BICYCLIST SAFETY AT INTERSECTIONS

North Central Texas
November 2021
The knowledge and practice of designing for bicyclists is rapidly changing. Images in these materials and other guidelines may be outdated. Always check for the latest MUTCD interim and experimental TCD’s.
WHAT ARE THE OPPORTUNITIES?

- 50% of trips are ≤ 3 miles
- > 1/3 of U.S. adults say they would commute by bike if safe facilities were available
- 1 out of every 11 U.S. households do not own an automobile
## Bicyclist Skill & Comfort

<table>
<thead>
<tr>
<th>Experienced &amp; Confident</th>
<th>Casual/Less Confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigate on streets</td>
<td>Difficulty gauging traffic or unfamiliar with rules of road</td>
</tr>
<tr>
<td>Some prefer bike lane, shoulders, shared-use paths when available</td>
<td>Prefer shared use paths or bike lanes on low volume streets</td>
</tr>
<tr>
<td>Prefer direct route</td>
<td>Prefer separation from traffic</td>
</tr>
<tr>
<td>Speeds up to 25 mph on level and 45 mph on downgrade</td>
<td>May ride on sidewalk</td>
</tr>
<tr>
<td>Longer trips</td>
<td>Avoid traffic</td>
</tr>
<tr>
<td></td>
<td>Speeds of 8 to 12 mph</td>
</tr>
<tr>
<td></td>
<td>Trips of 1 to 5 miles</td>
</tr>
</tbody>
</table>
Reasons for bicycling

- Recreation 26.0%
- Exercise or health reasons 23.6%
- To go home 14.2%
- Personal errands 13.9%
- To visit a friend or relative 10.1%
- Commuting to school/work 5.0%
- Bicycle ride 2.3%
- Other 4.9%
BICYCLIST CHARACTERISTICS

- Preferences
  - Feel safe
  - Feel secure
  - Lower speed
  - Lower volume
  - Lower truck %
  - Fewer lanes

- Behaviors
  - Violate traffic control
  - Slow on uphill
  - Fast on downhill
DEATHS AND INJURIES

In 2015

- 818 killed
- 45,000 injured
- Cyclists accounted for 2.3% of all traffic fatalities

...but make up 1% of all trips.
BICYCLE CRASH CHARACTERISTICS

- 57% of fatalities at non-intersection locations
- 58% of injuries at intersections
MOST COMMON CRASHES

- Rural
  - Turn/merge into path of motorist
  - Motorist overtaking
MOST COMMON CRASHES

- Urban
  - Motorist failed to yield
  - Bicyclist failed to yield at midblock
  - Bicyclist failed to yield at intersection

![Diagram of urban crash scenarios](image)
BICYCLIST DESIGN USER PROFILES

Interested but Concerned
51%-56% of the total population

Often not comfortable with bike lanes, may bike on sidewalks even if bike lanes are provided; prefer off-street or separated bicycle facilities or quiet or traffic-calmed residential roads. May not bike at all if bicycle facilities do not meet needs for perceived comfort.

Somewhat Confident
5-9% of the total population

Generally prefer more separated facilities, but are comfortable riding in bicycle lanes or on paved shoulders if need be.

Highly Confident
4-7% of the total population

Comfortable riding with traffic; will use roads without bike lanes.

LEVELS OF TRAFFIC STRESS (LTS)

- LTS 1: Suitable for almost all
- LTS 2: Suitable to most adult cyclists
- LTS 3: More traffic stress
- LTS 4: Strong and fearless
## Levels of Traffic Stress (LTS)

<table>
<thead>
<tr>
<th>LTS 1</th>
<th>LTS 2</th>
<th>LTS 3</th>
<th>LTS 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Physically separated from traffic or low-volume, mixed-flow traffic at 25 mph or less&lt;br&gt;• Bike lanes 6 ft wide or more&lt;br&gt;• Intersections easy to approach and cross&lt;br&gt;• Comfortable for children</td>
<td>• Bike lanes 5.5 ft wide or less, next to 30 mph auto traffic&lt;br&gt;• Unsignalized crossings of up to 5 lanes at 30 mph&lt;br&gt;• Comfortable for most adults&lt;br&gt;• Typical of bicycle facilities in Netherlands</td>
<td>• Bicycle lanes next to 35 mph auto traffic, or mixed-flow traffic at 30 mph or less&lt;br&gt;• Comfortable for most current U.S. riders&lt;br&gt;• Typical of bicycle facilities in U.S.</td>
<td>• No dedicated bicycle facilities&lt;br&gt;• Traffic speeds 40 mph or more&lt;br&gt;• Comfortable for “strong and fearless” riders (vehicular cyclists)</td>
</tr>
</tbody>
</table>
In order for this group to regularly choose bicycling as a mode of transportation, a physical network of visible, convenient, and well-designed bicycle facilities is needed.

City, Small Town, and Suburban Roadways

Identifies the preferred bikeway type.

**Design User Assumption:** Interested but concerned cyclist

**Analysis:** Bicycle Level of Traffic Stress
Rural Roadways

Identifies the preferred shoulder width.

**Design User Assumption:** Confident bicyclist

**Analysis:** Bicycle Level of Service
Designing for Bicyclist Safety

CORE SAFETY CONCEPTS
KEY SAFETY FACTORS

- Speed
- Number of lanes
- Visibility
- Traffic volume & composition
- Conflict points
- Proximity
- Bike control
- Connectivity
Vehicle traveling at 20 MPH
9 out of 10 pedestrians survive.

Vehicle traveling at 30 MPH
5 out of 10 pedestrians survive.

Vehicle traveling at 40 MPH
1 out of 10 pedestrians survive.
NUMBER OF LANES
TRAFFIC VOLUME & COMPOSITION
PROXIMITY
KEY SAFETY FACTORS

- Speed
- Number of lanes
- Visibility
- Traffic volume & composition
- Conflict points
- Proximity
- Bike control
- Connectivity
Bicyclist Safety at Intersections

SHARED-USE PATH CROSSINGS
SIDE-STREET CROSSINGS

![Diagram of side-street crossings]

<table>
<thead>
<tr>
<th>Adjacent Road Speed Limit (Mi/h)</th>
<th>Recommended Sidewalk Separation Distance at Crossings</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25 mi/h</td>
<td>6.5 ft (2.0 m)</td>
</tr>
<tr>
<td>35–45 mi/h</td>
<td>6.5–16.5 ft (2.0–5.0 m)</td>
</tr>
<tr>
<td>≥ 55 mi/h</td>
<td>16.5–24 ft (5.0–7.0 m)</td>
</tr>
</tbody>
</table>

*Separation distance may vary in response to available right of way, visibility constraints and the provision of a right turn deceleration lane.*
**Mid-Block Crossing Design Process**

1. Geometric alignment & terrain considerations
2. Roadway characteristics (lane, speed, volumes)
3. Evaluate sight triangles
4. Determine which leg has priority
5. Assess potential crossing treatments
SIGHT TRIANGLES
PATH YIELDS TO ROADWAY

Varies—See MUTCD Table 2C-1

W11-15/W16-7P (optional)
5 ft 32 ft 3 ft
(2.4 m) (10.0 m) (2.4 m)

W11-15/W11-15P/W16-3a

R1-2
D0-1 is optional

R8-3
NO MOTOR VEHICLES

W11-15/W16-7a

R5-3

Crosswalk markings legally establish midblock pedestrian crossing

Centerline as needed

Optional Path Markings
4 ft (1.2 m)
5 ft (1.5 m)
4 ft (1.2 m)

Shared-Use Path

W0-2 is optional

W16-8P is optional

ROAD NAME

ROAD NAME

0
YRD
0
YRD
ROAD YIELDS TO PATHWAY
Crossing Countermeasures

- Advance warning signs
- Advance yield/stop line
- Raised island/crossing
- RRFB/PHB
Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations

Table 1. Application of pedestrian crash countermeasures by roadway feature.

<table>
<thead>
<tr>
<th>Roadway Configuration</th>
<th>Posted Speed Limit and AADT</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicle AADT &lt;9,000</td>
<td>30 mph</td>
<td>35 mph</td>
<td>40 mph</td>
</tr>
<tr>
<td></td>
<td>Vehicle AADT 9,000-15,000</td>
<td>30 mph</td>
<td>35 mph</td>
<td>40 mph</td>
</tr>
<tr>
<td></td>
<td>Vehicle AADT &gt;15,000</td>
<td>30 mph</td>
<td>35 mph</td>
<td>40 mph</td>
</tr>
<tr>
<td>2 lanes (1 lane in each direction)</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>3 lanes with raised median (1 lane in each direction)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3 lanes w/o raised median (1 lane in each direction with a two-way left-turn lane)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4+ lanes with raised median (2 or more lanes in each direction)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4+ lanes w/o raised median (2 or more lanes in each direction)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Given the set of conditions in a cell:

#  Signifies that the countermeasure is a candidate treatment at a marked uncontrolled crossing location.

●  Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgment at a marked uncontrolled crossing location.

○  Signifies that crosswalk visibility enhancements should always occur in conjunction with other identified countermeasures.*

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgment.

1 High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning sign
2 Raised crosswalk
3 Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line
4 In-Street Pedestrian Crossing sign
5 Curb extension
6 Pedestrian refuge island
7 Rectangular Rapid-Flashing Beacon (RRFB)**
8 Road Diet
9 Pedestrian Hybrid Beacon (PHB)**

*Refer to Chapter 4, "Using Table 1 and Table 2 to Select Countermeasures," for more information about using multiple countermeasures.
**The PHB and RRFB are not both installed at the same crossing location.
BIKE “HAWK” PHB

- First installation Tucson, AZ
- “BIKES WAIT”/”BIKES OK”
BIKEHAWK AT PHB CROSSINGS

Normal PHB with Bike Facilities and R9-5 for cyclists to use pedestrian signals
Bicyclist Safety at Intersections

INTERSECTION DESIGN PRINCIPLES
INTERSECTION CONFLICTS

Typical conflicts for both pedestrians and motorists, plus:

- Right-turn/thru movement
- Weaving to left turn
Albuquerque, New Mexico
Albuquerque, New Mexico
RIGHT-TURN/THRU CONFLICT
WOULD YOU DARE?
WOULD YOU DARE?
WOULD YOU DARE?
WOULD YOU DARE?
LEFT-TURN CONFLICT
LEFT-TURN CONFLICT
INTERSECTION DESIGN PRINCIPLES

- Reduce speed
- Minimize exposure to conflicts
- Communicate right-of-way priority
- Provide adequate sight distance
DON'T GIVE UP AT THE INTERSECTION

BIKE LANE AHEAD

BIKE LANE ENDS

R3-17aP

R3-17bP
Bicyclist Safety at Intersections

INTERSECTION COUNTERMEASURES
RIGHT-TURN COUNTERMEASURES
SHOULDER RIDING AT INTERSECTION

- Shoulder not a travel lane
- Modify shoulder striping
- Opportunity to switch to shared lanes OR
- Add bike lane thru intersection
SHOULDER STRIPING

Motorist may proceed straight or turn right in front of bicyclist.

Striping causes right-of-way confusion for both users.

Shoulder "facility" ends for bicyclist.

TYPE II DOTTED LINES
Striping through intersection is optional at long or skewed crossings.

CENTER OF RADIUS

10' TYP.

END EDGELINE STRIPING ONCE SOLID SHOULDER STRIPING BEGINS

TYPE II DOTTED LINES
Add green pavement marking – bike lanes & sharrows
Add green pavement marking – bike lanes & sharrows
SIGHT LINES AND PARKING (DRIVEWAYS)
Additional/all lanes are shared at intersection
BIKE LANE THRU INTERSECTION
HIGHLIGHT CONFLICT ZONE

- Dotted Line Extensions
- Shared Lane Markings
- Colored Conflict Area
- Elephant’s Feet
Case Study—Orange Blossom Trail
Case Study—Orange Blossom Trail
Case Study—Orange Blossom Trail
Case Study—Orange Blossom Trail
BIKE LANE THRU INTERSECTION
BIKE LANE THRU INTERSECTION
IS THIS CONSISTENT WITH MUTCD?
RIGHT TURN SHARED LANE

ONLY EXCEPT

[Diagram showing a right turn shared lane with markings and distances indicated]
RIGHT-TURN SHARED LANE

Madison, Wisconsin
Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges

ITE 2016
GUIDING PRINCIPLES FOR PEDESTRIANS

- Ramp geometry
- Locate crosswalk
  - Best visibility
  - Before accelerate
- Crosswalk short w/out excessive deviation
- Widen sidewalks shared with bicyclists
GUIDING PRINCIPLES FOR BICYCLISTS

- Buffer where bicyclists are between moving vehicles more than 200 ft
- Provide bike “exit” option ahead of on-ramps
- Define a weaving area
LEFT-TURN COUNTERMEASURES
TWO-STAGE LEFT TURN BOX
TWO-STAGE LEFT-TURN QUEUE BOX

- Required design elements include:
  - Bicycle symbol
  - Turn or through arrow
  - Turn on red prohibition
  - Passive detection of bicycles
- Size to prevent conflicts
BIKE BOX

- Reduced conflicts between bicyclists and turning vehicles
- Reduced avoidance maneuvers
- Reduced encroachment into crosswalks
- Use clearly understood by motorists and bicyclists
**BIKE BOX**

- **Required elements:**
  - Advance stop line at 10’
  - Bike symbol in the box
  - RTOR prohibited
  - Setback from crosswalk
  - 50 feet of bike lane on approach
  - STOP HERE ON RED (R10-6/R10-6a) with EXCEPT BICYCLE text plaque
  - Countdown ped signal if box crosses multiple lanes
  - Yellow change & red clearance

- **Green pavement is optional**
BIKE BOX

Attachment IA-18-2

Pedestrian Signal with Countdown Display (required where bicycle box crosses more than one lane)

NO TURN ON RED

STOP HERE ON RED

EXCEPT BICYCLES

* Place in accordance with Section 28.54.
ROUNDABOUT INTERSECTIONS
MAKING ROUNDABOUTS WORK

- Slow speeds
  + Deflection
  + Truck apron
  + NO BIKE LANES

- Simple
  + Single lane
  + NO BIKE LANES

- Splitter islands

- Escape ramps
Bike lane ends at splitter island

Bend, Oregon
Slower speeds and fewer conflict points
Slower speeds and fewer conflict points
Bend, Oregon

Bike lane begins
Bend, Oregon

Bike ramp
BIKEWAY MARKINGS AT ROUNDABOUTS

Buffered Bike Lane

Green Bike Lanes Through Conflict Areas

Pleasant Hill Road / Olympic Blvd Roundabout Project
Lafayette, CA
PROTECTED INTERSECTIONS
“PROTECTED” INTERSECTIONS
“PROTECTED” INTERSECTIONS

Salt Lake City, UT

Chicago, IL

Austin, TX

Davis, CA
PROTECTED INTERSECTIONS

1. Corner refuge island
2. Forward bicycle queuing area
3. Motorist yield zone
4. Pedestrian crossing island
5. Pedestrian crossing of separated bike lane
6. Pedestrian curb ramp
VISIBILITY AT CONFLICT POINTS

motorist’s view at conventional bike lane

motorist’s view at separated bike lane
At a conventional intersection, the bike rider is hidden from the driver’s view as the driver makes the turn.
At a protected intersection, the bike lane is set back from the motor vehicle through/turn lane, so the bike rider is visible as the driver turns.
VISIBILITY AT CONFLICT POINTS

protected intersection

conventional bike lane
CORNER RADIUS

Design Vehicle  Control Vehicle  Managed Vehicle
Lower speeds lead to higher driver yielding rates at urban roundabouts. Roundabouts share important geometric features with protected intersections. Graph source: Geruschat, D.R., Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts. 2005.
**Vehicular turning design speed**

<table>
<thead>
<tr>
<th>Vehicular turning design speed</th>
<th>Minimum approach clear space</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 mph</td>
<td>20’</td>
</tr>
<tr>
<td>10 mph</td>
<td>40’</td>
</tr>
<tr>
<td>15 mph</td>
<td>50’</td>
</tr>
<tr>
<td>20 mph</td>
<td>60’</td>
</tr>
</tbody>
</table>
• Maximum taper 3:1
• Bend-out preferred (motorist yield zone, bus stops, pedestrian refuge area, loading and parking)
• Separation increases sight distance
• Corner island affects motorist yield zone

bend-out

bend-in
STREET BUFFER WIDTH

- 6’ preferred
- 2’ when constrained
- 1’ along raised SBL
- 6-16.5’ optimum for intersections
SLOW RIGHT TURNING SPEEDS

- Design for $\leq 10$ mph vehicle turns
- Mountable truck apron
  - 3” max.
  - Visually distinct
- Large radii reduces bicycle, pedestrian queuing areas
ADA ISSUES

- PROWAG was written over 15 years ago
- Still a “draft” but widely used and enforceable
- Did not consider SBL’s
- Must be interpreted

NO EASY ANSWERS
CONSIDERATIONS

- What happens at termini?
- What happens when bicycle facility type changes?
- Have you stranded or created a barrier to the less confident user?
- How many stops will bicyclist have to make to traverse transition?
EXAMPLE TRANSITIONS

into a two-way separated bike lane
EXAMPLE TRANSITIONS

into a conventional bike lane
ACCESS TO/FROM SIDE STREET
ACCESS TO/FROM SIDE STREET

Atlanta, GA
ACCESS TO/FROM SIDE STREET

Atlanta, GA
STEEP GRADE TO INTERSECTION

Atlanta, GA
STEEP GRADE TO INTERSECTION

Atlanta, GA
Bicyclist Safety at Intersections

SIGNAL STRATEGIES
SAFER SIGNALS FOR BICYCLISTS

- Bikes start-up and travel slower than cars
  - Differentiating bike detection to optimize signals
  - Set initial and gap times to accommodate bikes
- Leading Bike Interval
- Segregate Conflicting Movements
CLEARANCE & ALL RED INTERVALS
Application for:

- Bicyclist non-compliance
- Provide a leading or lagging bicycle interval
- Continue the bicycle lane on the right-hand side of an exclusive turn lane
- Augment the design of a segregated counter-flow
- Unusual or unexpected arrangements of the bicycle movement through complex intersections, conflict areas, or signal control.
BICYCLE DETECTION

- Buttons
- Loops
- Video
- Microwave
- Radar
- Infrared

Grand Prairie, Alberta
PUSH BUTTONS
LOOP DETECTION

Portland, OR

Directions of Travel:

- Square
- Quadrupole
- Diamond
- Diag. Quadrupole
PASSIVE DETECTION
MUTCD standard for signal loop marking for bicyclists

(Section 9C.05)
LBI & LAGGING LEFT TURN
LBI & LAGGING LEFT TURN
LBI & LAGGING LEFT TURN
PROTECTED PERMISSIVE
Bicyclist Safety at Intersections

ANALYSIS AND EVALUATION
SAFETY EVALUATION TOOLS

- Highway Safety Manual
- Bicycle Intersection Safety Indices
- Highway Capacity Manual
- Road Safety Audit
- BIKESAFE
HSM METHODOLOGY

- **Urban & Suburban Segments**

\[ N_{biker} = N_{br} \times f_{biker} \]

- \( N_{biker} \) – vehicle-bicycle collision frequency
- \( N_{br} \) – crash frequency, excluding bikes and peds
- \( f_{biker} \) – bicycle crash adjustment factor
  - \(< \) or \( > \) 30 mph posted speed
  - road type (2U, 3T, 4U, 4D, 5T)
  - values range from 0.002 to 0.050
HSM METHODOLOGY

- Urban & Suburban Intersections
  \[ N_{\text{bikei}} = N_{\text{bi}} \times f_{\text{bikei}} \]
  - \( N_{\text{bikei}} \) -- vehicle-bicycle collision frequency
  - \( N_{\text{bi}} \) -- predicted intersection crashes (no bikes/peds)
  - \( f_{\text{bikei}} \) -- bicycle crash adjustment factor
    - intersection type (3ST, 3SG, 4ST, 4SG)
    - values range from 0.011 to 0.018
## CMF LIMITATIONS

### Countermeasure: Install bicycle lanes

<table>
<thead>
<tr>
<th>CMF</th>
<th>CRF(%)</th>
<th>Quality</th>
<th>Crash Type</th>
<th>Crash Severity</th>
<th>Area Type</th>
<th>Reference</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.05</td>
<td>-5</td>
<td>★★★★★</td>
<td>All</td>
<td>All</td>
<td>Urban</td>
<td>Jensen, 2008</td>
<td></td>
</tr>
<tr>
<td>0.944</td>
<td>5.6</td>
<td>★★★★★</td>
<td>All</td>
<td>All</td>
<td>Urban</td>
<td>Chen et al., 2012</td>
<td></td>
</tr>
<tr>
<td>1.509</td>
<td>-50.9</td>
<td>★★★★★</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban</td>
<td>Chen et al., 2012</td>
<td></td>
</tr>
<tr>
<td>1.057</td>
<td>-5.7</td>
<td>★★★★★</td>
<td>All</td>
<td>All</td>
<td>Urban</td>
<td>Chen et al., 2012</td>
<td>Includes signalized, all-way stop controlled, ...</td>
</tr>
<tr>
<td>1.281</td>
<td>-28.1</td>
<td>★★★★★</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban</td>
<td>Chen et al., 2012</td>
<td>Includes signalized, all-way stop controlled, ...</td>
</tr>
</tbody>
</table>
### CMF LIMITATIONS

#### Countermeasure: Installation of bicycle lanes at signalized intersections

<table>
<thead>
<tr>
<th>CMF</th>
<th>CRF(%)</th>
<th>Quality</th>
<th>Crash Type</th>
<th>Crash Severity</th>
<th>Area Type</th>
<th>Reference</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.37</td>
<td>-37</td>
<td>★★★☆☆☆</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban and suburban</td>
<td>Turner et al., 2011</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>20</td>
<td>★★★★★☆</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban and suburban</td>
<td>Turner et al., 2011</td>
<td></td>
</tr>
<tr>
<td>0.63</td>
<td>37</td>
<td>★★★☆☆☆</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban and suburban</td>
<td>Turner et al., 2011</td>
<td>Crossing crashes at 90 degrees ... [read more]</td>
</tr>
<tr>
<td>1.33</td>
<td>-33</td>
<td>★★★☆☆☆</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban and suburban</td>
<td>Turner et al., 2011</td>
<td>Crash Type: Cyclist through, left ... [read more]</td>
</tr>
<tr>
<td>1.01</td>
<td>-1</td>
<td>★★★☆☆☆</td>
<td>Vehicle/bicycle</td>
<td>All</td>
<td>Urban and suburban</td>
<td>Turner et al., 2011</td>
<td>Crash Type: Rear end &amp; ... [read more]</td>
</tr>
</tbody>
</table>
Prioritize intersections crossings and intersection approaches for bicycle safety improvements

- Score of 1 (safest) to 6 (least safe)
- Score for each movement (thru, left turn, right turn)
BICYCLIST INTERSECTION SAFETY INDICES

Select Sites to Evaluate
Gather Data
Calculate Index Values
Prioritize Sites
BICYCLIST INTERSECTION SAFETY INDICES

Inputs:

- ADT on main and cross streets.
- Number of through vehicle lanes on cross street.
- Number, type, and configuration of traffic lanes on main street approach.
- Speed limit on main street.
- Presence of on-street parking on main street approach.
- Type of traffic control on approach of interest (signal or no signal).
BICYCLE LEVEL-OF-SERVICE

Interrupted flow:

- LOS reported separately for each mode
  - Purpose, length, and expectation differs
- Travel speed
- Intersection delay
- Bicyclist perception
BICYCLE LEVEL-OF-SERVICE

Factors in bicycle LOS score: 
*Interrupted flow*

- Motorized vehicle volume
- % heavy vehicles
- % occupied parking
- # lanes
- Outside lane width
- Median
- Curb
- Access
- Pavement condition
- Motorized vehicle speed
## Levels of Traffic Stress (LTS)

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• Comfortable for children | • Bike lanes 5.5 ft wide or less, next to 30 mph auto traffic  
• Unsignalized crossings of up to 5 lanes at 30 mph  
• Comfortable for most adults  
• Typical of bicycle facilities in Netherlands | • Bicycle lanes next to 35 mph auto traffic, or mixed-flow traffic at 30 mph or less  
• Comfortable for most current U.S. riders  
• Typical of bicycle facilities in U.S. | • No dedicated bicycle facilities  
• Traffic speeds 40 mph or more  
• Comfortable for “strong and fearless” riders (vehicular cyclists) |
ROAD SAFETY AUDIT

- Formal safety examination conducted by an independent, experienced, multidisciplinary team
- RSA Prompt List
- Bikeability checklist
D.8: Are the intersection/transition and paths leading to the transition adequately lit (see C.8)?

D.9: Is the visibility of cyclists as they make the transition from one facility or roadway geometry to another adequate from the perspective of all road users?

The transition, whether along a roadway or at an intersection, should allow drivers to see cyclists and understand their path and intent, and vice versa. The following should be investigated:

- Obstructions caused by roadside features (e.g., fences and vegetation).
- Adequacy of warning signs.
- Location of the transition with respect to roadway geometry (e.g., shoulder drop and turn lanes) (see also A.9 and C.9)

The picture to the left depicts a bike lane that hooks right through a major intersection and transitions to a protected bikeway. Chevrons on the pavement help guide cyclists and show motorists the path provided for cyclists through the intersection (note that the chevron pavement markings do not conform to the MUTCD).

D.10 and D.11: Are signs and markings at transition areas appropriate?

Transitions and termini should be appropriately signed and marked to warn cyclists of conditions ahead, particularly at locations at which cyclists do not expect transitions or termini. Likewise, motorized vehicles should have adequate warning when off-road bicycle facilities transition to on-road facilities. The intended paths of all road users should also be appropriately signed and marked at the point of transition. Additional attention may be given to locations with high volumes of unfamiliar users or tourists.
Go for a ride and use this checklist to rate your neighborhood's bikeability.

How bike-able is your community?

Location of bike ride (be specific): Rating Scale:  

1. Did you have a place to bicycle safely?
   a) On the road, sharing the road with motor vehicles?

      - [ ] Yes  [ ] No
      - Some problems (please note locations):
        - No space for bicyclists to ride
        - Bicycle lane or paved shoulder disappeared
        - Heavy and/or fast-moving traffic
        - Too many trucks or buses
        - No space for bicyclists on bridges or in tunnels
        - Poorly lighted roadways
        - Other problems: ____________________________

   b) On an off-road path or trail, where motor vehicles were not allowed?

      - [ ] Yes  [ ] No
      - Some problems:
        - Path ended abruptly
        - Path didn't go where I wanted to go
        - Path intersected with roads that were difficult to cross
        - Path was crowded
        - Path was unsafe because of sharp turns or dangerous downhills
        - Path was uncomfortable because of too many hills
        - Path was poorly lighted
        - Other problems: ____________________________

2. How was the surface that you rode on?

      - [ ] Good  [ ] Some problems, the road or path had:
        - Potholes
        - Cracked or broken pavement
        - Debris (e.g. broken glass, sand, gravel, etc.)
        - Dangerous drain grates, utility covers, or metal plates
        - Uneven surface or gaps
        - Slippery surfaces when wet (e.g. bridge decks, construction plates, road markings)
        - Bumpy or angled railroad tracks
        - Rumble strips
        - Other problems: ____________________________

   Overall Surface Rating: (circle one)
   1 2 3 4 5 6

3. How were the intersections you rode through?

      - [ ] Good  [ ] Some problems:
        - Had to wait too long to cross intersection
        - Couldn't see crossing traffic
        - Signal didn't give me enough time to cross the road
        - Signal didn't change for a bicycle
        - Unsure where or how to ride through intersection
        - Other problems: ____________________________
Existing signalized intersection
- Peak hour delays are a concern
- Speeds are a concern, especially off peak
- Higher crash location
- Several injuries and 1 fatality in the past
- Additional future delay and safety impacts expected with nearby development projects
- A roundabout is the preferred alternative
- However, ROW and utility impacts are a concern

The project team has requested analysis of a roundabout.
EXAMPLE (LOCATION)

Source: Google Earth Pro
Location: Southeastern Pennsylvania
Existing daily traffic counts (tube counters)
Existing peak hour counts (AM, MID, PM, SAT)
Projected peak hour counts (AM, MID, PM, SAT)
Little to no trucks or pedestrians
Existing crash data (fatal/injuries and PDO)
Some developer traffic impact studies
HCM2010-based peak hour capacity analysis
HSM predicted crashes
HSM crash modification factors
### Example (Traditional Analysis)

**Year 2018 (Opening Year)**
**HCM 6th Edition Analysis**
**Overall Intersection Results**

<table>
<thead>
<tr>
<th></th>
<th>Existing Signalized Intersection w/ Turn Lanes (Semi-Actuated, Isolated)</th>
<th>Proposed Roundabout (1-lane entries, 1 circulating lane, ~120’ ICD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak Hour (0700-0800) Average Control Delay in Seconds/Vehicle (LOS)</td>
<td>32.1 (C)</td>
<td>32.4 (D)</td>
</tr>
<tr>
<td>MID Peak Hour (1200-1300) Average Control Delay in Seconds/Vehicle (LOS)</td>
<td>19.9 (B)</td>
<td>16.4 (C)</td>
</tr>
<tr>
<td>PM Peak Hour (1700-1800) Average Control Delay in Seconds/Vehicle (LOS)</td>
<td>46.3 (D)</td>
<td>51.9 (F)</td>
</tr>
</tbody>
</table>

Source: Dave Petrucci FHWA-RC-SDTST
The project traffic study provides peak hour HCM analysis and overall intersection delay savings for opening and design years.

The roundabout option has slightly more peak hour delay than the no build option (signal).

We can consider more than just peak hour delay and leverage daily traffic estimates.
Proportional relationships between traffic volumes and delay values

No seasonal variations in traffic demand

To convert peak hour delay savings to annual vehicle-hours assume:

- 39 representative weeks of the year
- 12 summer weeks and 1 holiday week are excluded
- 3 representative weekdays per week (T, W, THURS)
- 1 representative weekend day per week (Saturday)

Derive vehicle-hours of delay

Extrapolate peak hour results for the entire day
Distribution of Daily Major Street Traffic

Source: Dave Petrucci FHWA-RC-SDTST
EXAMPLE (DAILY DELAY COMPARISON)

- Vehicle-hours of delay estimated (HCM)

Source: Dave Petrucci FHWA-RC-SDTST
What if we just used peak hour HCM analysis?
### EXAMPLE (SAFETY ANALYSIS)

Safety performance (using HSM SPF’s & CMF’s)

<table>
<thead>
<tr>
<th>Year</th>
<th>NO BUILD</th>
<th>BUILD</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>FI</td>
<td>PDO</td>
</tr>
<tr>
<td>2019</td>
<td>10.7</td>
<td>1.6</td>
<td>9.1</td>
</tr>
<tr>
<td>2020</td>
<td>10.9</td>
<td>1.6</td>
<td>9.3</td>
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<tr>
<td>2021</td>
<td>11.1</td>
<td>1.7</td>
<td>9.4</td>
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<td>2022</td>
<td>11.3</td>
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<td>2023</td>
<td>11.5</td>
<td>1.7</td>
<td>9.8</td>
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<td>2024</td>
<td>11.7</td>
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<tr>
<td>2028</td>
<td>12.5</td>
<td>1.9</td>
<td>10.6</td>
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</tbody>
</table>

Source: Dave Petrucci FHWA-RC-SDTST
## Monetization of Results

**EXAMPLE (ECONOMIC ANALYSIS)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Status</th>
<th>Project Year</th>
<th>Major AADT</th>
<th>Minor AADT</th>
<th>Capital</th>
<th>Operating</th>
<th>7.00% NPV Costs</th>
<th>Safety NPV Benefits</th>
<th>Operations NPV Benefits</th>
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<tbody>
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<td>2018</td>
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<td>2023</td>
<td>Maintenance</td>
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<td>Maintenance</td>
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<td>Maintenance</td>
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<tr>
<td>2026</td>
<td>Maintenance</td>
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<td>2027</td>
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<td>2029</td>
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<td>$0</td>
<td>$1,430,723</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Dave Petrucci FHWA-RC-SDTST

2.94 BCR
NCHRP Report 948 – Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

Applying the ‘20 Flag’ Assessment Method from NCHRP 07-25

Bastian Schroeder
Senior Principal, Kittelson

AASHTO TCGD
November 10, 2021
Integrate Multimodal Facilities in the Design Process, as opposed to ‘accommodating’ pedestrians and bicyclists at later stages.

Allow comparison of alternative intersections and interchanges (A.I.I.) with ‘conventional’ designs.

Focus on design elements of the intersection, rather than intersection form.

Follow a performance-based design process.
Design Flag Assessment Method – 20 Questions for Pedestrian and Bicyclist Safety

<table>
<thead>
<tr>
<th>Motor Vehicle Right Turns</th>
<th>Uncomfortable/Tight Walking Environment</th>
<th>Nonintuitive Motor Vehicle Movements</th>
<th>Crossing Yield- or Uncontrolled Vehicle Paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Paths</td>
<td>Executing Unusual Movements</td>
<td>Multilane Crossings</td>
<td>Long Red Times</td>
</tr>
<tr>
<td>Undefined Crossing at Intersections</td>
<td>Motor Vehicle Left Turns</td>
<td>Intersecting Driveways and Side Streets</td>
<td>Sight Distance for Gap Acceptance Movements</td>
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<tr>
<td>Grade Change</td>
<td>Riding in Mixed Traffic</td>
<td>Bicycle Clearance Times</td>
<td>Lane Change Across Motor Vehicle Lane(s)</td>
</tr>
<tr>
<td>Channelized Lanes</td>
<td>Turning Motorists Crossing Bicycle Paths</td>
<td>Riding Between Travel Lanes, Lane Additions, or Lane Merges</td>
<td>Off-tracking Trucks in Multilane Curves</td>
</tr>
</tbody>
</table>
Yellow vs. Red Flags

Yellow Flags, for design elements negatively affecting user comfort (in other words, increasing user stress) or the quality of the walking or cycling experience.

Red Flags, for design elements that are directly related to a safety concern for pedestrians or bicyclists.
Case Study Application:
Faulkland Rd (34) at Centre Rd. (141), Wilmington, DE
Results: Existing Conditions

- Motor Vehicle Right Turns
- Tight Walking Environment
- Crossing Yield Control Path
- Multilane Crossing
- Long Red Times
- Intersecting Driveways
- Sight Distance
- Riding in Mixed Traffic
- Bicycle Clearance Times
- Lane Change Across Vehicle Lanes
- Channelized Lanes
- Motorist Crossing Bike Path
- Riding Between Travel Lanes
Results: Existing Conditions

- Motor Vehicle Right Turns
- Tight Walking Environment
- Crossing Yield Control Path
- Multilane Crossing
- Long Red Times
- Intersecting Driveways
- Sight Distance
- Riding in Mixed Traffic
- Bicycle Clearance Times
- Lane Change Across Vehicle Lanes
- Channelized Lanes
- Motorist Crossing Bike Path
- Riding Between Travel Lanes
Assessment: Alt. 1 – Low Cost Strategies

1. Widen Island Cut-Throughs
2. Install Raised Crosswalks
3. Stripe Bike-Lane Through Intersection
4. Add Two-Stage Left-Turns
5. Consolidate Driveways
6. Build Driveway Islands
7. Install Stop Signs at Channelized Turn Lane Exits
8. Raised Refuge Islands and ‘noses’ to protect pedestrians

Disclaimer: Modifications not to scale, and need to be evaluated further for feasibility.
Results: Alt. 1 – Low Cost Strategies

- Motor Vehicle Right Turns
- Tight Walking Environment
- Crossing Yield Control Path
- Multilane Crossing*
- Long Red Times
- Intersecting Driveways*
- Sight Distance
- Riding in Mixed Traffic
- Bicycle Clearance Times
- Lane Change Across Vehicle Lanes
- Channelized Lanes*
- Motorist Crossing Bike Path
- Riding Between Travel Lanes

*Mitigated but not eliminated
Assessment: Alt. 2 – Median U-Turn (MUT)

Disclaimer: Modifications not to scale, and need to be evaluated further for feasibility
Results: Alt. 2 – Median U-Turn (MUT)

- Motor Vehicle Right Turns
- Tight Walking Environment
- Crossing Yield Control Path
- Multilane Crossing*
- Long Red Times*
- Intersecting Driveways*
- Sight Distance
- Riding in Mixed Traffic
- Bicycle Clearance Times
- Lane Change Across Vehicle Lanes
- Channelized Lanes

*Mitigated but not eliminated

Motorist Crossing Bike Path
- Riding Between Travel Lanes
Results

**Pedestrian Assessment**
- As-Built: 12% Yellow, 31% Red, 58% Not Flagged
- Alt. 1: 15% Yellow, 85% Red, 0% Not Flagged
- Alt. 2: 12% Yellow, 8% Red, 80% Not Flagged

**Bicycle Assessment**
- As-Built: 8% Yellow, 68% Red, 0% Not Flagged
- Alt. 1: 13% Yellow, 71% Red, 4% Not Flagged
- Alt. 2: 11% Yellow, 4% Red, 85% Not Flagged

Legend:
- PCT Yellow
- PCT Red
- PCT Not Flagged