Complete Streets

Low Stress Bicycle Facilities
Bicycle User Types

1% LESS THAN

STRENGTH AND FEARLESS
Riding is a strong part of my identity, and I am undeterred by traffic speed, volume, or other roadway conditions.

7%

ENTHUSED AND CONFIDENT
I am comfortable sharing the road with motor vehicles, but I prefer to use bike lanes and bike friendly streets.

60%

INTERESTED BUT CONCERNED
I like riding a bike, but I don’t ride much. I would like to feel safer when I do ride, with less traffic and slower speeds.

33%

NO WAY NO HOW
I don’t bike at all due to inability, fear for my safety, or simply a complete and utter lack of interest.

Source: Fehr & Peers
Level of Traffic Stress (LTS)

Level of Traffic Stress (LTS) is a way to evaluate the stress a bike rider will experience while riding on a road. It is used to categorize roads by the types of riders above who will be willing to use them. LTS is...
Bicycle Infrastructure

Class I: Bike Path

Class II: Bike Lane

Class III: Bike Route

Class IV: Separated Bikeway

Sources: Fehr & Peers, Metro & LA EcoVillage
What do we want?

Motivation ...
route type matters

- Separated from traffic
  - Paved bike path
  - Paved multi-use path
  - Unpaved multi-use path
  - Cycle track

- Quiet streets
  - Residential street
  - Bike route, with traffic calming

- Busy city streets & rural roads
  - Major street, with bike lane & no parked cars
  - Major street, with bike symbols & no parked cars
  - Major street, with bike symbols & parked cars
  - Rural road, with bike symbols & parked cars
  - Rural road, with bike lane & no parked cars
  - Rural road, with parked shoulder

regular cyclists
occasional cyclists
potential cyclists

Photo: Lanzarote Bike Buddies
Build more paths?

A BIKE NETWORK WITH JUST TRAILS IS LIKE A CAR NETWORK WITH JUST FREEWAYS

December 28, 2016

Michael Andersen, local innovation staff writer

Protected bike lanes like this are designed to complement off-street paths. Renderings: HOK Inc. for Trailnet.

If you’ve got a long way to go, or nowhere to go in particular, nothing beats an off-street path.

Build Separated Bikeways?
Caltrans – Class IV Bikeway Guidance
Design Information Bulletin Number 89 (DIB-89)

• Approved in December 2015
• Relies heavily on FHWA guide
• Criteria for:
  • Separation type
  • Separation width
  • Bikeway width
  • Approach tapes
  • Raised bikeways
Dedicated Space

EXHIBIT 3A: Separated Bike Lane Zones

Source: MassDOT Separated Bike Lane Planning and Design Guide
Paint and Flexible Delineators

San Francisco, CA. (Source: Dianne Yee)

Source: FHWA Separated Bike Lane Planning and Design Guide
Raised Median Curb

*Austin, TX (Source: City of Austin)*

Source: FHWA Separated Bike Lane Planning and Design Guide
Parking Protected

Source: FHWA Separated Bike Lane Planning and Design Guide
At Sidewalk Grade
It needs to be more than a buffered bike lane

Buffered Bike Lane:
A dedicated space for bicyclists in the roadway denoted by two white stripes that also has several feet of separation between the vehicle travel and bike lanes AND / OR the bike lane and parked cars.
What is a Caltrans Class IV bike way?

“Separated Bikeway” or “Protected Lane” or “Cycle Track”

A fully protected, dedicated space for bicyclists in the roadway separated from both automobiles and pedestrians. The protection comes from some kind of raised/vertical element: a parked car, planter boxes, raised curb, or flexible posts.
One-Way Separated Bikeway

- **Bicycle lane**
  - 7’ desired width (bicycle volume/gutter width/pavement condition)
  - Driveway conflict areas marked and signed
- **Buffer space**
  - 4’ preferred width (wheelchairs/baby strollers)
  - Define with solid outside lines/crosshatched center
  - Tubular markers (20-100’ midblock spacing, varies by location)
  - Consider maintenance vehicle width (street sweeper/snow plow)
- **Parking lane**
  - 7’ minimum width, 8’ desired width (bicycle volume/gutter width)
  - Driveway conflict areas should be marked and signed

Source: Fehr & Peers

7/7/2017 SACOG Corridor Working Group
Two-Way Separated Bikeway

- Most appropriate on
  - One-way streets
  - Areas with minimal interruptions on one side (such as along railroads, waterfronts)
  - Intersections that can accommodate dedicated bicycle signal phasing

- Design Considerations
  - Similar to one-way cycle track
  - Driveways
  - Pedestrian conflicts
  - Intersections
  - Sight lines
Two-Way Separated Bikeway Design Criteria

- **Bicycle lane**
  - 12’ desired width/8’ minimum in constrained locations
  - Dashed yellow centerline to separate bike traffic and define as two-way
  - Utilize enhanced treatments at conflict areas

- **Parking lane**
  - 7’ minimum width, 8’ desired width (bicycle volume/gutter width)
  - Should be restricted on approaches to driveways and intersections (30’)
  - Driveway conflict areas should be marked and signed

- **Buffer space**
  - 4’ preferred width when adjacent to parked cars
  - Define with solid outside lines/crosshatched center
  - Tubular markers (20-100’ midblock spacing, varies by location)
  - Consider maintenance vehicle width (street sweeper)
Two-Way Separated Bikeway

Source: LA Metro
Intersection Conflicts

Two-Way Cycle Track
• Sight line constraints and conflict points
• Ideally provide dedicated signalize left/right turn lanes to eliminate conflict

Source: Eric Léonard, GENIVAR, Inc.
Exposure of Bicyclist

EXHIBIT 4A: COMPARISON OF BICYCLIST EXPOSURE AT INTERSECTIONS

The diagrams on this page provide a comparison of the levels of exposure associated with various types of intersection designs.

**Exposure Level:**
- **High**
- **High to Medium**
- **Medium to Low**
- **Low**

**Conventional Bike Lanes and Shared Lanes**
Bike lanes and shared lanes require bicyclists to share and negotiate space with motor vehicles as they move through intersections. Motorists have a large advantage in this negotiation as they are driving a vehicle with significantly more mass and are usually operating at a higher speed than bicyclists. This creates a stressful environment for bicyclists, particularly as the speed differential between bicyclists and motorists increases. For these reasons, it is preferable to provide separation through the intersection.

**Separated Bike Lanes with Mixing Zones**
One strategy that has been used in the U.S. at constrained intersections on streets with separated bike lanes is to reintroduce the bicyclist into motor vehicle travel lanes and turn lanes at intersections, removing the separation between the two modes of travel. This design is less preferable to providing a protected intersection for the same reasons as discussed under conventional bike lanes and shared lanes. Where provided, mixing zones should be designed to reduce motor vehicle speeds and minimize the area of exposure for bicyclists.

**Separated Bike Lanes through Roundabouts**
Separated bike lanes can be continued through roundabouts, with crossings that are similar to, and typically adjacent to, pedestrian crosswalks. Motorists approach the bicycle crossings at a perpendicular angle, maximizing visibility of approaching bicyclists. Bicyclists must travel a more circuitous route if turning left and must cross four separate motor vehicle path approaches. Yielding rates are higher at single-lane roundabouts.

**Protected Intersections**
A protected intersection maintains the physical separation through the intersection, thereby eliminating the merging and weaving movements inherent in conventional bike lane and shared lane designs. This reduces the conflicts to a single location where turning traffic crosses the bike lane. This single conflict point can be eliminated by providing a separate signal phase for turning traffic.

MnDOT Separated Bike Lane Planning & Design Guide

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7/7/2017 SACOG Corridor Working Group 21
Bicycle Infrastructure: Experimental Designs

Bike Box
(Interim approval)
• 10-16’ deep
• Requires no right-turn on red
• Green pavement optional

Source: NACTO
7/7/2017 SACOG Corridor Working Group
Bicycle Infrastructure: Experimental Designs

Two-Stage Turn Queue Box
(Experimental)

- Requires arrow and bike stencil
- Requires no right-turn on red
- Green pavement optional
Interactions with transit
Interactions with transit

FAR-SIDE STOP WITH BIKE CHANNEL AT STREET LEVEL
Interactions with transit

![Image of a bus with "442 EXPRESS" on it parked at a curb with people waiting nearby, indicating interactions with transit.]
Protected intersections
Protected Intersection (Dutch Junction)

- Avoids mixing zones between bikes and cars
- Separates bicycles from pedestrians
- Improves sight lines for all users
- Creates lower stress left turning options for all bicycle riders

Source: MassDOT Separated Bike Lane Planning & Design Guide
Protected Intersection (Dutch Junction)

- Creates a motorist yield zone – 20’ long is recommended
- Bicycle advanced storage – greater than 6’ long (length of bike) and width of protected bikeway
- Pedestrian refuge – 6’ min. long to meet ADA standards and full width of crosswalk
- 15’ maximum curb return radius to slow right turning vehicles (consider truck aprons if needed)

Source: MassDOT Separated Bike Lane Planning & Design Guide
What Are Important Geometric Design Principles?

• Tight curb radius

The curb radius needs to be designed as small as feasible based on the design vehicle, number of accepting lanes and width of traveled lanes. NACTO Urban Street Design Guide recommends 10-15 ft radius, but a much tighter curb radius can be used depending on the effective turning radius of the design vehicle. With protected intersections the effective radius will be closer to the actual radius because of the lack of bike lane and possible inclusion of a bulb out or curb extension.

Be wary of applying large truck turning templates and sacrificing some of the benefits of a protected intersection. Like roundabouts, truck turning aprons can be used to keep the intersection tight for passenger cars.
What Are Important Geometric Design Principles?

- Sight lines

Permissive right-hand turns that allow for the turning vehicle to yield to crossing bikes and pedestrians without hindering through traffic is one of the key features of a protected intersection. To be effective and safe, sight lines should be maintained for both the vehicle and bicycle to anticipate the appropriate yielding vehicle at the intersection. This may mean restricting on-street parking at the intersection for a greater distance than MUTCD standard of 20 ft.
What Are Important Geometric Design Principles?

• Crossing setback or motorist yielding zone

Bicycle and pedestrian crossings set back from the intersection create space for turning motorists to yield to bicyclists and pedestrians. This feature improves motorist view of approaching bicyclists by reducing need for motorists to turn their head. It also creates space for a motorist to yield to bicyclists and pedestrians without blocking traffic and to stop prior to the crossing.

There is a variety of guidance on this distance:

• The typical and minimum crossing setback for a roundabout is 20’ (6m) from the NCHRP 672 Roundabout Informational Guide. This has been the conventional wisdom for protected intersection design.

• The FHWA Seperated Bike Lane Guide, dimensions their “Bend-Out” distance as 15’ - 25’.
  The MASS DOT guidance shown is 6’ – 16.5’ (2m – 5m) which is based on a 2011 Dutch study.

Be cautious about using setbacks less than 20’, as the average vehicle length is longer in the US than the Netherlands and driver behavior is different towards bicycles. This is especially important for early adopters of a protected intersections. The one exception would be for intersections where right-turns occur exclusively from the through bicycle phase.
How Are the Signals Operated?

• One-way protected bike lanes:
  • Left-turning conflicts allowable (up to 150 total vehicles per hour, L+R)
    *Intervention: protected left-turns*
  • Turning conflicts allowable from a shared through/right-turn lane (up to 150 total vehicles per hour, L+R)
    *Intervention: dedicated right-turn lane and protected right-turns*
  • Turning conflicts not recommended from a dedicated right-turn lane
    *Intervention: protected right-turns*

• Two-way protected bike lanes:
  • Turning conflicts not recommended when a two-way protected bike lane is involved
    *Intervention: protected left-turns and right-turns*
How Are the Signals Operated?

- Delay effects:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Motor Vehicles</th>
<th>Bicycles</th>
<th>Pedestrians</th>
<th>Total</th>
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<tbody>
<tr>
<td>Standard</td>
<td>53.5</td>
<td>25.4</td>
<td>42.8</td>
<td>51.2</td>
</tr>
<tr>
<td>1. Right Turn Yield</td>
<td>40.5</td>
<td>28.1</td>
<td>41.8</td>
<td>40.3</td>
</tr>
<tr>
<td>2. Leading Interval</td>
<td>64.3</td>
<td>28.1</td>
<td>40.3</td>
<td>60.6</td>
</tr>
<tr>
<td>3. Scramble Phase</td>
<td>103.8</td>
<td>31.2</td>
<td>47.4</td>
<td>95.2</td>
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<tr>
<td>4. Right Turn Phase</td>
<td>66.1</td>
<td>29.8</td>
<td>45.5</td>
<td>62.7</td>
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</table>

<table>
<thead>
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<th>Demand Volume (vehicles per hour)</th>
<th>Motor Vehicles</th>
<th>Bicycles</th>
<th>Pedestrians</th>
<th>Total</th>
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<tr>
<td></td>
<td>2,400</td>
<td>320</td>
<td>160</td>
<td>2,880</td>
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</table>

Note: Average intersection delay reported in seconds per vehicle.

Simulation Analysis of Intersection Treatments for Cycle Tracks, Stanek & Alexander
Who Has Installed a Protected Intersection?

- First wave (2015):
  - Austin, TX
  - Davis, CA
  - Salt Lake City, UT
  - Vancouver, BC

- Second wave (2016):
  - Atlanta, GA
  - Berkeley, CA
  - Chicago, IL
  - San Francisco, CA
  - College Station, TX
Protected Intersections
J Street and East Covell Blvd, Davis CA
Are separated bikeways and protected intersections safer?
Safety Research

Safety Efficacy: A Review of NACTO Treatments, Fehr & Peers, 2017

Key contributors:

**Fehr & Peers Bicycle and Pedestrian Discipline Group:**

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Planner | Oakland  
L.reis@fehrandpeers.com
Confidence Levels

• **High**
  The high confidence level was reserved for devices with studies that include robust safety data and/or consistent findings across multiple studies that show a reduction in collisions.

• **Medium**
  Devices were assigned to the medium confidence level when there were gaps in the research but ultimately no significant safety concerns.

• **Low**
  The low confidence level category includes devices for which there are limited if any studies, or studies that did not document the locations well enough to fully understand the context of the results. In general, the low confidence level represents devices for which research is inconclusive or incomplete.
## Bicycle Treatments Reviewed

<table>
<thead>
<tr>
<th>Level</th>
<th>Devices</th>
</tr>
</thead>
</table>
| High   | • Bicycle Boulevards  
        | • Green Pavement  
        | • Leading Pedestrian Interval  
        | • Raised Bicycle Crossing  
        | • Separated Bike Phasing (Traffic Signals)  |
| Medium | • Bend-Out Crossing  
        | • Bike Boxes  
        | • Buffered Bike Lanes  
        | • Contraflow Bike Lanes  
        | • Conventional Bike Lanes  
        | • Coordinated Signal Timing  
        | • Mixing Zone  
        | • One-way Protected Bikeway  
        | • Two-way Protected Bikeway  |
| Low    | • Bend-in Crossing  
        | • Combined Bike Lane/Turn Lane  
        | • Intersection Crossing Markings (Non-green)  
        | • Through Bike Lane  
        | • Two-stage Left Turn Box  |

Safety Efficacy: A Review of NACTO Treatments, Fehr & Peers, 2017
## Bicycle Treatments Reviewed

<table>
<thead>
<tr>
<th>Category</th>
<th>Devices</th>
</tr>
</thead>
</table>
| **High** | - Bicycle Boulevards  
- Green Pavement  
- Leading Pedestrian Interval  
- Raised Bicycle Crossing  
- Separated Bike Phasing (Traffic Signals) |
| **Medium** | - Bend-Out Crossing  
- Bike Boxes  
- Buffered Bike Lanes  
- Contraflow Bike Lanes  
- Conventional Bike Lanes  
- Coordinated Signal Timing  
- Mixing Zone  
- One-way Protected Bikeway  
- Two-way Protected Bikeway |
| **Low** | - Bend-in Crossing  
- Combined Bike Lane/Turn Lane  
- Intersection Crossing Markings (Non-green)  
- Through Bike Lane  
- Two-stage Left Turn Box |

*Safety Efficacy: A Review of NACTO Treatments, Fehr & Peers, 2017*
Where do you install a separated bikeway?
City of Sacramento Bikeway Selection Guidance

Bikeway Facility Selection Guidelines

- Separated Bikeway
- Buffered Bike Lane
- Bike Lane
- Bike Route
- Bike Boulevard

Average Daily Traffic

- 25,000
- 20,000
- 15,000
- 10,000
- 5,000

Posted Travel Speed

- 60 mph
- 50 mph
- 40 mph
- 30 mph
- 20 mph
### Considerations separated bikeways

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Less Applicable</th>
<th>Applicable</th>
<th>Most Applicable</th>
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<tbody>
<tr>
<td>Traffic Speed</td>
<td></td>
<td></td>
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<tr>
<td>&lt; 25 mph</td>
<td>O</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Traffic Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 6000 ADT</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Large Truck Volume</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
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</tr>
<tr>
<td>Number of Traffic Lanes</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>&gt; 4</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Excess Width (wide lanes, shoulders, r/w)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
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</tr>
<tr>
<td>Some</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Access Control and Intersection Spacing</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>High</td>
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</table>

7/7/2017
Considerations for separated bikeways

<table>
<thead>
<tr>
<th>Consideration</th>
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<tr>
<td>Bicyle Crash History</td>
<td>None</td>
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<tr>
<td>Bike Volume</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Pedestrian Volume</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Proximity to Schools / Parks / Seniors</td>
<td>&gt; 2 Miles</td>
<td>1/2 miles to 2 miles</td>
<td>&lt; 1/2 Miles</td>
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<td>Extension or Gap fill of Class I</td>
<td>Parallel to Class I</td>
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Considerations for separated bikeways

<table>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Bus Stop</td>
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<td></td>
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<tr>
<td>Loading Zone</td>
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<td></td>
</tr>
<tr>
<td>Parking</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Accessible Parking</td>
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<td></td>
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<tr>
<td>One-way Street (with need for bike contraflow)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Frequency</td>
<td></td>
<td></td>
<td>High Frequency</td>
</tr>
<tr>
<td>Occasional / Off Peak</td>
<td></td>
<td></td>
<td>Many / Peak Hour</td>
</tr>
<tr>
<td>Low Turnover</td>
<td></td>
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<td>High Turnover</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
Costs & Funding

Typical Unit Costs

Bikeways

Restriping bike lanes with slurry seal – $350,000 per mile

Protected bikeways – $1m to $2m per mile (depending on vertical element)
Costs & Funding

Typical Unit Costs
Intersection And Crossings
Protected Intersection – $2m each
Traffic signal – $500k each
Pedestrian Hybrid Beacon – $250k each
Rectangular Rapid Flashing Beacon (RRFB) – $30k each

Source: John Greenfield
Case studies
Telegraph Avenue, Berkeley

• First phase has been completed with parking protected lanes and striping only
• Maintenance was major concern
• Subsequent phases will include raised medians
• Well received but still have education to do
Bruceville Road
Bruceville Road
Bruceville Road
Bruceville Road
Bruceville Road