Designing for Bicyclist Safety

Brooke Struve

Federal Highway Administration

January 22, 2018

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Designing for Bicyclist Safety

POLICIES, TOOLS, AND GUIDANCE FOR IMPROVED QUALITY OF BICYCLING FACILITIES

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Note of Caution

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 Images in these materials and other guidelines may be outdated.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.

Imperative for Improvement

DESIGNING FOR BICYCLIST SAFETY

Poll Question #1

50 %

Poll Question #2

1 to 5 miles

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

Would you dare?

Would you dare?

Would you dare?

Would you dare?

Would you dare?

Would you dare?

Bicyclist Skill & Comfort

Experienced & Confident

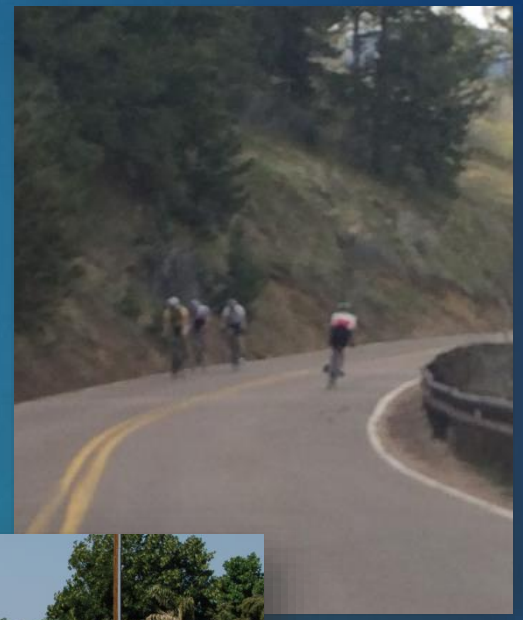
- Navigate on streets
- Some prefer bike lane, shoulders, shared-use paths when available
- Prefer direct route
- Speeds up to 25 mph on level and 45 mph on downgrade
- Longer trips

Casual/Less Confident

- Difficulty gauging traffic or unfamiliar with rules of road
- Prefer shared use paths or bike lanes on low volume streets
- Prefer separation from traffic
- May ride on sidewalk
- Avoid traffic
- Speeds of 8 to 12 mph
- Trips of 1 to 5 miles

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 (⬆ 840 in 2016)
- 45,000 injured
- Cyclists accounted for 2.3% of all traffic fatalities

...but make up 1% of all trips.

Highway Safety Manual

- 1st Edition 2010
- Predictive models
- Based on data
- Crash frequency

Safety Performance Function

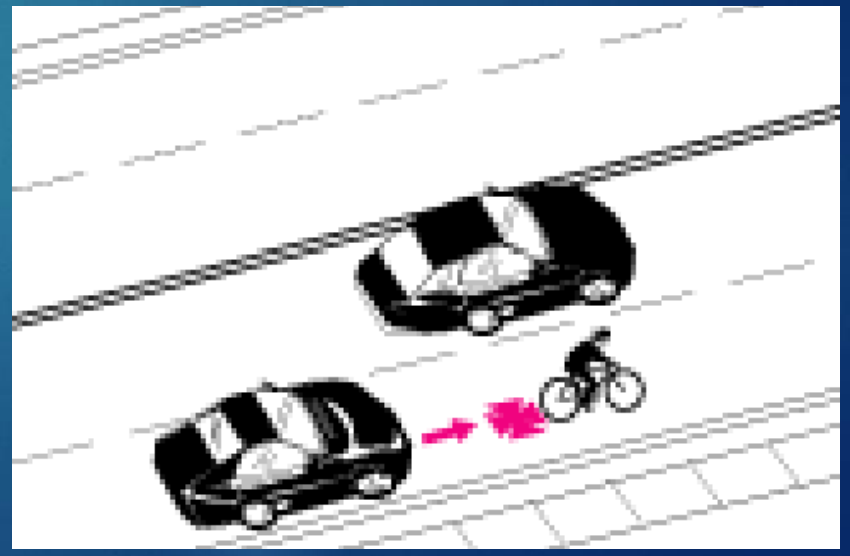
- SPF = N = number of crashes per year
- Function of:
  - Traffic volume
  - Selected roadway characteristics
  - Selected intersection characteristics

Prediction of Bicyclist Crashes

- 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

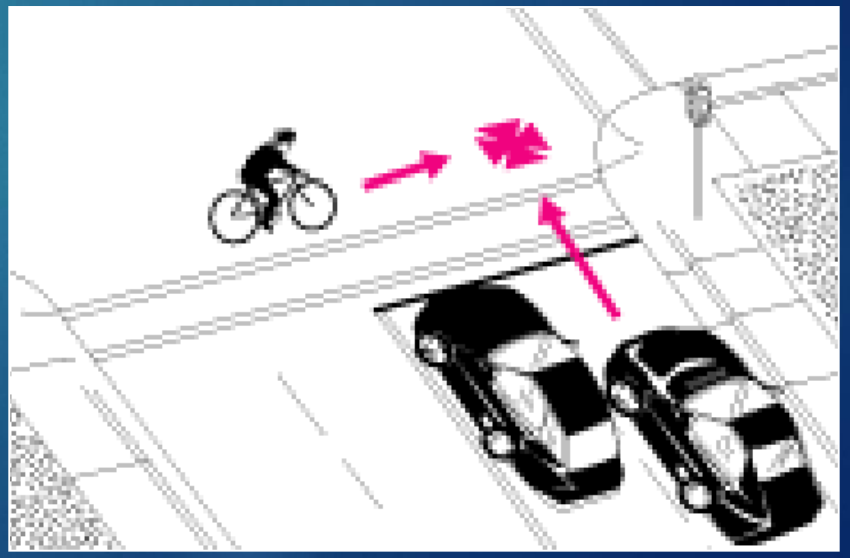


Prediction of Bicyclist Crashes

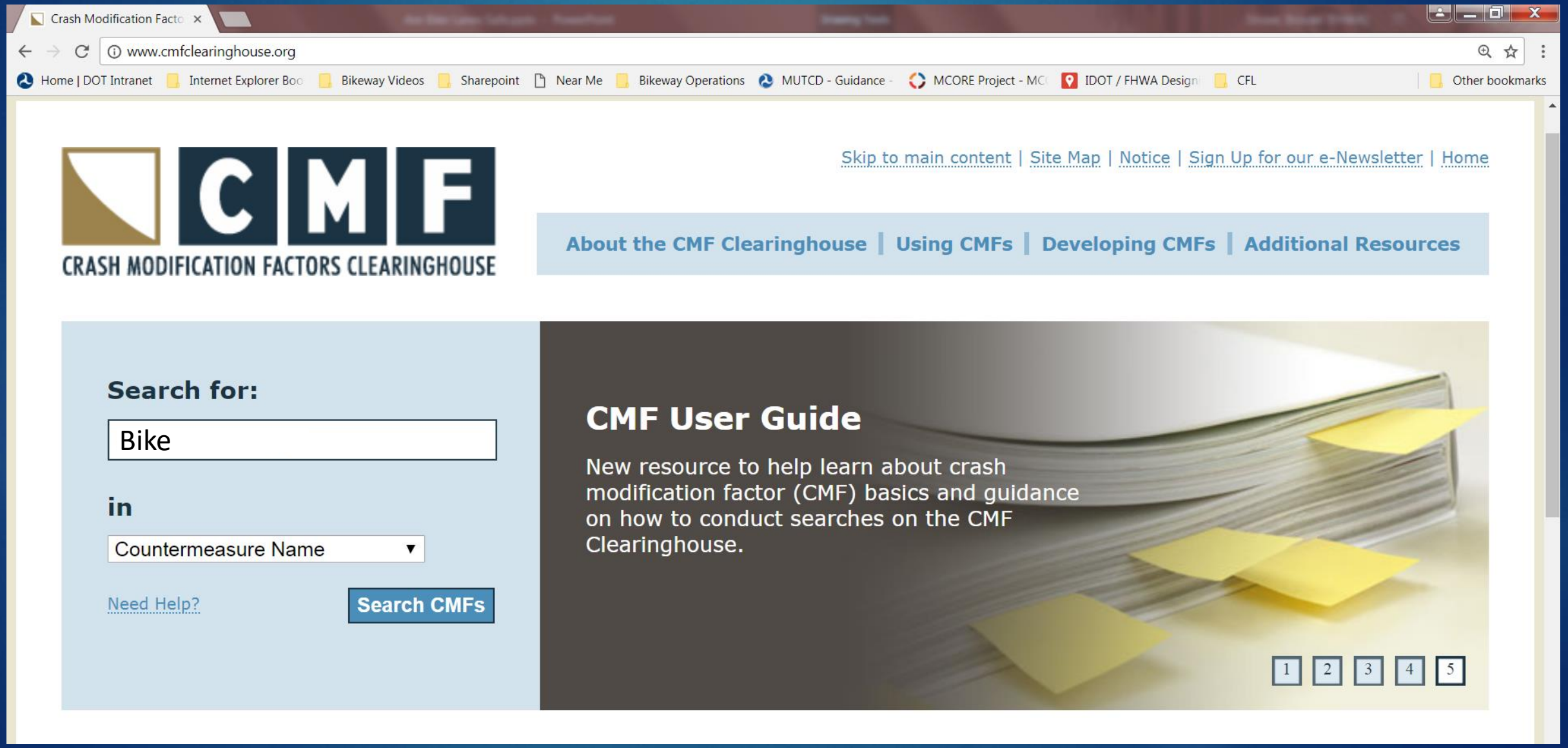
- Urban & Suburban Intersections

$$N_{bikei} = N_{bi} \times f_{bikei}$$

  - N_{bikei} -- vehicle-bicycle collision frequency
  - N_{bi} -- predicted intersection crashes (no bikes/peds)
  - f_{bikei} – bicycle crash adjustment factor
    -- intersection type (3ST, 3SG, 4ST, 4SG)
    -- values range from 0.011 to 0.018



Crash Modification Factors



Countermeasure: Install bicycle lanes

Compare	CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
☐	1.05	-5	★★★☆☆	All	All	Urban	Jensen, 2008	
☐	1.14	-14	★★★☆☆	All	K,A,B,C	Urban	Jensen, 2008	
☐	1.01	-1	★★★☆☆	All	O	Urban	Jensen, 2008	
☐	1.15	-15	★★★☆☆	All	K,A,B,C	Urban	Jensen, 2008	
☐	1.22	-22	★★☆☆☆	All	K,A	Urban	Jensen, 2008	
☐	1.05	-5	★★☆☆☆	All		Urban	Jensen, 2008	
☐	0.83	17	★★☆☆☆	Vehicle/pedestrian	K,A,B,C	Urban	Jensen, 2008	Pedestrian, all injuries ... [*read more*]
☐	0.92	8	★★☆☆☆	Vehicle/pedestrian	K,A,B,C	Urban	Jensen, 2008	Pedestrian injuries, intersections ... [*read more*]

								[read more]
☐	1.49	-49	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Jensen, 2008	Bicycle and moped riders, all ... [read more]
☐	1.57	-57	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Jensen, 2008	Bicycle and moped riders, all ... [read more]
☐	1.14	-14	★★☆☆☆	All	K,A,B,C	Urban	Jensen, 2008	
☐	1.27	-27	★★☆☆☆	All	K,A,B,C	Urban	Jensen, 2008	
☐	0.68	32	★★☆☆☆	All	All	Urban	Abdel-Aty et al., 2014	
☐	0.73	27	★★☆☆☆	All	K,A,B,C	Urban	Abdel-Aty et al., 2014	
☐	0.42	58	★★☆☆☆	Vehicle/bicycle	All	Urban	Abdel-Aty et al., 2014	
☐	0.4	60	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Abdel-Aty et al., 2014	

“Install Bicycle Lanes”
“Provide Bicycle Lanes”

☐	1.49	-49	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Jensen, 2008	Bicycle and moped riders, all ... [*read more*]
☐	1.57	-57	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Jensen, 2008	Bicycle and moped riders, all ... [*read more*]
☐	0.4	60	★★☆☆☆	Vehicle/bicycle	K,A,B,C	Urban	Abdel-Aty et al., 2014	
☑	0.65	35	★★☆☆☆	Vehicle/bicycle	K,A,B,C		Rodegerdts et al., 2004	

"Installation of Bicycle Lanes at Signalized Intersection with Exclusive Right Turn Lanes"

Compare	CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
☐	1.36	-36	★★☆☆☆	Vehicle/bicycle	All	Urban and suburban	Turner et al., 2011	note: study was performed in ... [*read more*]
☐	0.97	3	★★☆☆☆	Vehicle/bicycle	All	Urban and suburban	Turner et al., 2011	note: study was performed in ... [*read more*]

"Increase Bike Lane Width"

Compare	CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
☐	F(x)		★★★☆☆	Vehicle/bicycle	All	Urban	Park and Abdel-Aty, 2016	This CMF is for KABCO ... [*read more*]
☐	F(x)		★★★☆☆	Vehicle/bicycle	K,A,B,C	Urban	Park and Abdel-Aty, 2016	This CMF is for KABC ... [*read more*]
☐	F(x)		★★★☆☆	Vehicle/bicycle		Urban	Park and Abdel-Aty, 2016	This CMF is for KAB ... [*read more*]

"Increase Bike Lane Width"

CMFunction:

$$CMF = \exp\{0.1155 \times (U_{BLW} - Base_{U_{BLW}})\}$$

Where:

$$U_{BLW} = \ln\{47.24 + 11.859\,(PropBikeLaneWidth - 7) + 3.7\,(PropBikeLaneWidth - 7)^2\}$$

$$Base_{U_{BLW}} = \ln\{47.24 + 11.859\,(ExistBikeLaneWidth - 7) + 3.7\,(ExistBikeLaneWidth - 7)^2\}$$

Where:

$PropBikeLaneWidth$ = Proposed bicycle lane width in feet

$ExistBikeLaneWidth$ = Base, or existing, bicycle lane width in feet

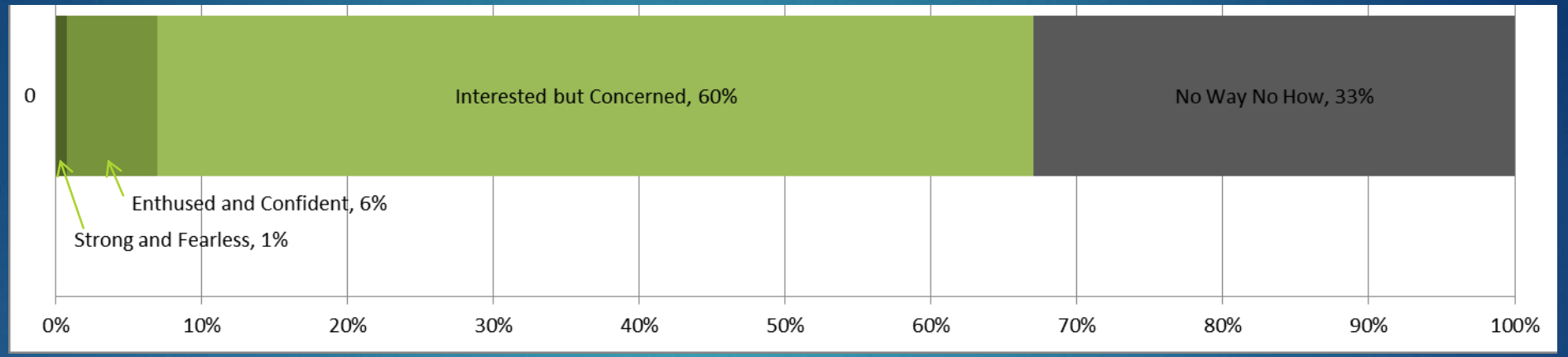
Using CMF's for Bikes

- Consider the star rating
- Read underlying research
- Consider applicability to your location
- Remember effects on crash rate
- Wait for methodology to evolve
- Use your judgement

How do we measure safety?

- Alive
- Whole
- Calm and confident

Types of bicyclists – City of Portland



Strong & Fearless

Enthused & Confident

Interested, but Concerned

Not Interested

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)

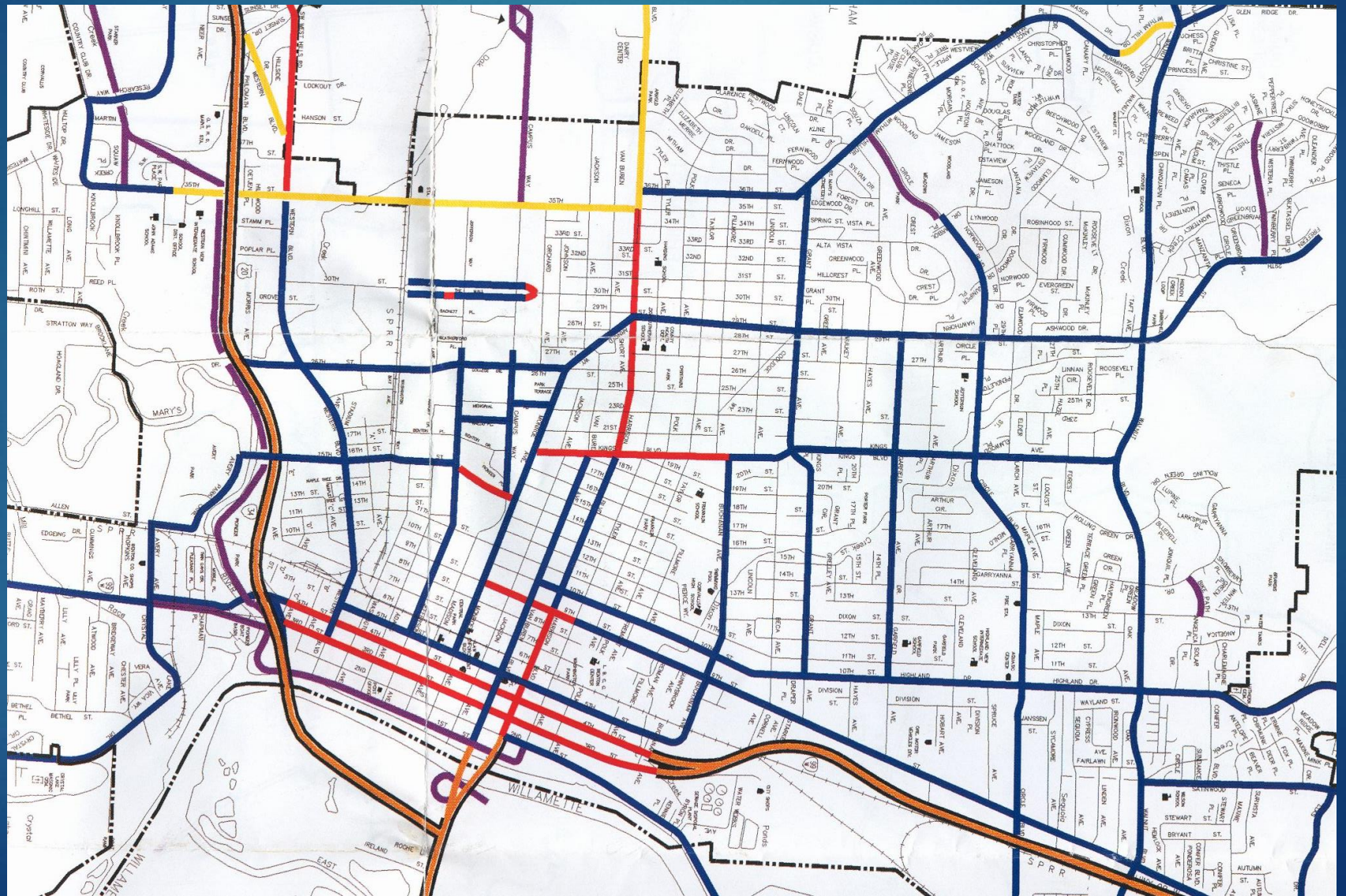
Levels of Traffic Stress			
LTS 1	LTS 2	LTS 3	LTS 4
• Physically separated from traffic or low-volume, mixed-flow traffic at 25 mph or less • Bike lanes 6 ft wide or more • Intersections easy to approach and cross • Comfortable for children	• Bike lanes 5.5 ft wide or less, next to 30 mph auto traffic • 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)

Casual/Less Confident

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.

AASHTO Guide for the Development of Bicycle Facilities 2012

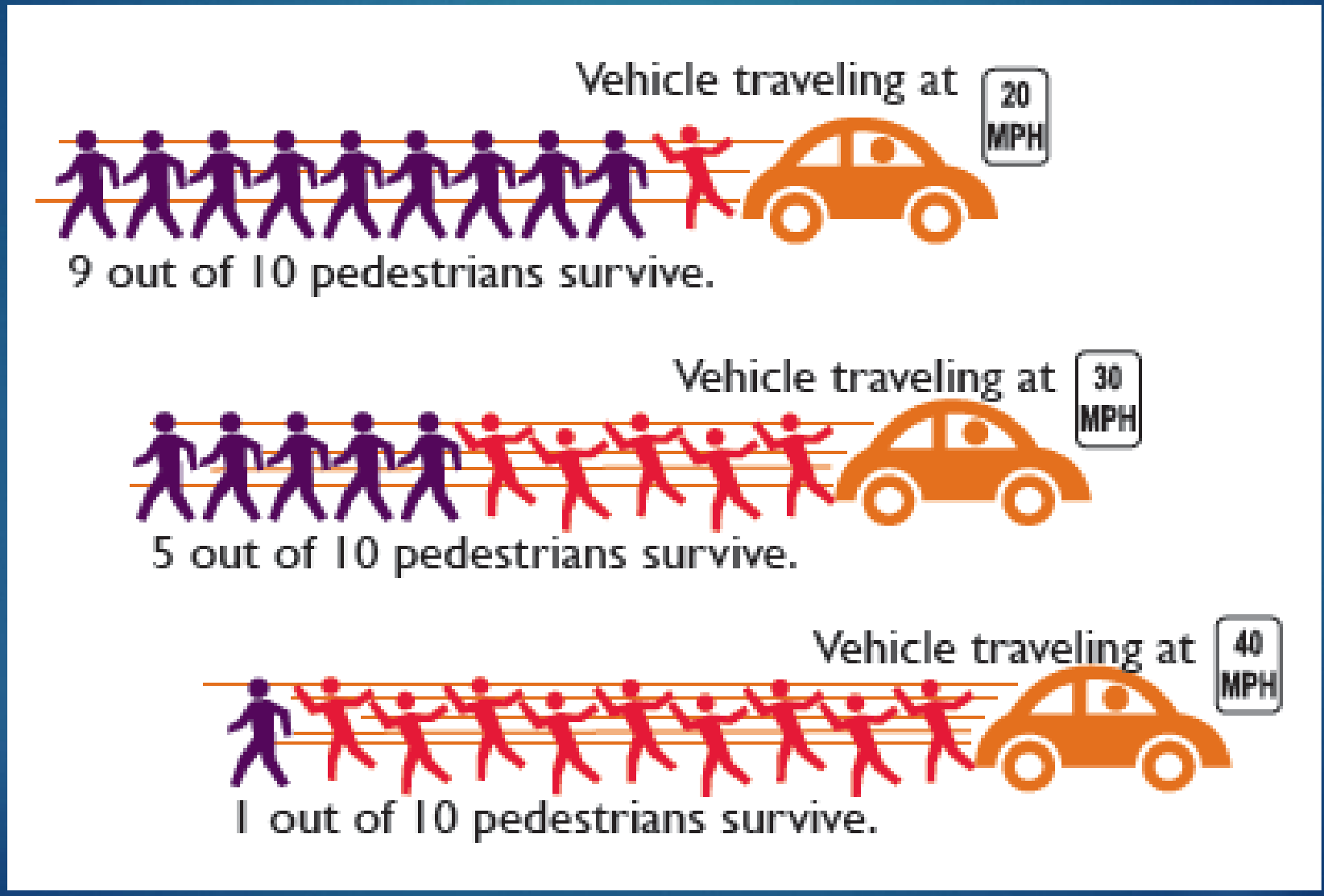
Well-Connected Network



Core Safety Concepts

DESIGNING FOR BICYCLIST SAFETY

Speed


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.

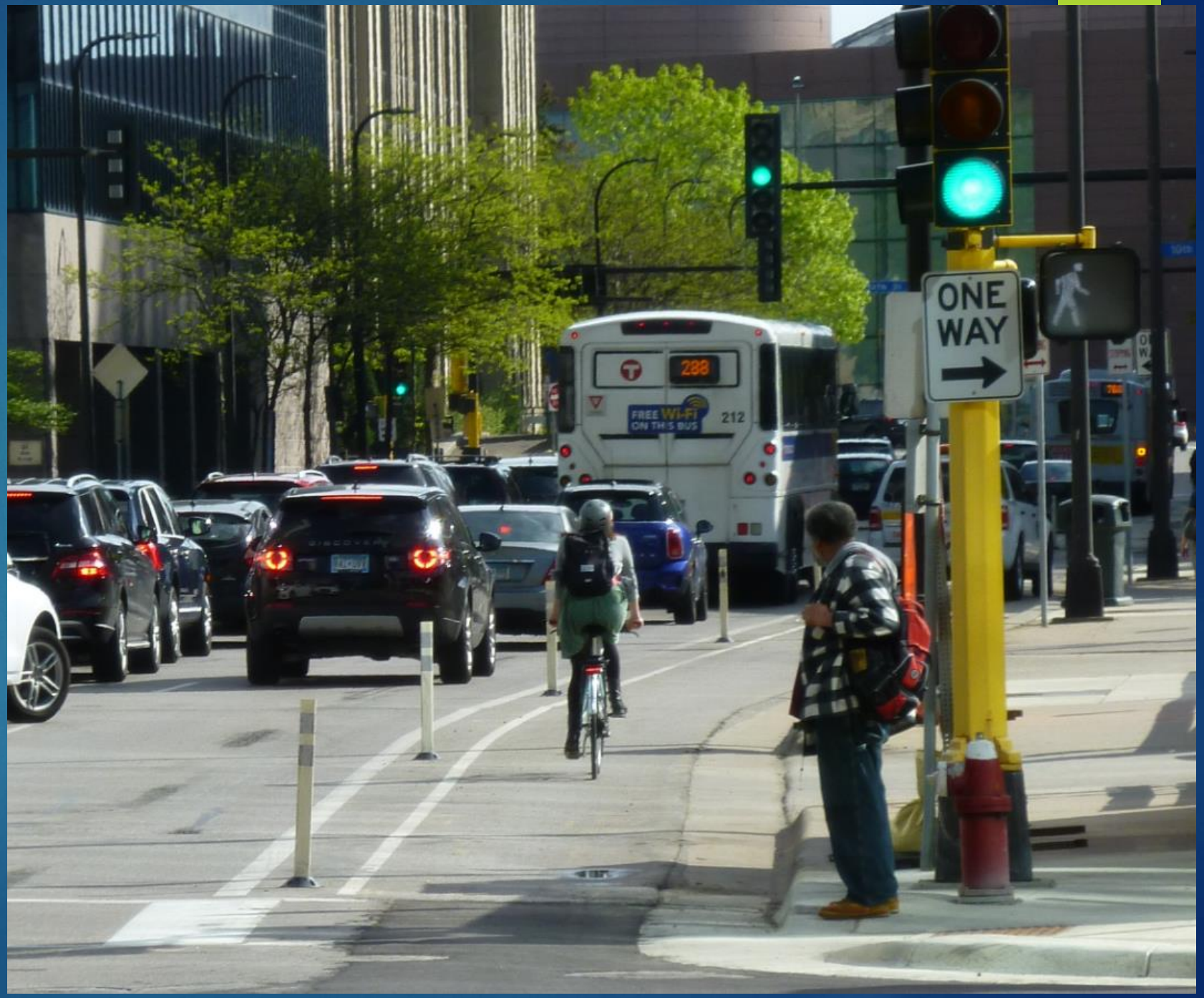
Number of Lanes

Visibility/Conspicuity

Traffic Volume & Composition

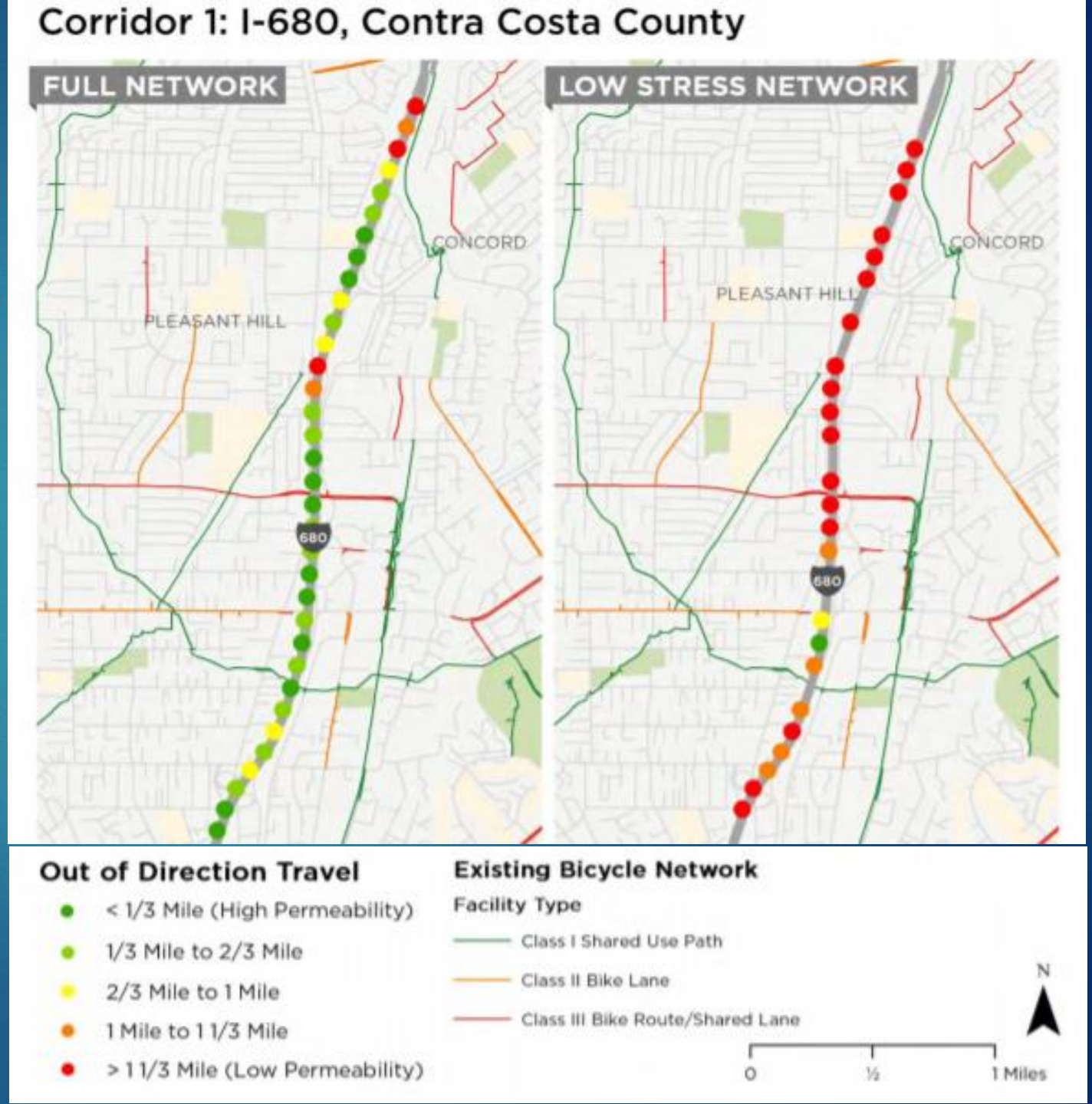
Conflict Points

Proximity



Bike Control

Connectivity



Key Safety factors

Important Message

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

Design Policies

DESIGNING FOR BICYCLIST SAFETY

Federal Law

- Consider bicycle facilities, where appropriate, with new construction and reconstruction.
- Consider safety and contiguous routes for bicyclists in plans and projects.

What does consider mean?

USDOT Policy

Signed on March 11, 2010 and announced March 15, 2010

Every transportation agency, including DOT, has the responsibility to improve conditions and opportunities for walking and bicycling and to integrate walking and bicycling into their transportation systems.

USDOT Policy

Recommended Actions:

- Consider bicycling as equal with other modes
- Ensure transportation choices for all ages and abilities, especially children
- Go beyond minimum design standards
- Integrate bicycle accommodation on bridges
- Collect data on bicycle trips
- Remove snow – same maintenance as roads required for facilities built with federal funds
- Improve bicycle facilities during maintenance projects

Evaluating Needs

DESIGNING FOR BICYCLIST SAFETY

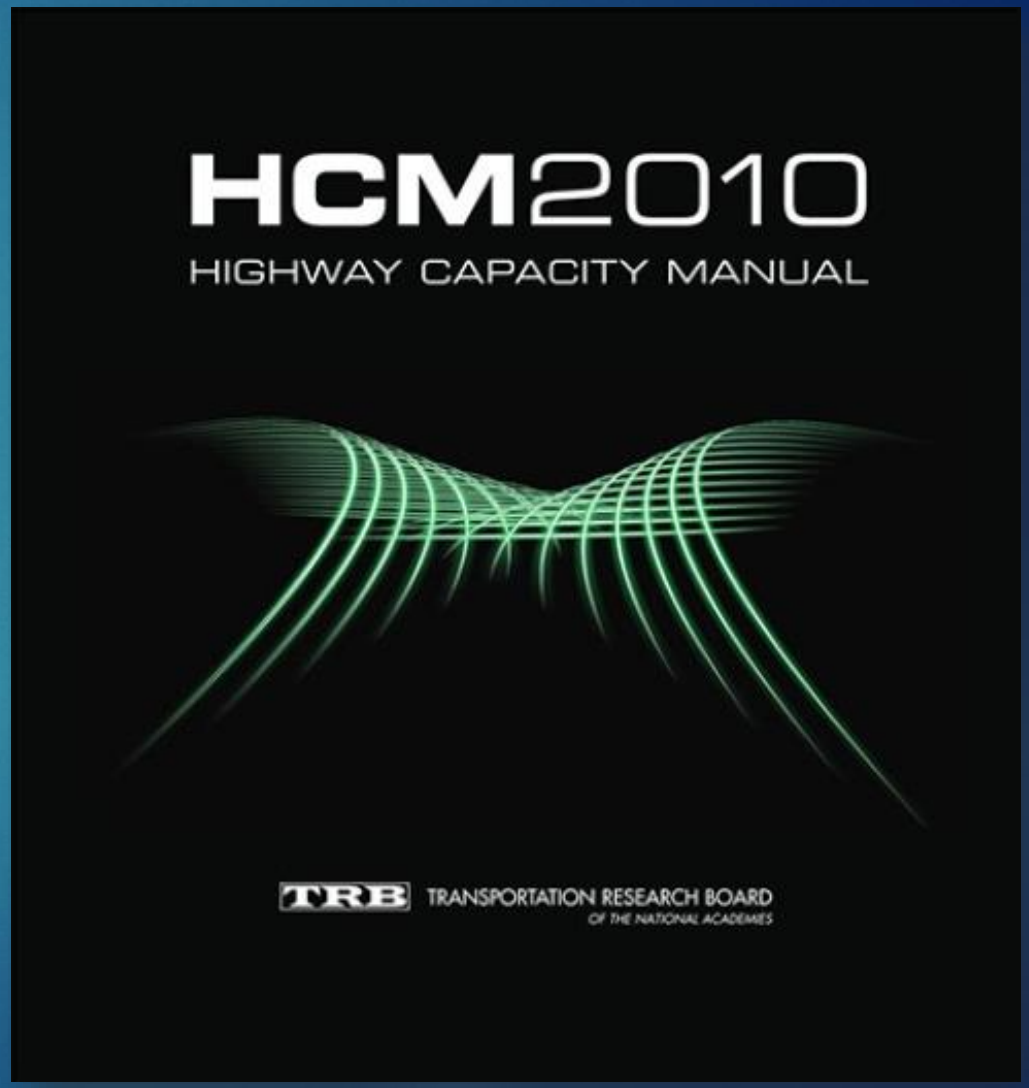
Other Analysis Methods

- Highway Capacity Manual
- Level of Traffic Stress
- Intersection Safety Indices
- Road Safety Audit
- Measuring Network Connectivity

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

- Motorized vehicle volume
- % heavy vehicles
- % occupied parking
- # lanes
- Outside lane width
- Median
- Curb
- Access
- Pavement condition
- Motorized vehicle speed

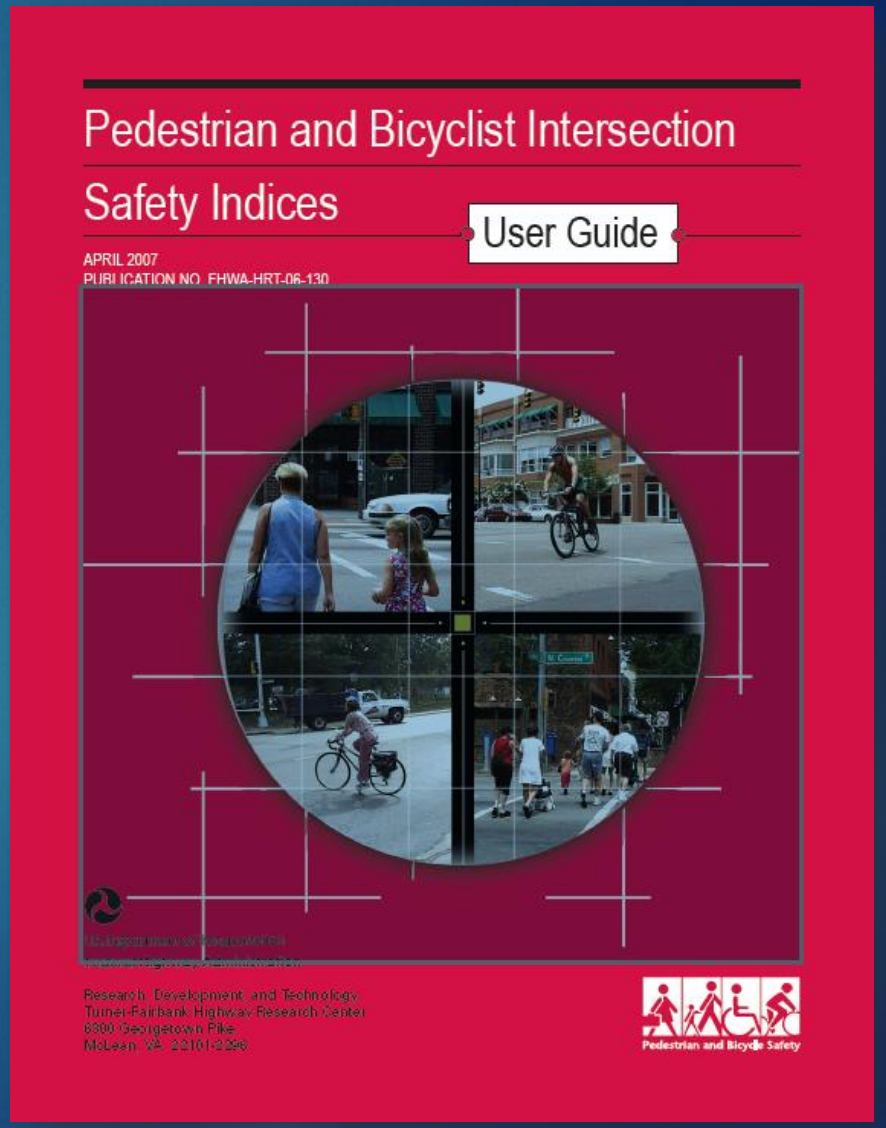
Level of Traffic Stress

Levels of Traffic Stress			
LTS 1	LTS 2	LTS 3	LTS 4
• Physically separated from traffic or low-volume, mixed-flow traffic at 25 mph or less • Bike lanes 6 ft wide or more • Intersections easy to approach and cross • 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)

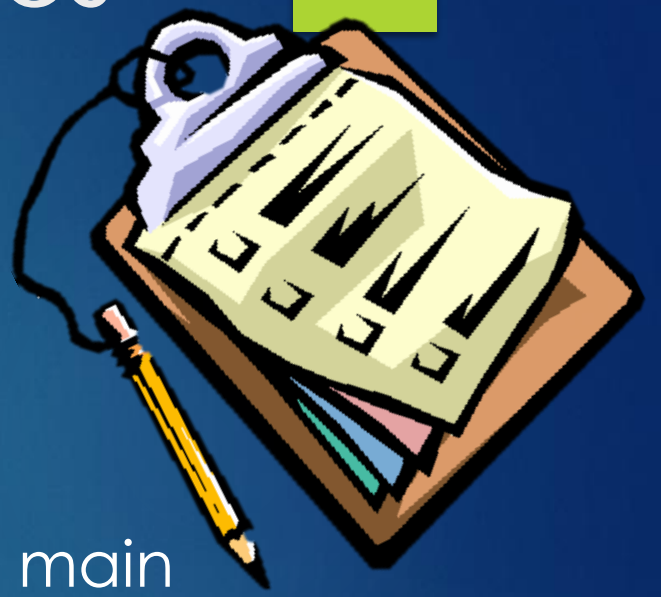
Bicyclist Intersection Safety Indices

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

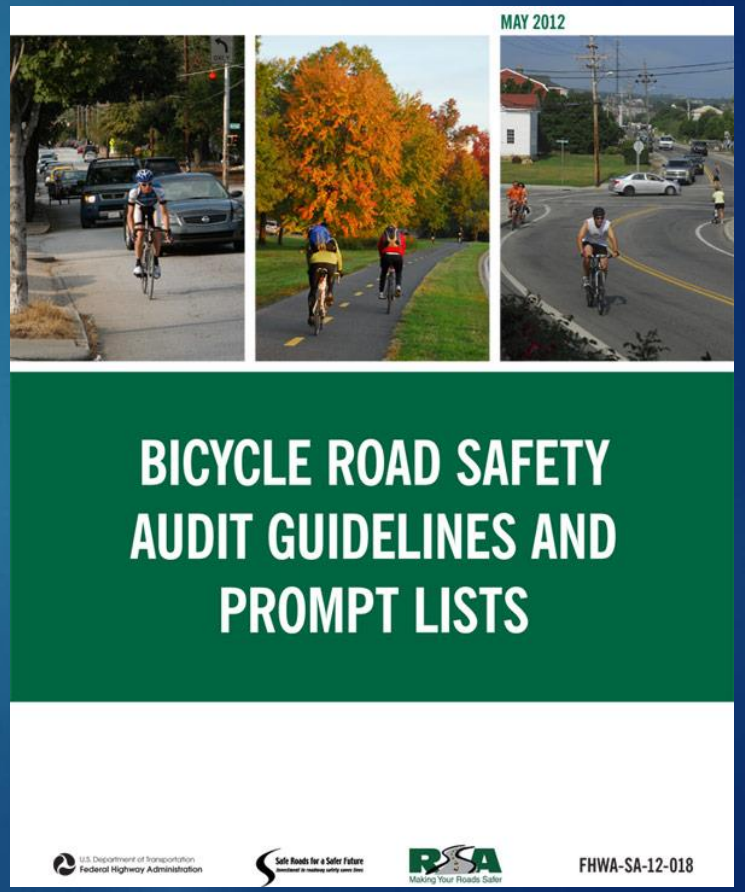


Inputs:

- 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).

Road Safety Audit

- Formal safety examination conducted by an independent, experienced, multidisciplinary team
- RSA Prompt List
- Bikeability checklist



RSA Prompt List

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:

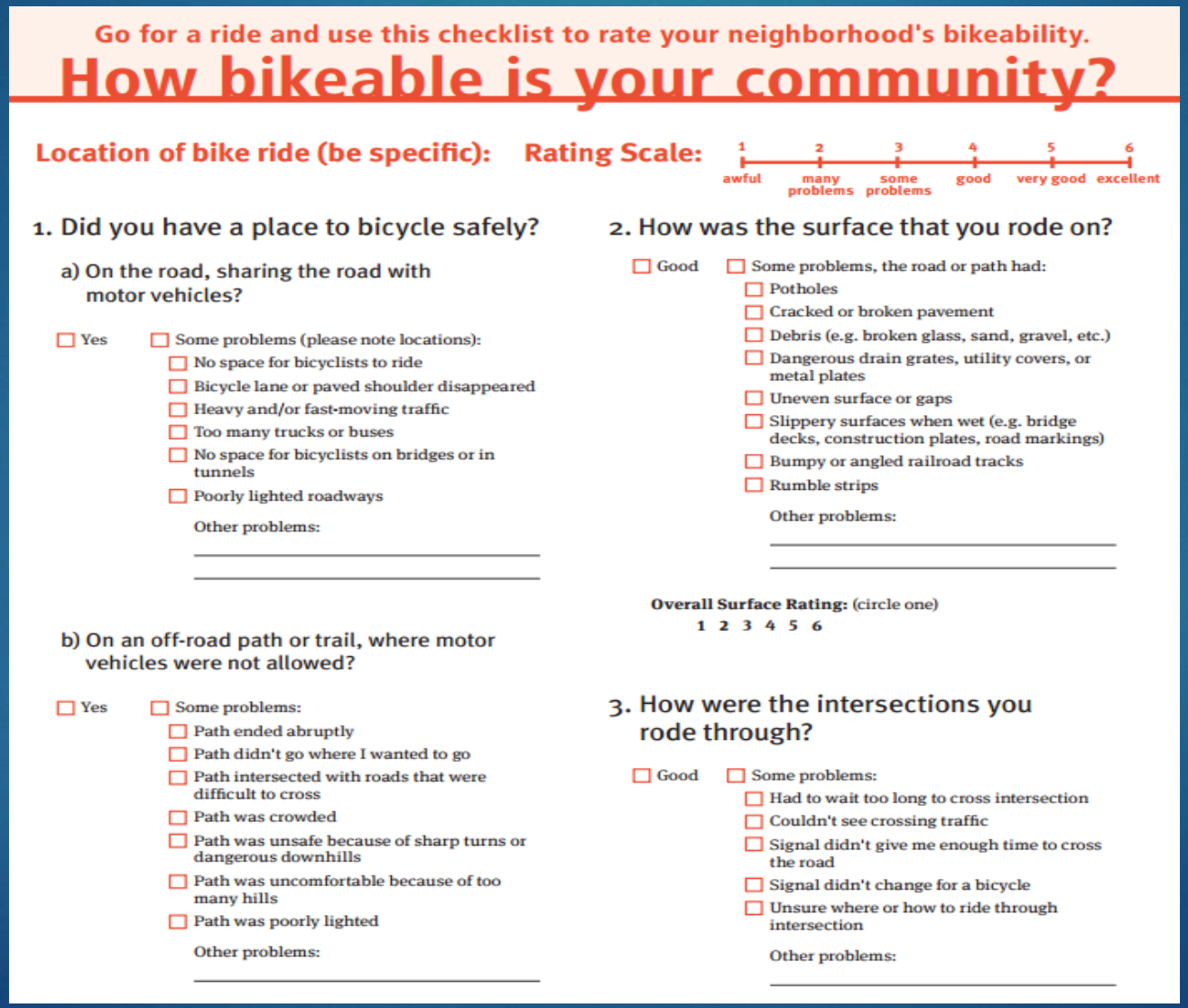
- Obstructions caused by roadside features (e.g., fences and vegetation).
- Adequacy of warning signs.
- Location of the transition with respect to roadway geometry (e.g., shoulder drop and turn lanes) (see also A.9 and C.9).

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.

Bikeability Checklist



Go for a ride and use this checklist to rate your neighborhood's bikeability.

How bikeable is your community?

Location of bike ride (be specific):

Rating Scale: 1 awful; 2 many problems; 3 some problems; 4 good; 5 very good; 6 excellent

1. Did you have a place to bicycle safely?

a) On the road, sharing the road with motor vehicles?

- ☐ Yes
- ☐ 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
- ☐ 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

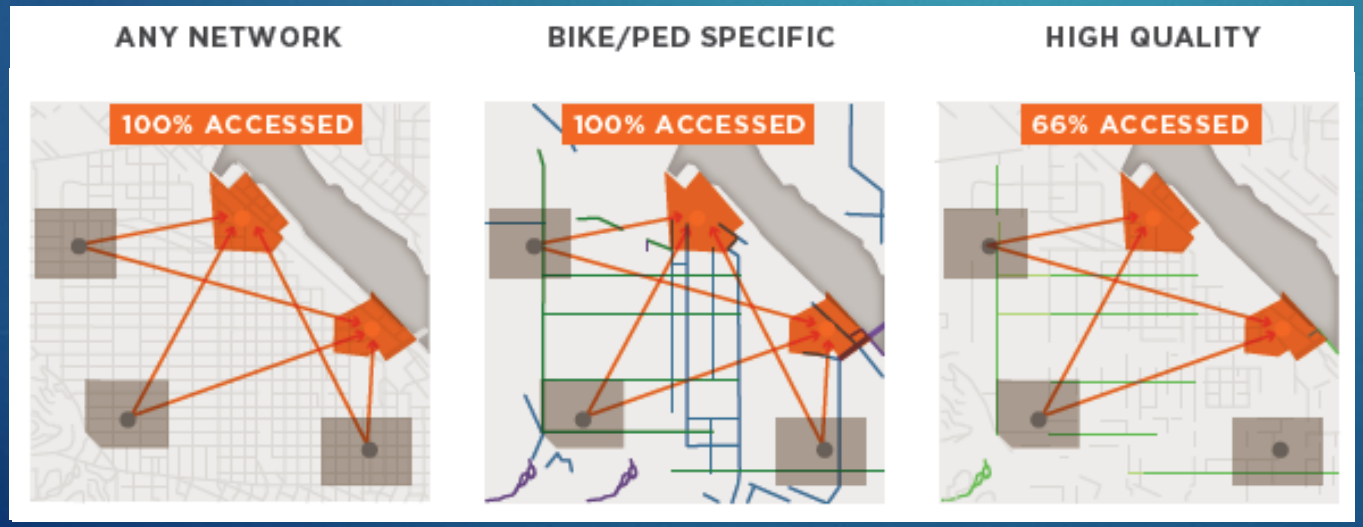
3. How were the intersections you rode through?

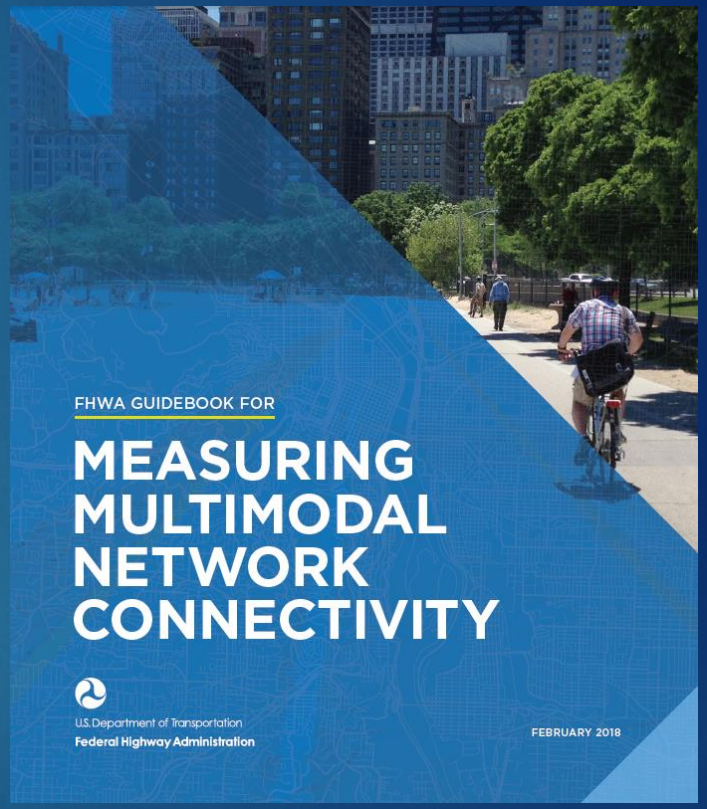
- ☐ Good
- ☐ Some problems:
  - ☐ Had to wait too long to cross intersection
  - ☐ Couldn't see crossing traffic
  - ☐ Signal didn't give me enough time to cross the road
  - ☐ Signal didn't change for a bicycle
  - ☐ Unsure where or how to ride through intersection

  Other problems: _____

Measuring Network Connectivity

- How complete is the network?
- How dense is the network?
- How direct is the network?
- What destinations can you access with the network?

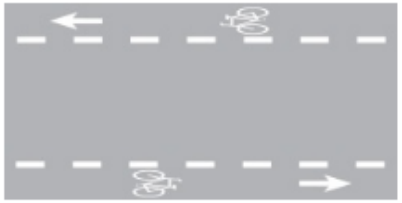




Selecting Countermeasures

DESIGNING FOR BICYCLIST SAFETY

Dare to Experiment

Subject to Experimentation	Available through Interim Approval	Interpretations
 Two-Stage Turn Box	 Green-Colored Pavement	 Use of R4-11 Sign on Roads with Speed Limits Above 35mph
 Dashed Bicycle Lanes	 Alternate Design for the U.S. Bicycle Route (M1-9) Sign	 Modified Bicycle Destination Sign
 Destination Guide Signs for Shared-Use Paths	 Bicycle Signal Faces	 Installation of Advance Turn and Directional Assemblies for Bike Route Signs
 Green-Colored Pavement for Use with the Shared-Lane Marking	 Bicycle Box	 Pavement Markings for Designated Bicycle Routes

Design Guidelines

- FHWA Memorandum – August 20, 2013
  "Bicycle and Pedestrian Facility Design Flexibility"
  - **Support for taking a flexible approach**
  - Guide for the Development of Bicycle Facilities (AASHTO)
  - Designing Urban Walkable Thoroughfares (ITE)
  - Urban Bikeway Design Guide (NACTO)
  - **New 2015:** Separated Bike Lanes Planning & Design Guide (FHWA)
  - **New 2015:** Separated Bike Lanes Planning & Design Guide (MassDOT)
  - **New 2016:** Achieving Multimodal Networks: Applying Flexibility and Reducing Conflicts (FHWA)
  - **New 2017:** Small Town and Rural Multimodal Networks (FHWA)
  - **New 2018:** Measuring Multimodal Network Connectivity (FHWA)

PEDBIKESAFE.ORG

The **Bicycle Safety Guide and Countermeasure Selection System** is intended to provide practitioners with the latest information available for improving the safety and mobility of those who bike. The online tools provide the user with a list of possible engineering, education, or enforcement treatments to improve bicycle safety and/or mobility based on user input about a specific location.

GUIDE

Background
Understand what is needed to create a viable bicycle network.

Analysis
How crash typing can lead to the most appropriate countermeasures.

Statistics
Learn about the factors related to thebicycle crash problem.

Implementation
Needed components for treatments.

COUNTERMEASURES

Selection Tool
Find countermeasures based on desired objectives.

Countermeasure List
A comprehensive list of all countermeasures.

Selection Matrices
Find countermeasures based on crash types and performance objectives.

Shared Lane Marking

- More than 1 lane Downhill or level
- Short segment to fill gap in bikeway
- Speed < 30 mph
- High bicycle use

- Single lane
- Uphill
- Parallel route option
- Long segment
- Speed > 40 mph
- Low bicycle use

Poll Question #3

- Which sign is preferred for a shared roadway?

Shared Road Signs

- Reminder for motorists

Separated Bike Lanes

- Exclusive bike facility
- Adjacent to or on roadway
- One-way or contra-flow
- Separated from traffic by vertical element

Separated Bike Lanes

Advantages

- Very low stress midblock
- Encourages bike riding
- More conspicuous
- Crash rate reductions

Separated Bike Lanes

Disadvantages

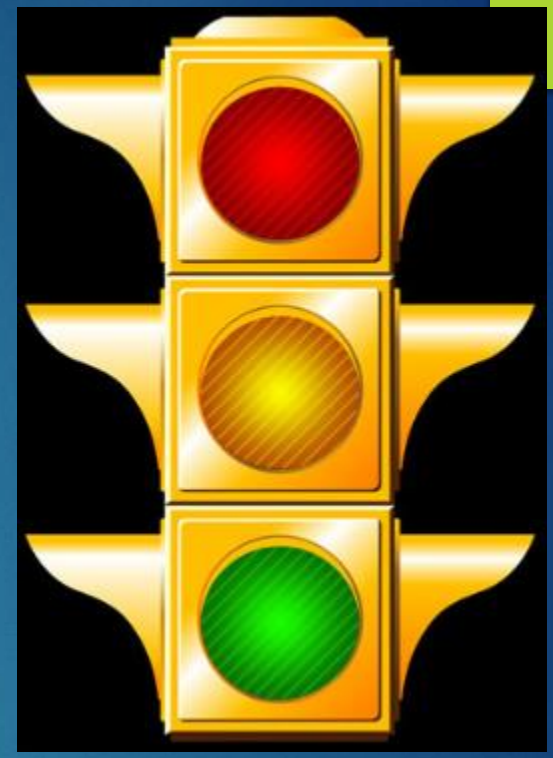
- Special treatments for
  - Intersections
  - Driveways
  - Parking
  - Transit
  - Loading zones
- Additional space needed
- More costly than bike lanes
- More to learn

Safer Signals for Cyclists

- Set initial and gap times for bicyclists
- Differentiate detection to optimize signal
- Leading bicyclist interval (LBI)
- Segregate conflicting movements

Signal Timing

- MUTCD
  - Section 9D.02
    - Standard: On bikeways, signal timing and actuation shall be reviewed and adjusted to consider the needs of bicyclists.
- Yellow change interval
- Red clearance interval



Bicyclists are slower!

Leading Bicyclist Interval

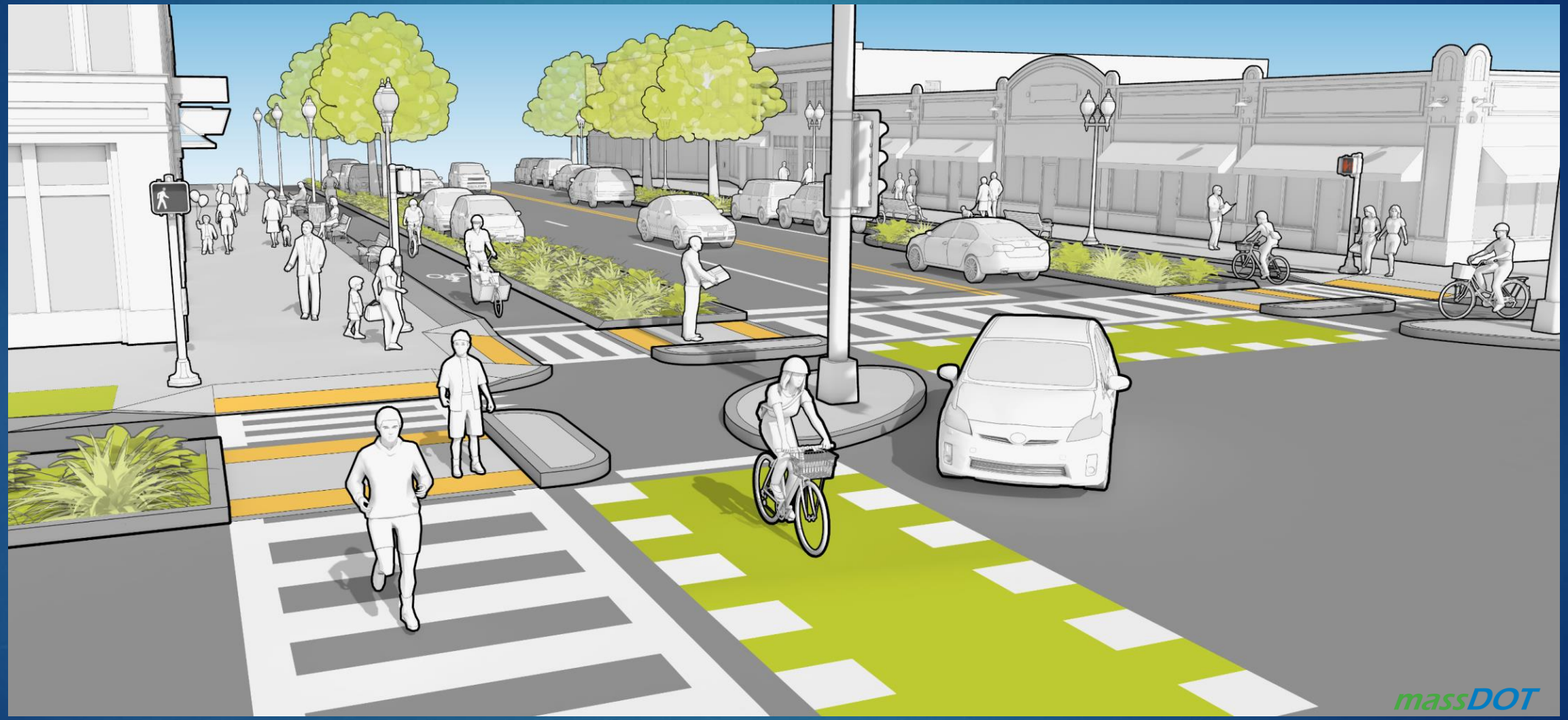
Segregate Conflicting Movements

Bicycle Signal Face

- 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

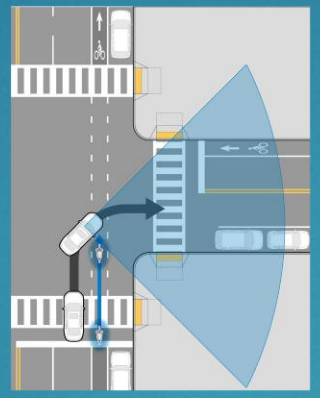
Roy Crisman/Flickr

“Protected” Intersections

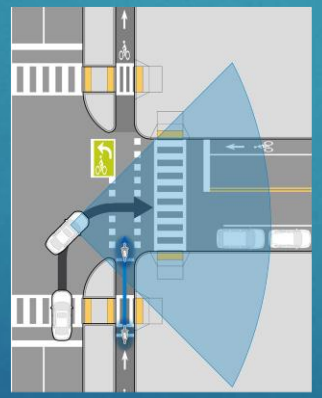


Visibility at Conflict Points

motorist's view at conventional bike lane

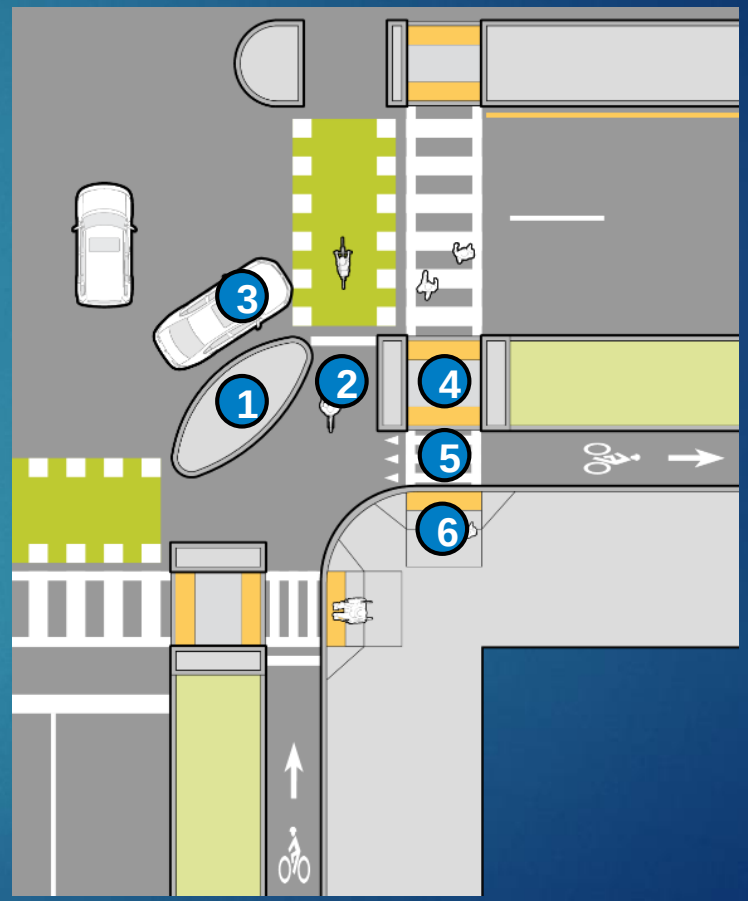


motorist's view at **separated bike lane**



“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



massDOT

“Protected” Intersections

Useful References

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- https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/multimodal_connectivity/
- http://www.pedbikesafe.org/bikesafe/
- http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/index.cfm
- City of Edmonton video on bike box: https://www.youtube.com/watch?v=siixA3FJc1I

Summary Thoughts

DESIGNING FOR BICYCLIST SAFETY

Summary Thoughts

- SPF provides a crash frequency, not a crash rate
- HSM is a new methodology with more research and reliability to come
- Look to other tools in the meantime
- Engineering judgement based on key safety factors for bicyclists
- Safety is more than getting home alive

Key Safety factors

Important Message

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

Questions

DESIGNING FOR BICYCLIST SAFETY

Discussion

- Send us your questions 
- Follow up with us:
  - Brooke Struve brooke.struve@dot.gov
  - General Inquiries pbic@pedbikeinfo.org
- Archive at www.pedbikeinfo.org/webinars