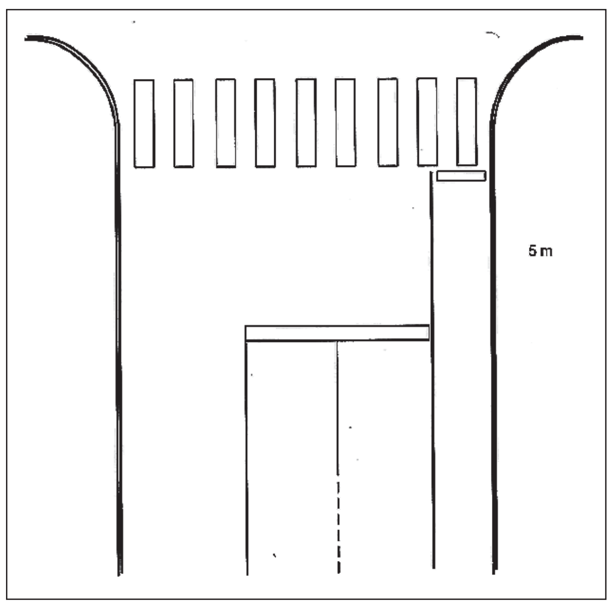
- It is preferable for the cycle lane and the advanced stop box reservoir to have a different surface coloring from the rest of the roadway. The cycle logo should be included in the reservoir. The cycle lane should ideally be at least 1.5 meters (5 feet) wide. An "anti-skid" material may also be of value;
- Advanced stop boxes can be installed at junctions with wide-ranging motor vehicle flows. In this study, motor vehicle flows were up to 8000 vehicles in one day (over 650 per hour at several sites);
- An advanced stop box layout which does not have a second signal head at the motorist stop line has proven to be as safe as the original layout, and cheaper to install.

Germany (Munich)
In Munich, advanced stop boxes are currently being considered for some locations but have not yet been widely implemented. The boxes allow cyclists to approach a traffic light in front of motor vehicles, and are used in combination with a separate signal to give them an advanced start to clear the intersection ahead of cars.

According to the Director of the Traffic Control Division of Munich, this type of bicycle facility is not recommended for use when the modal split of cyclists is low compared to that of motor vehicles. This is due to concern that the box will cause confusion and disrupt traffic flow if only a few cyclists are using it, especially throughout colder seasons.

Recessed motor vehicle stop line

Denmark
In 1991, the Road Safety and Environment Department of Denmark's Road Directorate launched a three-year research program to study the safety of cyclists in urban areas. In a study of signalized intersections with bicycle lanes leading up to the pedestrian crossing, vehicle stop lines were moved back by 5 meters (16.5 feet) relative to the cyclists' stop line (at the side of the roadway). It is important to note that unlike advanced stop boxes, the use of recessed stop lines *does not place cyclists directly ahead of motorists* at intersections.



Intersection layout with recessed stop line.
Source: Report 10, Road Directorate, Denmark

The underlying idea was to improve the visibility of cyclists, especially to vehicles turning right at the intersection, after both parties had been waiting at a red light. An assumption was made that recessed stop lines would also benefit pedestrians on the crossing, as pedestrians and drivers of vehicles would have a clearer view and more time in which to assess each others' intentions at signal changes. For motorists, it was determined that moving the stop line would not normally incur any extension of signal timing (see Appendix F).

Analysis was based on a comparison of all Type 312 accidents (a conflict between a right-turning vehicle and cyclist continuing straight through an intersection). Accidents included in the study occurred at the beginning of the green period at 30 intersections, before and after recessed stop lines were implemented.

A total of 382 accidents were studied; of these 28 were Type 312 accidents; of these it was possible to refer 11 to the start of the green period. Ten of these accidents were recorded before implementation of the recessed vehicle stop line (advanced cycle line), and only one accident was recorded after implementation.

Despite the limited amount of accident material available for this study, it was concluded that the recessing of vehicle stop lines increases the safety of cyclists at signalized intersections, where there are extended bicycle paths. This analysis is supported by a similar study conducted in Sweden, described below.

Sweden

A study of the effects of recessed stop lines conducted in Sweden used video recordings for analyses of four intersections. The study assumed that the beneficial effects of recessed stop line implementation included not only the safety of cyclists, but also reduced exposure to the exhaust fumes emitted by idling vehicles.

The results of this study showed that the average risk reduction was 35% per cyclist (measured as the reduction in the number of serious conflicts per cyclist). One inconvenience noted after implementation was that the time taken for vehicles to cross the junction increased by approximately one second.

Intersection redesign (bicycle lane with profiled markings)

Profiled marking intersection redesign (variation 1). Source: Report 10, Road Directorate, Denmark

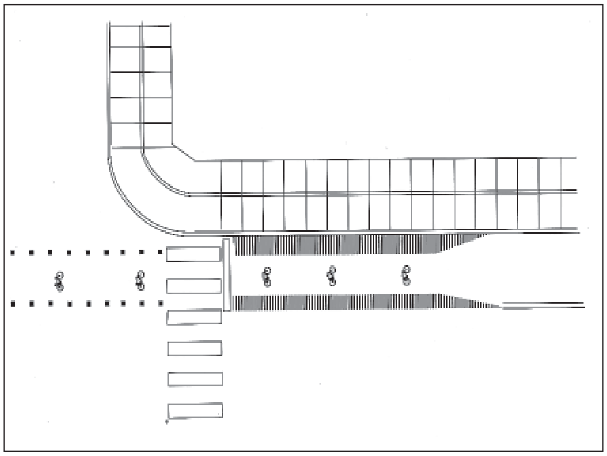
Denmark

Two new designs for cyclists at major, urban intersections which used profiled (slightly raised) markings were studied as part of the research program of the Danish Road Directorate. Both designs were tested at junctions where (1) a cycle path extended up to the pedestrian crossing and (2) at junctions where a cycle path was truncated, causing cyclists and vehicle traffic to share the right-hand turning lane.

Variation 1 (profiled markings)

A total of seven junctions were reconstructed for the first design variation, two of which initially had truncated cycle paths. The new design was intended to give cyclists an exclusive (but narrowed) area right up to the pedestrian crossing, to make cyclists and drivers more alert to one another's presence. Cycle paths which had previously been raised above the level of vehicle lanes were lowered to grade, and any curbs were removed 20 to 30 meters (66 to 99 feet) before the intersection. The width of the cycle area was reduced to between 1.1 and 1.7 meters (3.6 and 5.6 feet), and cyclists and drivers were separated from each other by a white line, 30 cm (1-foot) wide, implemented as a profiled marking.

At each intersection a cycle area (marked with cycle symbols) was laid through the crossing in either blue thermoplastic, or demarcated by two broken strips.



Profiled marking intersection redesign (variation 1). Source: Report 10, Road Directorate, Denmark

From video recordings made before and after reconstruction, the interaction between cyclists and right-turning drivers was analyzed as they approached the intersection. Only cyclists whose progress was not impeded by other cyclists, and who arrived at the intersections at the same time as a vehicle were studied. Interactions in which the cyclists and driver entered the junction without first being required to stop for a red light were recorded separately.

The difference in early and late interactions that occurred before and after the profiled lane was implemented was sought. Special attention was given to interaction on the part of drivers, as their alertness in relation to their duty to give way was considered highly significant to the safety of cyclists.

An interaction was considered early if a driver reacted visibly to the presence of a cyclist more than 1.5 seconds before passing the intersection point; an interaction was considered late if a reaction could only be seen less than 1.5 seconds before passing the conflict point. The conflict point was defined as the point at which the paths of the parties intersected.

An overall evaluation of the results of analysis showed that, in most cases, the profiled lane design led to changes in road-user behavior, which are expected to result in an increased level of road safety for cyclists at major urban junctions. In particular, it was concluded that with the new intersection design:

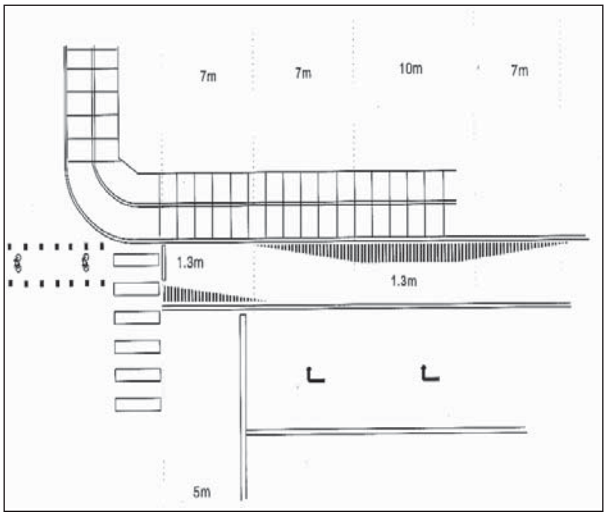
- overall, the proportion of drivers engaging in early interaction increased, as did the implementation of a cycle area extending through a junction;
- the overall trend indicates no change in the proportion of late driver interactions;
- more drivers adapt their speed to cyclists and keep behind the stop line;
- fewer drivers turn right in front of cyclists (neglecting their duty to give way to them);
- at all junctions, the new design brought cyclists an average of 0.26 meters (0.9 feet) closer to vehicles (which is expected to increase the likelihood that the various parties will notice each other in time, thereby avoiding accidents).

Variation 2 (profiled markings)

Profiled marking intersection redesign (variation 2). Source: Report 10, Road Directorate, Denmark

A second profiled bicycle lane design for cyclists at urban intersections was also studied by the Danish Road Directorate. A total of four junctions were reconstructed for this study, of which two initially had truncated cycle paths.

The second junction design used a long, profiled strip on the nearside of the cycle path, towards the curb, and a shorter strip on the offside. The lengths and locations of the strips are shown in the figure below:



Profiled marking intersection redesign (variation 2). Source: Report 10, Road Directorate, Denmark

The width of the profiled strips reduced the cycle areas to 1.3 meters (4.3 feet). These strips had a height of between 8 and 10 mm. (.32 and .4 inches). The purpose of the nearside strip on the cycle path was to guide the cyclists closer to vehicles as they approach the junction, in order to increase the attentiveness of both parties. The distance between the parties was then increased again at the junction, giving drivers up to 0.5 seconds more time in which to react if they had overlooked a cyclist. In addition, the stop line for drivers was moved back by 5 meters (16.5 feet) in all lanes.

A cycle area, demarcated using either blue pigment or two broken lines and marked with cycle symbols, was also implemented through the intersection. The width of the cycle area was increased from 1.3 meters to the cycle-path width on the opposite side of the junction.

A cycle lane across the junction was intended to increase drivers' attentiveness to any cyclists and to show them how far into the junction they could drive without inconveniencing bicyclists, as well as control the behavior of cyclists.

Similar video recordings were used to evaluate intersection redesign variations 1 and 2. From these, analyses recorded the speed of cyclists, the distance between the reaction point and the junction and the lateral location of cyclists on the cycle path. The behavior of drivers as they approached the junction was also recorded. Finally, the time separation between cyclists and vehicles at a junction and the number of serious conflicts were recorded. A "serious conflict" was considered to occur when either one or both of the road users undertook precipitate evasive action in order to avoid a collision.

Overall, the behavior study indicated that the new junction design changed the behavior of cyclists and drivers in a way that will likely result in improved road safety. Specifially, it was found that:

- the average distance between cyclists' reaction points and the stop line increased by between 1 and 3 meters (3.3 and 9.9 feet) at all four junctions. Thus, cyclists reacted between 0.2 and 0.6 seconds earlier after the intersection was reconstructed;
- at three junctions, the proportion of drivers exhibiting "good driving behavior" (drivers who adapted their speed to cyclists and remained at rest behind the stop line) increased by 8 to 18%;
- at three junctions, the time elapsing between cyclists and vehicles passing the conflict point increased by between 0.4 and 0.7 seconds, meaning that the physical distance between these road users had also increased;
- at all junctions, the number of simultaneously arrived drivers who made right turns in front of cyclists (despite the fact that they were bound to give way) dropped from between 12 and 24% to between 3 and 6% after implementation.