NCHRP Project No. 20-44(35)

IMPLEMENTATION SUMMARY REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies of Sciences, Engineering, and Medicine

Prepared by

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SPECIAL NOTE: This report **IS NOT** an official publication of the National Cooperative Highway Research Program, Transportation Research Board, National Research Council, or the National Academies.

Acknowledgements (include in report)

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INTRODUCTION

The objective of this research is to share and disseminate the results of the NCHRP 07-25 research with public agencies, and to provide hands-on technology transfer assistance to these agencies. That original project produced NCHRP Report 948: Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges.

NCHRP Report 948 is a guide for transportation practitioners to improve and integrate pedestrian and bicycle safety considerations at alternative intersections and interchanges (A.I.I.) through planning, design, and operational treatments. The method is also applicable to conventional intersections and interchanges and was specifically designed to allow for a comparison between alternative and conventional designs, or design elements. This implementation project brought the unique opportunity to disseminate the NCHRP Report 948 methodology and assist public agencies with integration of pedestrian and bicyclist safety into the planning, design, and evaluation of A.I.I.s.

The key deliverables of this implementation effort were:

(1) Development of materials for a training website hosted by NCHRP;
(2) Development and delivery of two national webinars with an estimated combined attendance of over 1,000 people;
(3) Presentations at three national conferences with an estimated combined audience of 450 to 500 people;
(4) Preparation of a 90-minute self-paced e-learning module that was a mandatory pre-requisite for all in-person training course attendees;
(5) Development of a one-day training course, including hands-on example problems and local case studies; and
(6) Delivery of the one-day training to nine state DOTs and local agencies across the US, with a total of 188 attendees.

The materials developed as part of NCHRP Report 948 served as the basis for this implementation program. The audiences for these workshops included engineers/administrators who may be responsible for making decisions about intersection and interchange safety for pedestrians and bicyclists.

As part of the preparation of the training materials and case studies included in the training, the research team further identified several clarification needs related to the originally-published chapters in NCHRP Report 948. Accordingly, the research team prepared a summary of these items.

This document contains the following sections:

- A summary of webinar and conference presentations delivered;
- A summary of training materials produced;
- A summary of all workshops delivered under the contract;
- Documentation of potential changes or enhancements to the methodology based on participant feedback and testing; and
- Several appendices that contain the relevant materials:
    - Appendix A: Sample Training Flyer
    - Appendix B: Case Studies developed for workshop
    - Appendix C: Select slides for conference presentations and webinars
    - Appendix D: Details Summary of 20 design flags (basis for web-based training)
    - Appendix E: Slides for In-Person workshop
    - Appendix F: Other Training Handouts

SUMMARY OF WEBINARS AND CONFERENCE PRESENTATIONS

The primary goal of this project was to provide training and technology transfer of the materials published as NCHRP Report 948. As part of that effort, the team delivered two national webinars, and three in-person conference presentations. Table 1 summarizes the webinars

Table 1. Summary of Webinars

Webinar Number	Webinar Sponsor	Date
1	TRB Webinar Series	October 22, 2022
2	ITE Webinar Series	June 22, 2023

Attempts to schedule a 3rd webinar were not successful, as the webinar hosts generally felt that there was no new material to present (after two national webinars with strong attendance). The team had submitted abstracts to the Association of Pedestrian and Bicycle Professionals (APBP) twice and reached out to the FHWA Pedestrian and Bicycle Information Center (PBIC), but neither were compelled to offer an additional webinar.

For the first of these events, the team delivered a webinar through the TRB webinar series on Tuesday, October 25, 2022. The webinar was one of the most-attended webinars TRB had hosted at the time with 603 sites attending. The webinar was titled *Safer Intersections for Pedestrians and Bicyclists* and presented a general overview of NCHRP Report 948 and the 20-flag methodology. The learning objectives were:

1) Attendees will be able to apply the 20-flag method to evaluate intersection safety for pedestrians and bicyclists
2) Attendees will be able to assess design elements at alternative and conventional intersections that contribute to multimodal safety

The second webinar titled *Safety by the Numbers: Measuring the Pedestrian and Bicyclist Experience at Intersections from Alternatives Analysis Through Final Design* was hosted by ITE on June 22, 2023. It had approximately 180 attendees. The 90-minute webinar was aimed at practitioners and had four learning objectives:

1) Attendees will be able to describe at what point in the design process the 20 Flags Method can be applied.
2) Attendees will be able to describe methods for mitigating identified flags.
3) Attendees will be able to identify additional two additional sources for further instruction on the 20 Flags Method.
4) Attendees will be able to recall at least 4 of the flags in the 20 flags method.

Combined, the two webinars reached nearly 800 sites. Considering that webinars often have multiple viewers in the same room (arguably less so after the pandemic), it is conservatively estimated that well over 1,000 people participated in the two webinars.

Table 2 summarizes the three conference presentations delivered as part of this effort.

Table 2. Summary of Conference Presentations

Presentation Number	Conference	Date and Location
1	TRB Annual Meeting	January 2023, Washington, DC
2	Lifesavers Conference	April 2023, Seattle, WA
3	ITE Annual Meeting	August 15, 2023, Portland, OR

For the first conference presentation, the team was able to make in-person presentations to four standing committees at the TRB Annual Meeting held in Washington, DC in January 2023:

- ACH10 – Standing Committee on Pedestrians
  - Presented at the Research Subcommittee on Wednesday, January 11, 2023
- ACH20 – Standing Committee on Bicycle Transportation
  - Presented at the Research Subcommittee on Wednesday, January 11, 2023
- AKD10 – Standing Committee on Performance Effects of Geometric Design
  - Presented at the full committee meeting on Tuesday, January 10, 2023
- AKD20 – Standing Committee on Roundabouts and Other Intersection Design and Control Strategies
  - Presented at the full committee meeting on Wednesday, January 11, 2023

Attendance at the committee meetings varied, but the team estimates that each of the four sessions had at least 50 unique participants for a total of 200 people hearing the project overview.

The second conference presentation was made on April 3 in Seattle, Washington at the national LifeSavers Conference. Use of the '20 Flag' Method was part of the panel session *Pedestrian, Bicycle, & Micromobility Ideas in a Box* attended by approximately 60 conference attendees. The presentation focused on presenting the 20 flags method as a means for community advocates to communicate safety concerns to owner/operator practitioners. Feedback was positive with multiple attendees approaching the presenter following the session and two follow up emails. One such email was from an FHWA employee looking to share the material with colleagues.

The third conference presentation was made on August 15, 2023 at the ITE Annual Meeting. The presentation was part of a session titled “Innovative Intersection Design” that also included an update on the new Roundabout Guide. The session had standing room only with over 200 participants, and the team received a lot of interest from the audience in the method.

Combined, the three conference outreach efforts are estimated to have reached between 450 and 500 people. The slides for the two webinars are included in Appendix C; the conference presentations were generally abbreviated versions of these full webinars.

SUMMARY OF TRAINING MATERIALS

The largest effort of this implementation project was the development and delivery of detailed training materials to summarize concepts and methodology in NCHRP Research Report 948. The team developed two primary training elements:

1. A 90-minute web-based training module, designed for asynchronous, self-paced learning, and
2. A one-day in-person training course, designed for synchronous, instructor-led instruction.

The two training elements were designed to work together, with participants of the in-person training expected to complete the online modules prior to attending the class. Specifically, the web-based training covers the fundamentals of the methodology, while the in-person training provides hands-on practice on the method using example problems, as well as local case studies. The web-based training also serves as a standalone resource for anyone looking to learn the basics of the design flag method. The online training course is available for free at the following URL:

https://project.kittelson.com/NCHRP_Report_948/

For the in-person training, the team developed three example problems to serve as hands-on exercises during the training. The example problems were based on CAD design drawings (horizontal layout only) and were designed to mirror what engineers and planners may encounter during the intersection design stage. The three example problems include one signalized intersection, one multi-lane roundabout, and one restricted crossing U-Turn (RCUT) intersection. For each training, the team selected two of these example problems to work through in the class.

In addition, the team identified several real-world intersections that formed the basis of the group exercises during the training. The case studies represent a cross-section of different intersection types and land use contexts. For each training, the team selected locations that were most representative of what the local agencies may be likely to encounter in their day-to-day work. While the CAD-based example problems represented intersections in the planning and design stage, the objective of the real-world examples was to illustrate how the method could be applied to retrofit and enhance existing intersections.

Figure 1 shows the three example problems developed for the training. Appendix B includes full-page versions of all example problems and real-world case studies used in the training. Training materials for the in-person training are included in Appendix E. Appendix D contains a detailed summary of all design flags, which was also the basis of the web-based training modules. Appendix F contains other training handouts developed by the team to facilitate group exercises. Specifically, the team designed an 11x17 handout showing all flags, a two-sided handout with all design flag thresholds, and two worksheets to assist in application of the method. The team further developed a spreadsheet implementation of the methodology that allows users to keep track of the design flag assessment and creates automated summary statistics and charts.

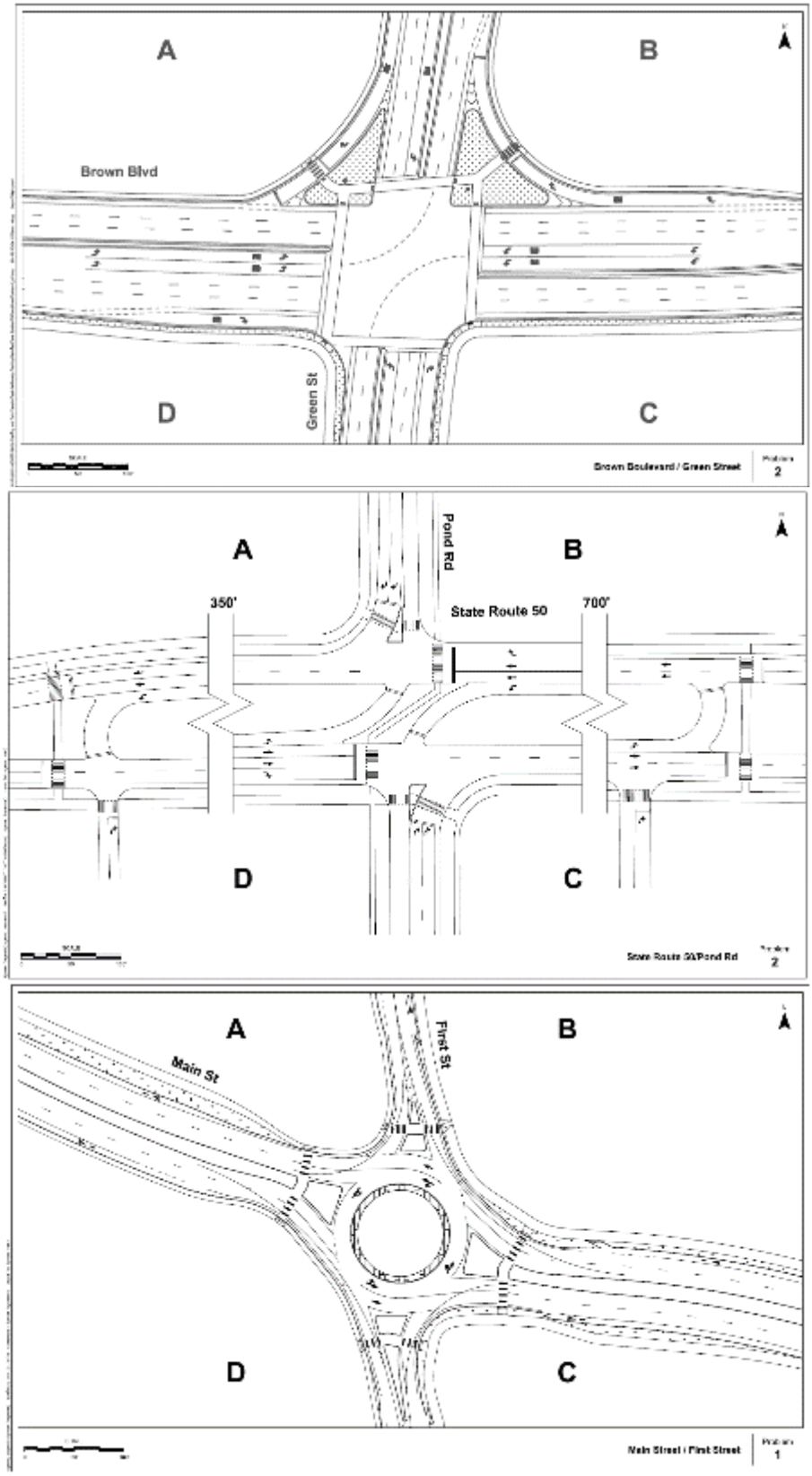


Figure 1: Example Problems Developed for In-Person Training

SUMMARY OF IN-PERSON WORKSHOPS

A cornerstone of the implementation effort was the delivery of nine in-person workshops, with up to 30 participants in each session. All workshop participants were further instructed to take the web-based training prior to attending the workshop. This format allowed the in-person workshops to be focused on hands-on practice of the methodology using two example problems, as well as two local case studies tailored to the specific training location. A summary of the training locations and number of participants for each is shown in Table 3.

Table 3. Summary of In-Person Workshops

Workshop Number	State	Location	Date	Number of Participants
1	North Carolina	Raleigh, NC	May 11, 2023	24
2	Oregon	Salem, OR	June 6, 2023	18
3	Washington	Vancouver, WA	June 8, 2023	14
4	Maryland	Hanover, MD	August 10, 2023	19
5	Arizona	Phoenix, AZ	September 12, 2023	19
5	Texas	Austin, TX	September 13, 2023	23
6	Minnesota	Shoreview, MN	September 20, 2023	23
7	Massachusetts	Worcester, MA	November 14	30
9	North Carolina	Charlotte, NC	November 28	18
			TOTAL	**188**

In addition to these locations, the team had been coordinating with Florida and Idaho to host a training but was not able to get local commitment to a time and location within the period of performance of the project. As a result, the team hosted a second workshop in North Carolina in the Charlotte area, given that the first workshop in Raleigh, NC had a waitlist with several participants turned away.

In total, the project was able to train 188 people across nine states in the use of the method. The breakdown of participants was as follows:

- State DOT: 74% (139 people)
- Private Consultants: 17% (32 people)
- Local Agencies: 9% (16 people)
- Federal Highway Administration: 1% (1 person)

In the past quarter, the team delivered four additional training sessions in Phoenix, AZ, Hanover, MD, Shoreview, MN, and Austin, TX. All trainings were well attended, including significant waitlists for the Minnesota and Texas trainings. Both states expressed an interest for additional training sessions in the future, which was also the case for North Carolina.

For all sessions, the classes included classroom discussions, and small-group exercises in applying the method to a series of sample intersections, as well as local case studies. The feedback from classes was generally positive with participants eager to start applying the method to their projects. A sample of photos from the classes is shown in Figure 1.

Classroom Training in Raleigh, NC

Small-Group Exercise in Raleigh, NC

Classroom Training in Salem, OR

Small-Group Exercise in Salem, OR

Classroom Training in Vancouver, WA

Small-Group Exercise in Vancouver, WA

Classroom Training in Phoenix, AZ

Small-Group Exercise in Phoenix, AZ

Figure 2: Photos of Classroom Trainings and Activities

For each training, the team produced a two-page flyer with registration details, as well as set-up a web-based registration. Once confirmed, registration for all events were available on the registration page: https://events.kittelson.com/NCHRPReport948. A sample registration flyer is shown in **Appendix A**.

DOCUMENTATION OF POTENTIAL CHANGES TO METHODOLOGY

This section describes a series of takeaways and potential next research steps for the assessment method based on the workshop implementation feedback and research team debriefs. In particular, there were four key takeaways from the testing and workshops:

1. Need to clarify flag definition and terminology;
2. Distinction between primary and secondary flags;
3. Re-consider flag thresholds related to vehicle speeds and volumes; and
4. Clarification regarding the application of flags.

The following sections explore each of these items in more detail. Agencies considering adopting the 20-flag methods are strongly encouraged to integrate these recommendations into their methods and practices.

It is noted here that none of the training materials have been revised to reflect these recommendations to assure that the training remains consistent with the published NCHRP Report 948 materials.

Flag Definition and Terminology

The printed guide and the accompanying workshop materials refer to red flags as "design elements directly related to a safety concern for pedestrians and bicyclists" and to yellow flags as "design elements negatively affecting user comfort." In reality, the research team has determined through internal discussions, the development of example problems and case studies for the training, and in conversation with workshop participants that flags and their thresholds as defined in the guidebook have more nuance.

First, in some cases, the red versus yellow flag distinction simply represents an exacerbation of a safety issue rather than safety versus comfort. Yellow versus red flags frequently represent different levels of exposure and risk (higher speeds and more traffic volume) related to that same safety issue. In such a case, the yellow does not stand in for comfort, but a milder version of the same safety issue that the accompanying red flag represents.

Second, we have noted that when applying the assessment, an analyst with a given agency will naturally (formally or informally) apply different weights to the flags. The guidebook presents all 20 flags (all 13 pedestrian flags and all 17 bicyclist flags) without providing any ranking or weighting. However, a number of reasons could motivate an agency to apply more weight to some flags than others. One would be data indicating that a certain flag aligns more closely with crash frequency and severity than others do. Such calibration is a logical next step for the assessment methodology but has not yet been done. A second reason would be local conditions (e.g., an intersection is right next to a regional bike trail, so bicycle circulation is less important than other outcomes). In any event, some natural or global grouping of flags may be in order, resulting in the following potential four-tier classification of flags:

Table 4: Priority of Flag Application

Flag Type	Primary	Secondary
Red	1st	2nd
Yellow	3rd	4th

Further research could classify flags as primary versus secondary and redefine red versus yellow flags as matters of degree rather than safety versus comfort, as discussed below.

Primary and Secondary Design Flags

As written in NCHRP Report 948, all 20 design flags have equal ranking in the assessment. Through repeated testing and user feedback, the team determined that some of the flags may need to be given a higher weight than others. While all flags represent a potential safety concern, some are associated with elevated risk and potential severity of crashes than others. By distinguishing primary and secondary flags, greater weight would be given to the more sever flags.

In the application of the method, users may want to consider prioritizing design modifications and countermeasures that address *red primary flags*, then turn attention to *red secondary flags* etc as discussed above. At this time, the following nine primary and eleven secondary flags are proposed.

Primary Flags: Most immediate safety concern and direct correlation with known crash problems.

- Flag 1: Motor Vehicle Right-Turns
- Flag 4: Crossing Yield-Controlled or Uncontrolled Vehicle Paths
- Flag 7: Multilane Crossings
- Flag 10: Motor Vehicle Left Turns
- Flag 14: Riding in Mixed Traffic
- Flag 16: Lane Change Across Motor Vehicle Travel Lanes
- Flag 17: Channelized Lanes
- Flag 18: Turning Motorists Crossing Bicycle Path
- Flag 19: Riding Between Travel Lanes, Lane Additions, or Lane Merges

Secondary Flags: Less clear correlation to known crash patterns involving pedestrians and cyclists.

- Flag 2: Uncomfortable/Tight Walking Environment
- Flag 3: Nonintuitive Motor Vehicle Movements
- Flag 5: Indirect Paths
- Flag 6: Executing Unusual Movements
- Flag 8: Long Red Times
- Flag 9: Undefined Crossings at Intersections
- Flag 11: Intersecting Driveways and Sidestreets
- Flag 12: Sight Distance for Gap Acceptance Movements
- Flag 13: Grade Change

- Flag 15: Bicycle Clearance Times
- Flag 20: Off-Tracking Trucks in Multilane Curves

Further research is recommended to further test this approach, including correlation with actual crash data.

Flag Thresholds

The flag thresholds presented in the guidebook frequently present a good faith attempt to capture a distinction between less severe yellow flag conditions and more severe red flag conditions. In administering the training, the research team has observed that some thresholds almost always result in red flags in real-life scenarios in a way that renders the designer with limited or no options to affect the results.

In particular, three of the flags in the NCHRP Report 948 use a combination of vehicle speed and vehicle volume to distinguish yellow and red flags. These three flags are:

- Flag 1: Motor Vehicle Right-Turns
- Flag 4: Crossing Yield-Controlled or Uncontrolled Vehicle Paths
- Flag 10: Motor Vehicle Left Turns

The thresholds for yellow and red flags for each of these three flags are as follows (Table 5):

Table 5: Current NCHRP Report 948 Yellow and Red Flag Thresholds for Flags 1, 4, and 10

Measure of Effectiveness	Yellow Flag Threshold	Red Flag Threshold
Vehicle Speed & Vehicle Volume	<= 20 mph **AND** <= 50 vph	> 20 mph **OR** > 50 vph

mph = miles per hour; vph = vehicles per hour

In application of the method, three concerns with these thresholds were identified.

- First, the vehicle volume threshold for red flags appears to be too low;
- Second, the "OR" condition for the Red Flag results in the flags being triggered for virtually all intersections – regardless of vehicle volume; and
- Third, the yellow flag is always triggered – regardless of vehicle volume or speed.

Table 6 illustrates how the application of the current thresholds results in red flags for the majority of vehicle speed and vehicle volume combinations.

Table 6: NCHRP Report 948 Yellow and Red Matrix for Flags 1, 4, and 10

Vehicle Volume \ Vehicle Speed	<=15 mph	>15 mph AND <=20 mph	>20 mph AND <=25 mph	>25 mph AND <=30 mph	>30 mph AND <=35 mph	>35 mph
<= 50 vph	YELLOW	YELLOW	RED	RED	RED	RED
51 - 100 vph	RED	RED	RED	RED	RED	RED
101 - 200 vph	RED	RED	RED	RED	RED	RED
201 – 300 vph	RED	RED	RED	RED	RED	RED
> 300 vph	RED	RED	RED	RED	RED	RED

To address these concerns, the team proposes to use a gap acceptance-based threshold to identify the threshold for yellow flags for vehicle volumes, and to revise the **OR** condition for red flags.

Specifically, a volume threshold of 300 vehicles per hour per lane (vphpln) is proposed as the new boundary. That volume corresponds to an average gap size of 12 seconds between vehicles. For a typical single-lane crossing of 14-foot lane width (12-foot lane plus 2-foot shoulder), the required time to cross is 4 seconds at the MUTCD-recommended walking speed of 3.5 ft/s. Adding a 2 second buffer time (as recommended in the Highway Capacity Manual) results in a critical gap time of 6 seconds. The 12-second average headway then, is twice the minimum required critical gap.

In addition, more nuance is proposed to distinguish different combinations of vehicle speed and volume. A low-speed (less than or equal to 20 mi/h) and low-volume (less than 300 vphhpln) combination is proposed to not result in a flag. A somewhat higher speed (greater than 20 and less than or equal to 30 mi/h) combined with a volume less than 300 vphpln would be given a yellow flag. Volumes in excess of 300 vphpln combined with a speed less than or equal to 20 mi/h would also result in a yellow flag. And speeds in excess of 30 mi/h, as well as speeds in the 20-30 mi/h range combined with a volume in excess of 300 vphpln would result in a red flag. The recommended revised thresholds for Flags 1, 4, and 10 are shown in Table 7.

Table 7: Proposed Revised Yellow and Red Flag Thresholds for Flags 1, 4, and 10

Measure of Effectiveness	Yellow Flag Threshold	Red Flag Threshold
Vehicle Speed & Vehicle Volume	> 20 mph **AND** <= 30 mph **AND** <= 300 vphpln **OR** > 300 vphpln	> 20 mph **AND** > 300 vphpln **OR** > 30 mph

mph = miles per hour; vphpln = vehicles per hour per lane

The resulting updated matrix for yellow and red flags for different combinations of vehicle speeds and vehicle volumes is shown in Table 6.

Table 8: Proposed Yellow and Red Matrix for Flags 1, 4, and 10

Vehicle Volume \ Vehicle Speed	<=15 mph	>15 mph AND <=20 mph	>20 mph AND <=25 mph	>25 mph AND <=30 mph	>30 mph AND <=35 mph	>35 mph
<= 50 vphpln	NO FLAG	NO FLAG	YELLOW	YELLOW	RED	RED
51 - 100 vphpln	NO FLAG	NO FLAG	YELLOW	YELLOW	RED	RED
101 - 200 vphpln	NO FLAG	NO FLAG	YELLOW	YELLOW	RED	RED
201 – 300 vphpln	NO FLAG	NO FLAG	YELLOW	YELLOW	RED	RED
> 300 vphpln	YELLOW	YELLOW	RED	RED	RED	RED

The team tested this revised concept with training participants in the later classes, and generally received positive feedback. This more nuanced threshold approach, along with calibration

between flags and crash risk and severity, presents a logical next step for developing and applying the assessment method.

The team further proposes additional guidance on how the speeds in aforementioned table should be determined. In the application of the method, the team has generally referred to the speed-radius relationship documented in the AASHTO Green Book as a good approximation for determining the free-flow speed for the appropriate right-turn or left-turn movements. That method has further been adapted in the Roundabout Informational Guide, where the 'fastest path method' is used to estimate that speed of vehicles entering or exiting the roundabout using the same AASHTO Green Book relationship. The team has found the use of the measured fastest path radius for right-turns and left-turns as a reasonable approximation of speeds for the purpose of applying the design flags.

Flag Applicability to Innovative Designs

In some cases, workshop participants (and even research team members) arrived at different answers for a given intersection assessment. This can be expected in some cases where an intersection is not representative of the types of intersections used to develop the assessment: some "gray area" is inevitable.

One example of an intersection with gray areas is a roundabout. For a roundabout, the following points of clarification are helpful:

- In the opinion of the research team, Flag 1 (Motor Vehicle Right Turns) and Flag 4 (Crossing Yield- or Uncontrolled Vehicle Paths) are redundant in a roundabout context. Either may be applied, and the appropriate application can depend on the design. If an exit pedestrian crossing is sufficiently far from the circulatory roadway, then the vehicle-pedestrian conflict does not represent the spirit of Flag 1 and aligns instead with Flag 4. Similarly with entry crossings: if the crossing and the circulatory entry are spaced at least a car length apart, then the design provides the conflict described with Flag 4 rather than with Flag 1. Regardless, the team recommends that either Flag 1 OR Flag 4 be used at roundabouts, with preference for just using Flag 4.
- Flag 10 (Motor Vehicle Left Turns) does not apply at a roundabout. A driver is never judging gaps in oncoming traffic to complete a left turn with a concurrent pedestrian crossing. Drivers in the circulatory roadway have the right-of-way over conflicting entering drivers. Of course, drivers do make left turns at roundabouts, but in the context of the multimodal safety assessment, these movements are covered by design flag 4 as described above.

This guidance for modern roundabouts (to focus on flag 4 and generally forgo flags 1 and 10) is consistent with the recommendation in the NCHRP Guide for Roundabouts that was published in 2023 and uses the 20-flag method to evaluate pedestrian and bicyclist safety at roundabouts.

In addition to roundabouts, the application of flags for certain alternative intersection and interchange forms should be clarified. In particular, the Restricted Crossing U-Turn (RCUT) and Median U-Turn (MUT), each have several redirected movements. Specifically, both RCUT and MUT redirect one or more left-turning movements to become right turns, followed by a U-turn

movement, and potentially another right turn. In the application of the 20-flag method, the redirected left-turning movements may trigger Flag 1, 4, or 10, but only one flag should be counted at each conflict point.

For example, a minor street through movement at an RCUT may trigger Flag 1 when entering the main line, may trigger Flag 4 at the U-Turn location (if unsignalized), and may trigger Flag 1 again at the right-turn from main-line to side street on the opposite side of the street. In this case, the overall movement may be flagged for Flag 1 and/or Flag 4 at each of the three conflict points, but shouldn't also be counted for Flag 10.

Further research could clarify examples where intersection forms or other subtle distinctions affect the interpretation of the 20 flags.

Flag Application Sequence

In teaching the 20-flag method in the training courses, participants appreciated having a clear sequence of steps for applying the method. The training slides articulated the following steps for applying the 20-flag method:

- Step 0: Obtain design drawing and/or aerial of intersection and each alternative to evaluate
- Step 1: Assign pedestrian paths and bicyclist movements; Document assumptions
- Step 2: Evaluate flags for existing conditions
- Step 3: Evaluate flags for alternative configuration(s)
- Step 4: Compare results
- Step 5: Update design
- Step 6: Re-evaluate flags

Having this sequence generally helped participants understand the process. In particular, *Step 1: Assign pedestrian paths and bicyclist movements*, provide to be very important to properly document the assumptions for what paths people use to walk or ride through the intersection.

For each of the flags, the team then explained the application of the method through three basic questions:

1. **WHERE** in the intersection or interchange would the flag potentially apply?
2. **WHAT** are the characteristics of that particular conflict point and do they trigger a yellow or red flag?
3. **WHICH** movements pass through that conflict point and are therefore assigned the yellow or red flag?

Using these three questions provides a systematic way to assess intersection designs. For example, if an intersection has a channelized right-turn lane with a yield-controlled exit point for vehicles merging into downstream traffic without an acceleration lane. That merge point represents a potential conflict for Flag 4: Cyclists Crossing Yield-Controlled or Uncontrolled vehicle path (Question 1). That conflict point is then evaluated using vehicle speed and volumes and may be

determined to be a red flag (Question 2). The analyst then determines which cycling movements pass through that conflict point, which include both the perpendicular through movement and the opposing left-turn movement (Question 3). All movements passing through the flagged conflict point are assigned the red flag.

SUMMARY

Overall, this implementation effort was highly successful with over 1,000 people participating the national webinars, close to 500 people attending the conference sessions, and 188 people being trained in the in-person workshops. The training materials developed through this effort will continue to be available to those interested in the methodology, with different formats catering to different learning styles. The example problems developed through this implementation effort serve as hands-on exercises in the use of the method, and the supplemental handouts and spreadsheets streamline the application of the method.

APPENDIX A – SAMPLE TRAINING FLYER

---------- Example Flyer for NCDOT Training ----------

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

KITTELSON & ASSOCIATES

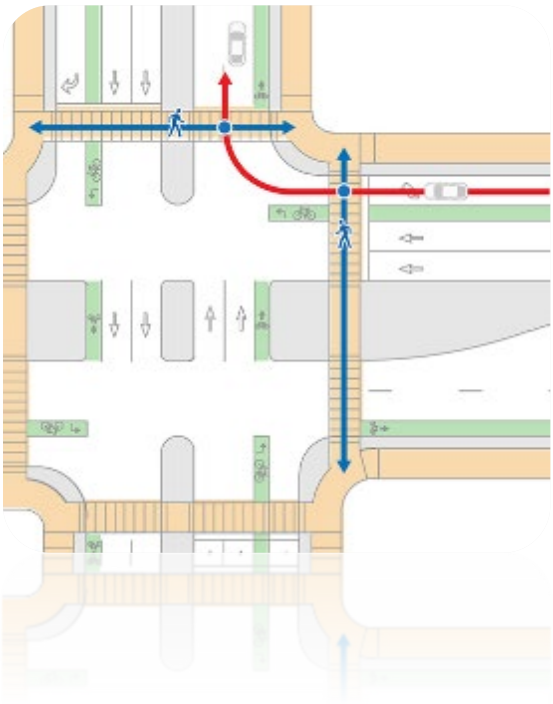
NCHRP Report 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

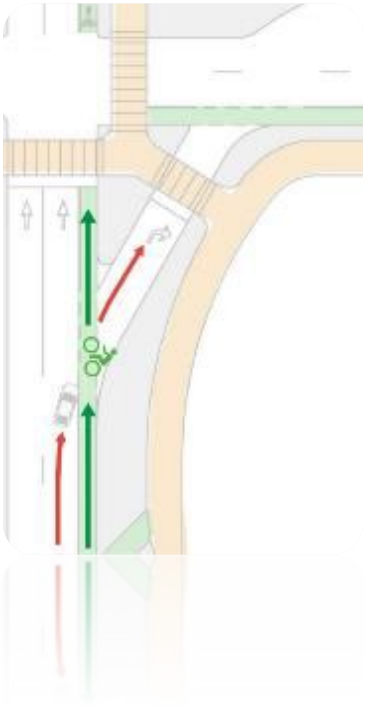
May 11, 2023

NCDOT Greenfield Parkway Location, Garner, NC

Free[1]

8 PDH Hours





[1] Travel and lunch will be the responsibility of the participants.

Description: What is the biggest challenge pedestrians and cyclists face on the road? For some it is navigating turning vehicles. For others it is waiting for excessively long red-light times or determining unmarked or unclear paths through intersections, or inadequate sight distance. In designing intersections and infrastructures the most vulnerable road users need to be considered. This training will explore 20 performance measures, or design flags, that can help identify potential safety, accessibility, operational, or comfort issues for pedestrians and bicyclists. These design flags represent issues that can be addressed in the development and evaluation intersections and interchanges.

This training is based on NCHRP Report 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges, and has two components:

1. A two-hour web-based module participants are asked to complete on their own first;
2. A one-day in-person and instructor-led training that will be hosted by the DOT.

Each participant will receive 8 Professional Development Hours (PDHs) for completing the combination of web-based and in-person training.

Course Instructors:

Bastian Schroeder, Kittelson & Associates, Inc. Bastian is a Senior Principal Engineer for Kittelson based in Wilmington, NC and serves as the firm's Director of Research and Innovation. Bastian has a passion for developing solutions to complex problems across all areas of transportation with a focus on advancing agency processes and integrating research into standard practices. He served as Principal Investigator for NCHRP Project 07-25, which produced Report 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges.

Liz Byrom, Engineer, Kittelson & Associates, Inc. Liz Byrom is an engineer with Kittelson & Associates in Raleigh, North Carolina. At Kittelson, Liz has completed corridor studies, safety studies, conceptional design and alternative development, final design, and traffic operational analyses.

Express interest[2] at

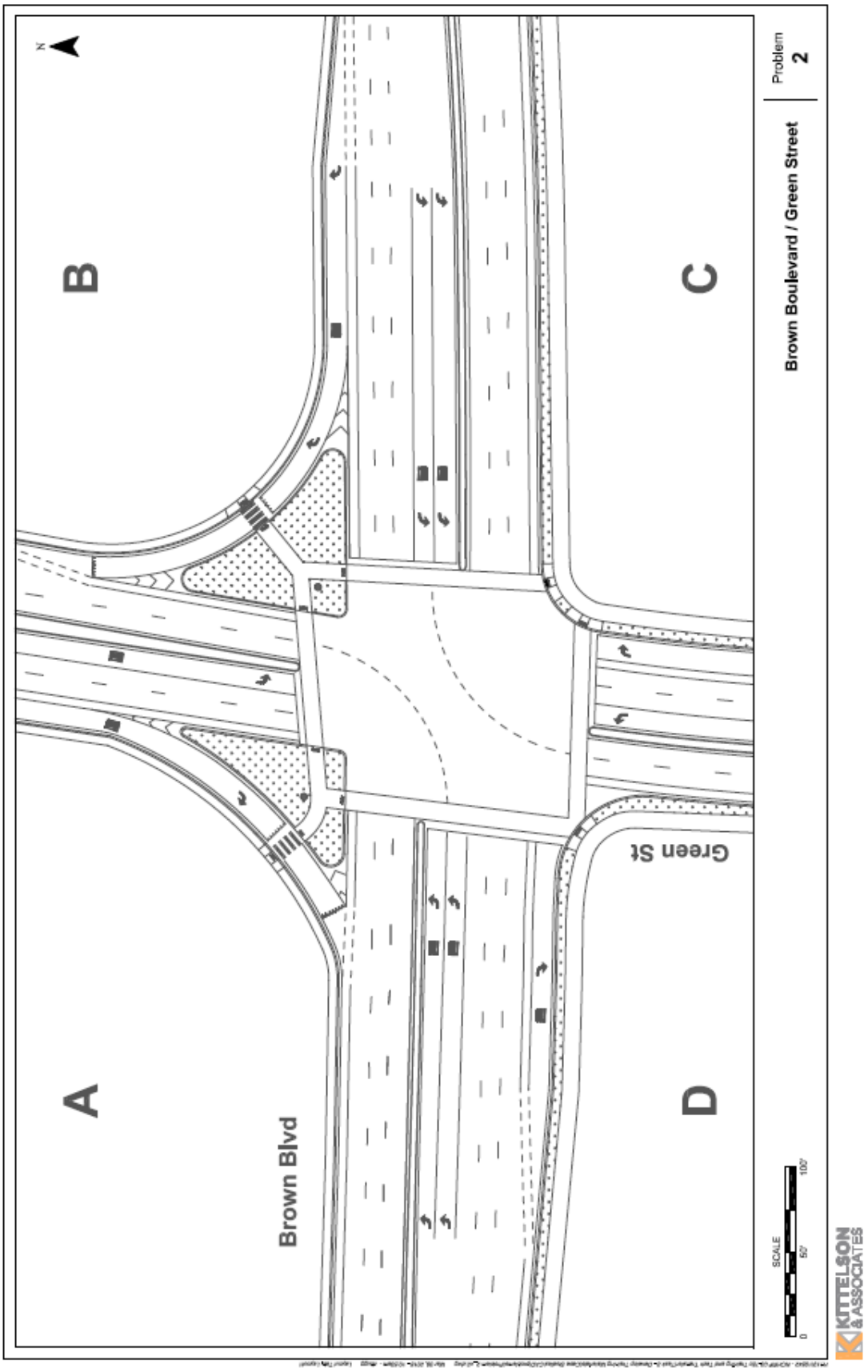
https://events.kittelson.com/NCHRPReport948.

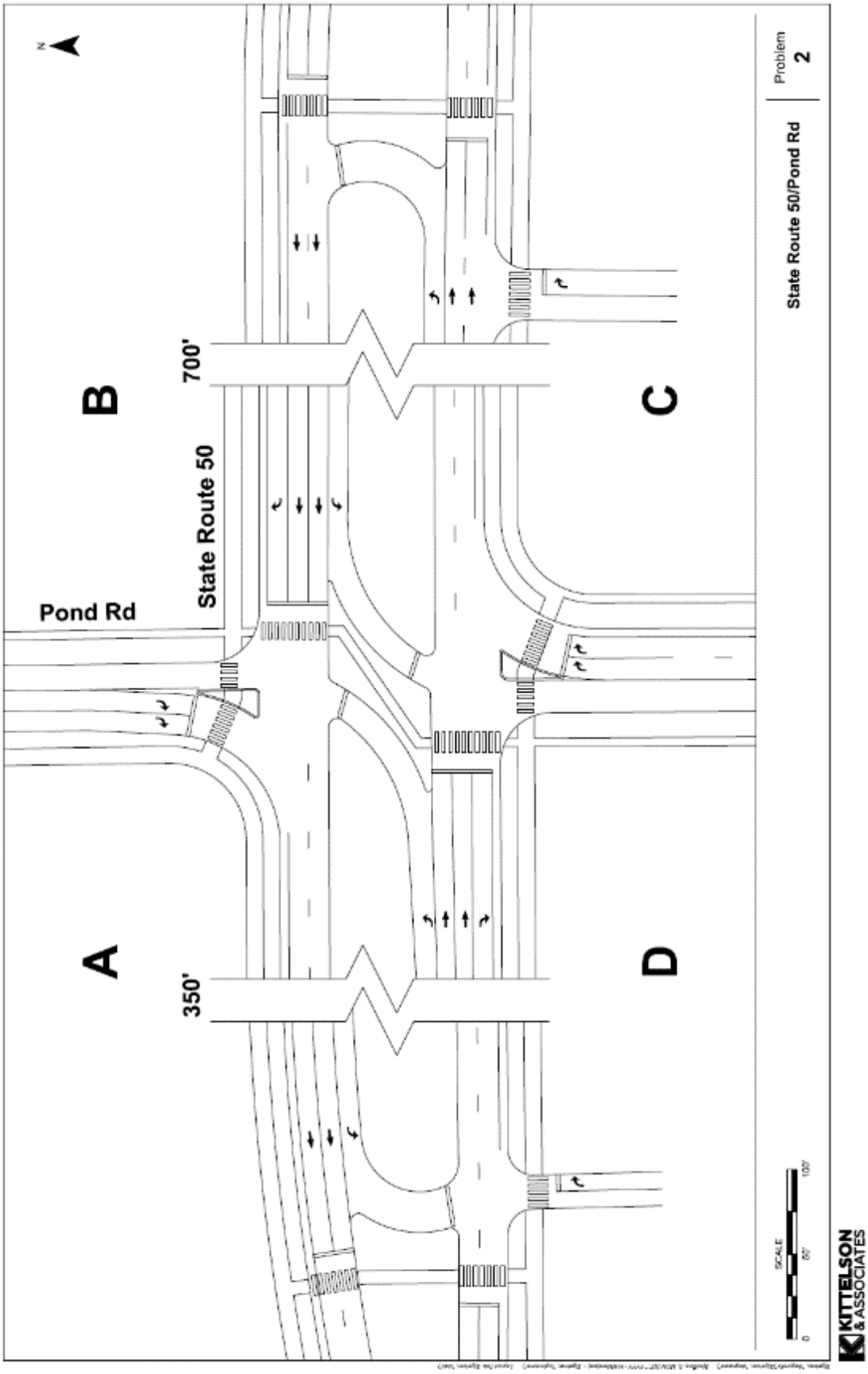
For any questions, please email Liz Byrom at lbyrom@kittelson.com

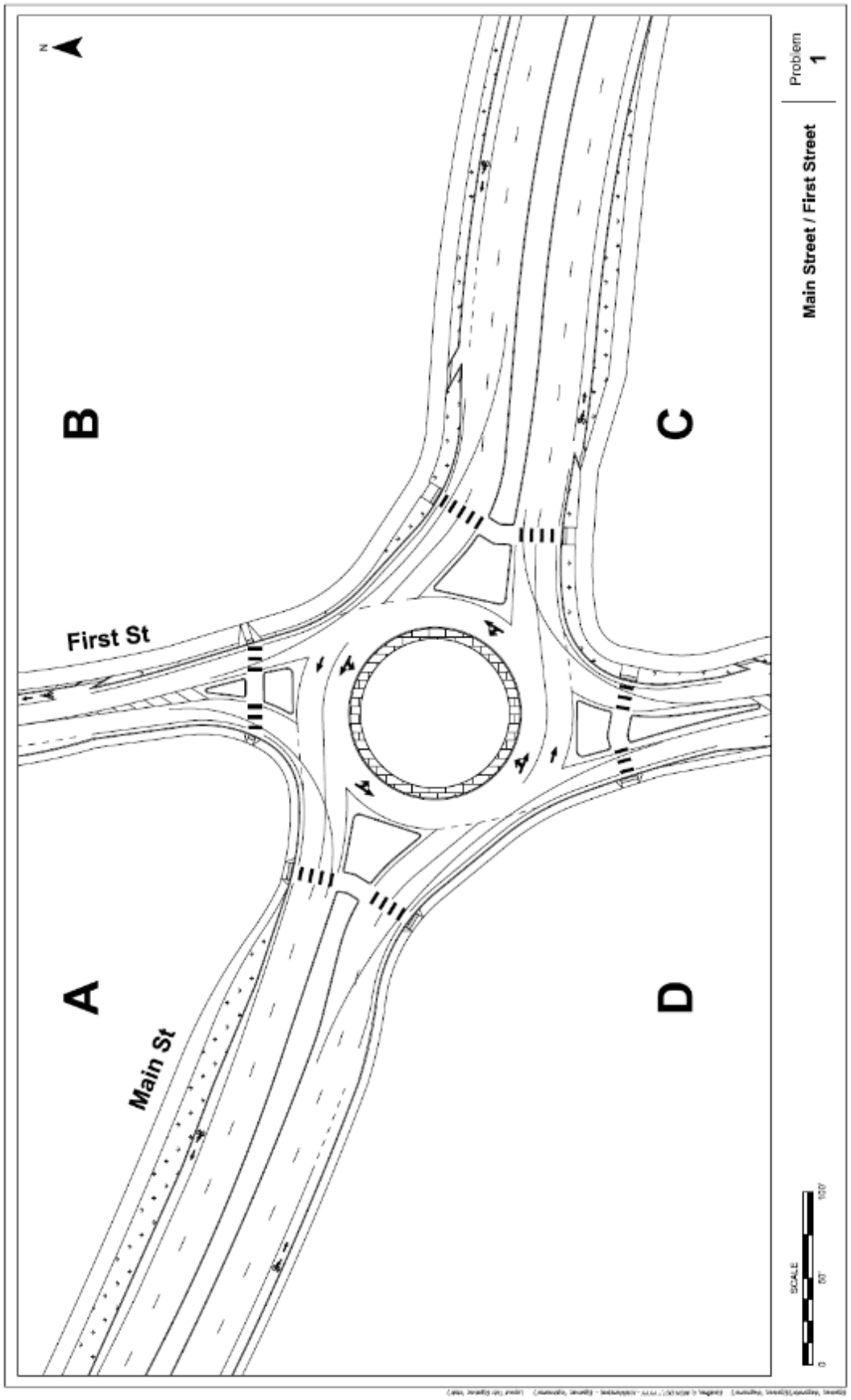
[2] Registrations will be processed in the order they are received, while assuring diverse participation from multiple DOT units and other agencies.

APPENDIX B – CASE STUDIES DEVELOPED FOR WORKSHOPS

The team developed three example problems to serve as hands-on exercises during the training. This appendix contains full-page versions of these examples. In addition, the team identified several real-world intersections that formed the basis of the group exercises during the training. The case studies represent a cross-section of different intersection types and land use contexts. For each training, the team selected locations that were most representative of what the local agencies may be likely to encounter in their day-to-day work.

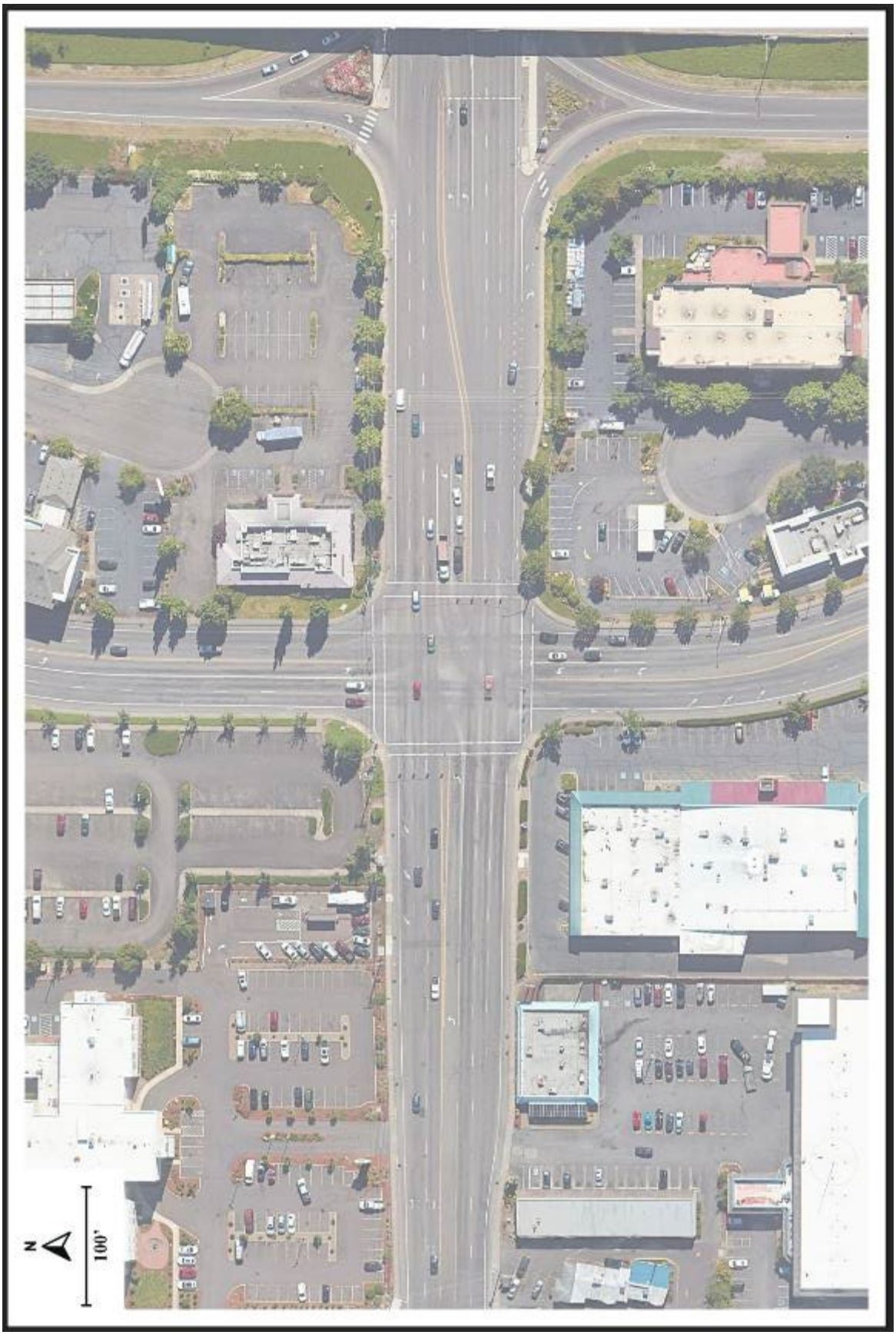

Problem
2
Brown Boulevard / Green Street
A
B
C
D
Brown Blvd
Green St
SCALE
0
50'
100'
KITTELSON
& ASSOCIATES


Problem
2
State Route 50/Pond Rd
Pond Rd
State Route 50
700'
350'
A
B
C
D
SCALE
0
KITTELSON
& ASSOCIATES


Problem
1
Main Street / First Street
First St
Main St
A
B
C
D
SCALE
0
50'
100'
KITTELSON
& ASSOCIATES


Wake Forest, NC
35°56'38.0"N
78°33'27.5"W
N
100'

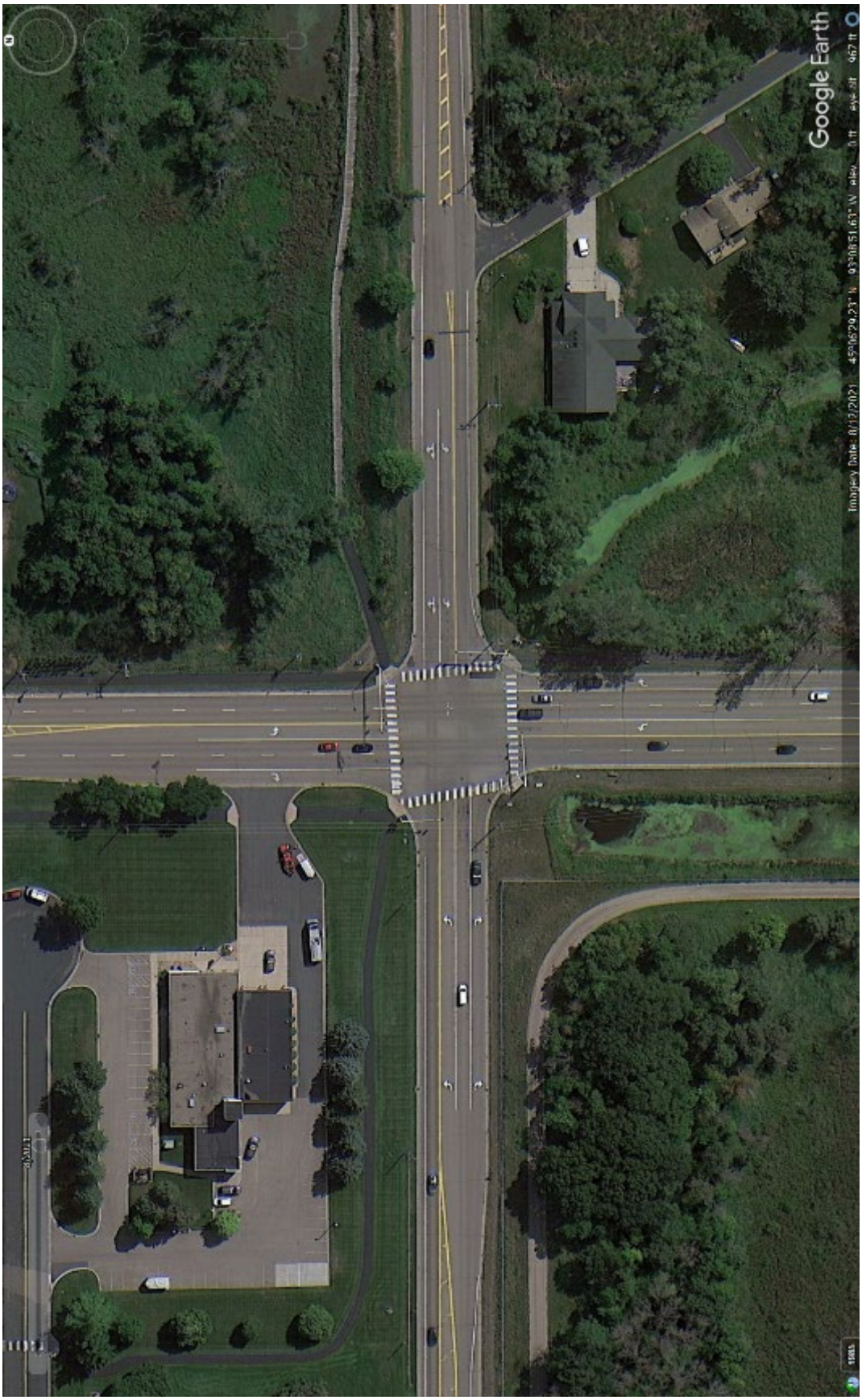

Holly Springs, NC
35°39'27.30"N
78°50'54.58"W
N
100'

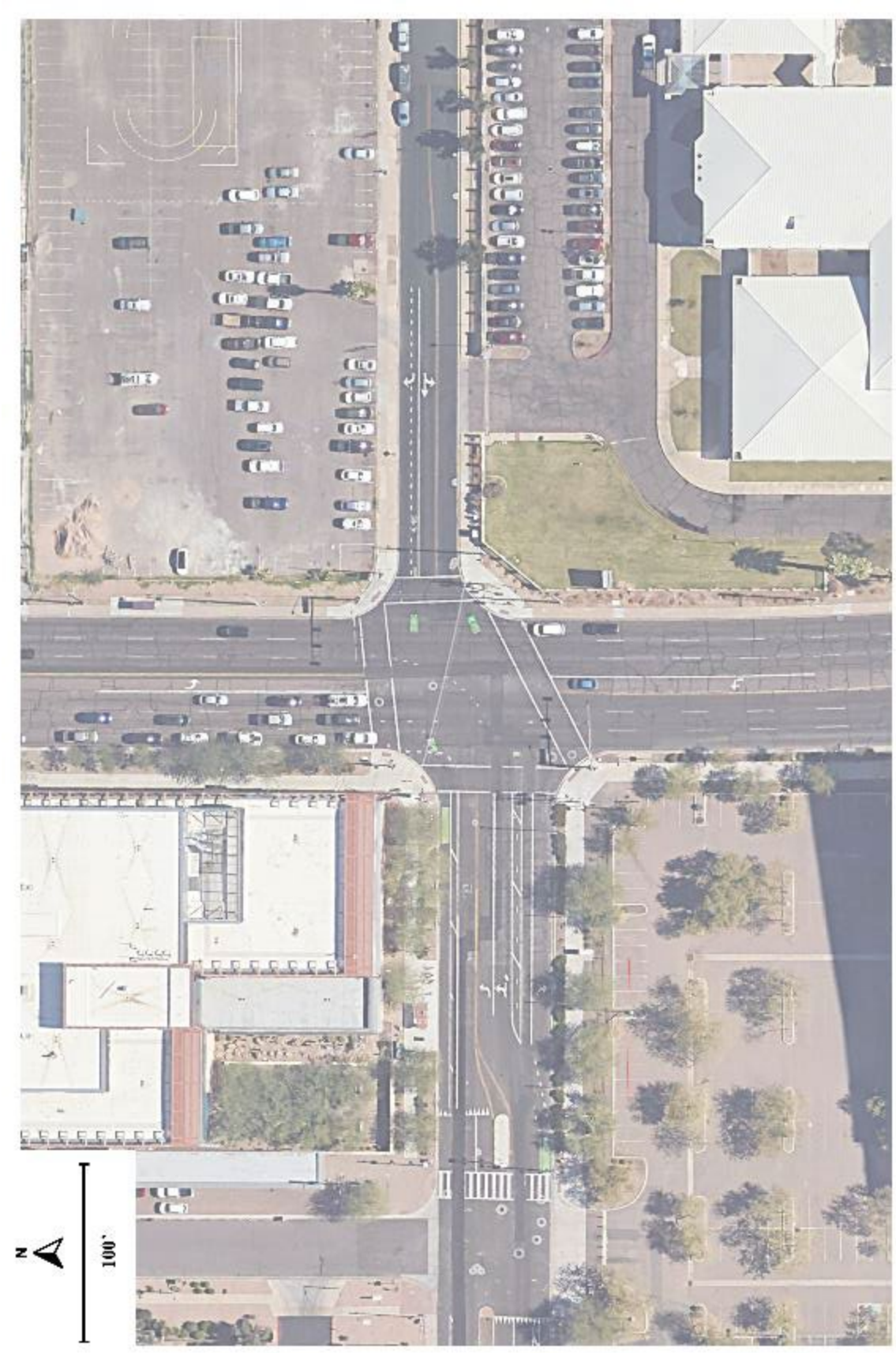

N
100'


N
100'


Google Earth


Google Earth


Google Earth


N
100'


N
100'

APPENDIX C – SELECT PRESENTATION SLIDES

This appendix contains the slides for the two webinars delivered through this contract. The conference presentation are not explicitly shown, as they were a combination of these webinars and the classroom trainings.

Safer Intersections for Pedestrians and Bicyclists

NCHRP Report 948 - Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

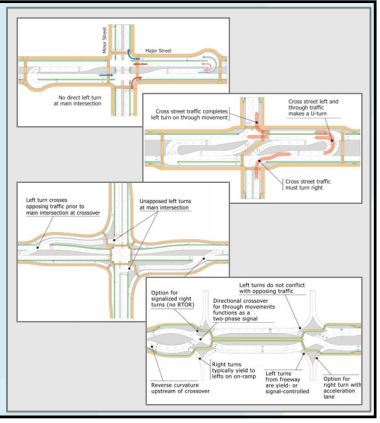
NCHRP 20-44(35) Implementation

October 25, 2022

1

Project Objectives

The objective of this research was to develop a guide for transportation practitioners to improve and integrate pedestrian and bicyclist safety at (Alternative) Intersection and Interchanges through planning, design, and operational treatments.



2

Guiding Principles

1. **Integrate** Multimodal Facilities in the Design Process, as opposed to '*accommodating*' pedestrians and bicyclists at later stages
2. Allow **comparison** of alternative intersections and interchanges (A.I.I.) with 'conventional' designs
3. Focus on **design elements** of the intersection, rather than intersection form
4. Follow a **performance-based** design process

3

3

Design Flag Assessment Method

20 Questions for Pedestrian & Bicyclist Safety

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

4

4

Yellow Flags vs. Red Flags

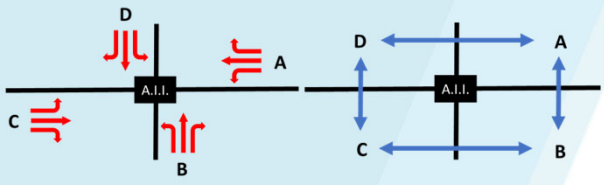
Yellow Flags, for design elements negatively affecting user comfort (in other words, increasing user stress) or the quality of the walking or cycling experience

Red Flags, for design elements that are directly related to a safety concern for pedestrians or bicyclists.

5

5

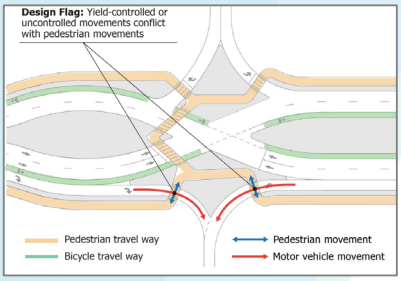
Applying Design Flag Checks



6

6

Design Flag 4: Crossing Yield- or Uncontrolled Vehicle Paths



7

7

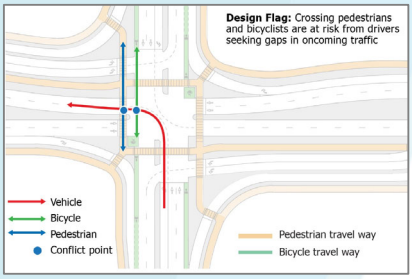
Design Flag 4 at Conventional Intersection

Yield controlled channelized turn lanes.

8

8

Design Flag 10: Motor Vehicle Left Turns



9

9

Design Flag 10 at Conventional Intersections

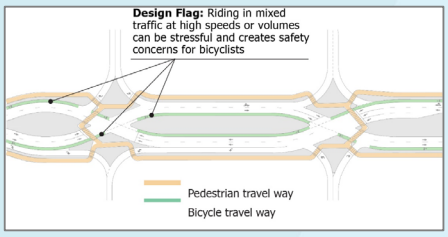
Conflict between left-turning vehicle and pedestrians.

Permissive left turns across unmarked pedestrian crossings.

10

10

Design Flag 14: Riding in Mixed Traffic



11

11

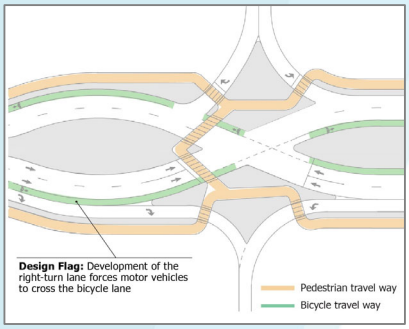
Design Flag 14 at Conventional Intersection

On-street bicycle lanes adjacent to heavy volume roadway.

12

12

Design Flag 18: Turning Motorists Crossing Bicycle Path



13

13

Design Flag 18 at Conventional Intersections

Right-turning vehicles crossing bicycle lane with exclusive right turn lane.

Right-turning vehicles crossing bicycle lane with shared through-right lane.

14

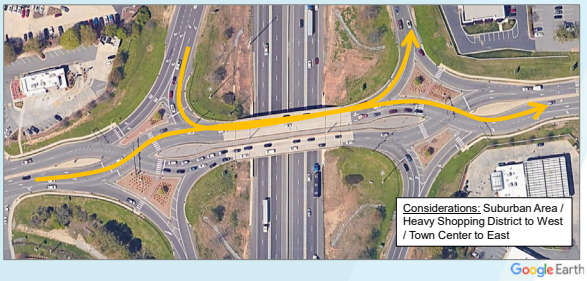
14

Example Applications

- Diverging Diamond Intersections (DDI)
- Restricted Crossing U-Turn (RCUT)

15

Diverging Diamond Interchange Design 1



16

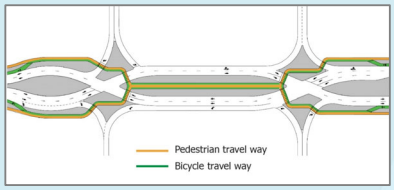
16

DDI Design 1

17

17

Inner Walkway Concept

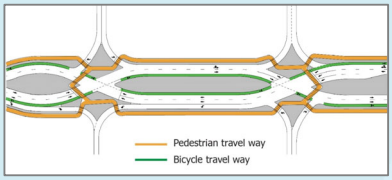


Design Flag
Motor Vehicle Right Turns (Section 4.4.1)
Uncomfortable/Tight Walking Environment (Section 4.4.2)
Crossing Yield Controlled or Uncontrolled Vehicle Movements (Section 4.4.4)
Indirect Path (Section 4.4.5)
Executing Unusual Movements (Section 4.4.6)
Multi-Lane Crossings (Section 4.4.7)
Sight Distance for Gap Acceptance Movements (Section 4.4.12)
Grade Change (Section 4.4.13)

18

18

Outer Walkway Concept



Design Flag
Motor Vehicle Right Turns (Section 4.4.1)
Nonintuitive Motor Vehicle Movements (Section 4.4.3)
Crossing Yield Controlled or Uncontrolled Vehicle Movements (Section 4.4.4)
Executing Unusual Movements (Section 4.4.6)
Multi-Lane Crossings (Section 4.4.7)
Sight Distance for Gap Acceptance Movements (Section 4.4.12)
Grade Change (Section 4.4.13)
Motor Vehicle Right Turns (Section 4.4.1)

19

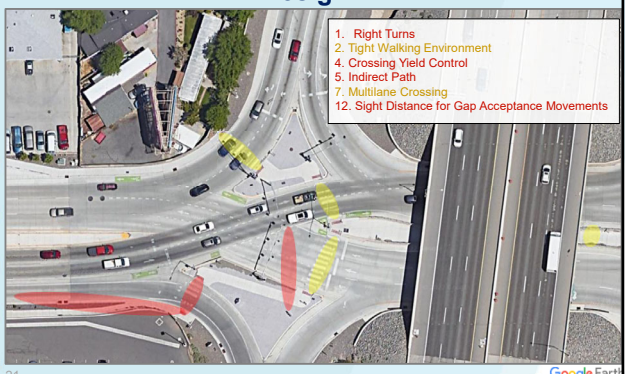
19

Diverging Diamond Interchange Design 2

20

20

DDI Design 2

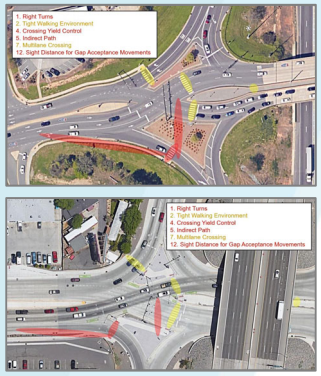


21

21

DDI Comparison

Design Option	Categories with Yellow Flags	Categories with Red Flags
First	2	4
Second	2	2



22

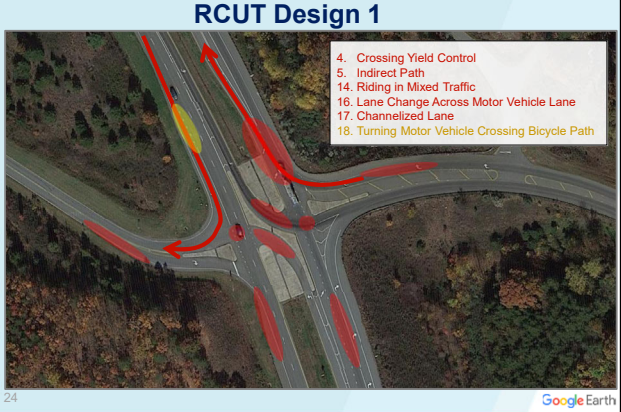
22

Restricted Crossing U-Turn Design 1

23

23

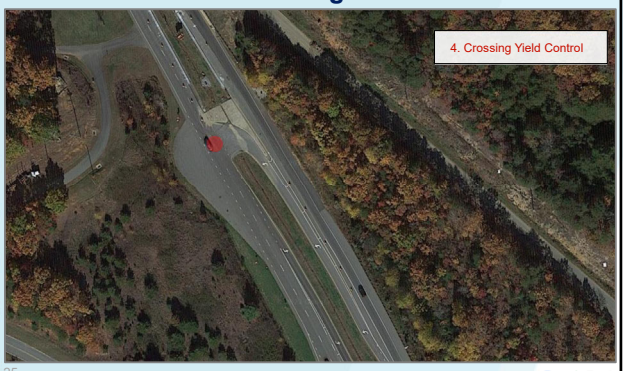
RCUT Design 1



24

24

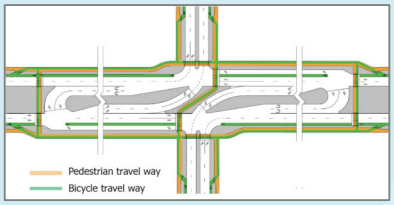
RCUT Design 1



25 Google Earth

25

Bike Lane & SUP

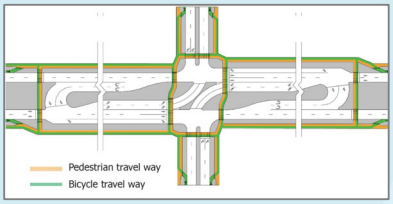


Flags Remaining
Motor Vehicle Right Turns (Section 4.4.1)
Uncomfortable/Tight Walking Environment (Section 4.4.2)
Indirect Path (Section 4.4.5)
Multilane Crossings (Section 4.4.7)
Long Red Times (Section 4.4.8)

26

26

SUP w/ H Crossing



Flags Remaining
Motor Vehicle Right Turns (Section 4.4.1)
Multilane crossings (Section 4.4.7)
Long Red Times (Section 4.4.8)

27

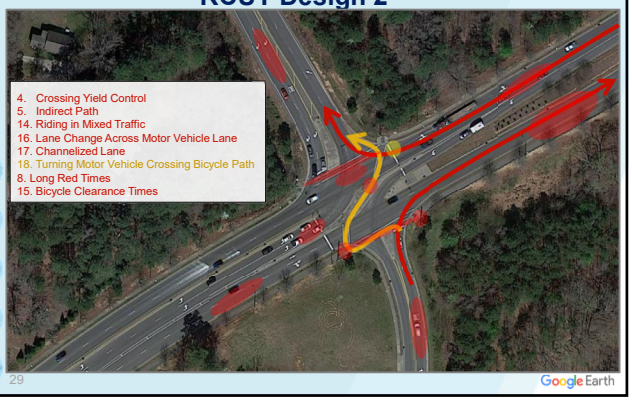
27

Restricted Crossing U-Turn Design 2

28 Google Earth

28

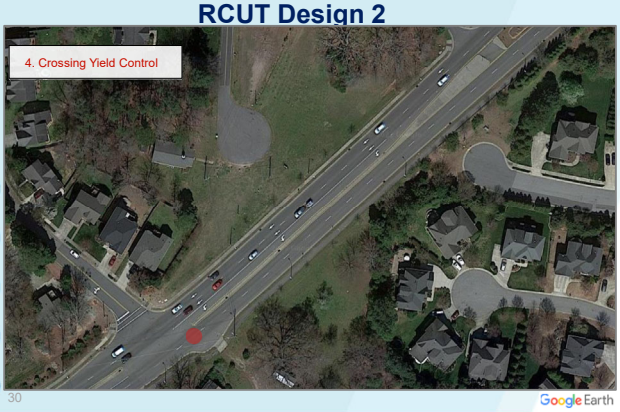
RCUT Design 2



29 Google Earth

29

RCUT Design 2

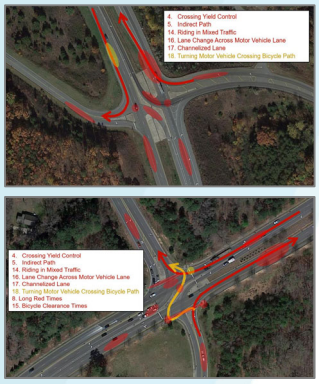


30 Google Earth

30

RCUT Comparison

Design Option	Categories with Yellow Flags	Categories with Red Flags
First	1	5
Second	1	3



31

31

Design Flag Assessment Method

20 Questions for Pedestrian & Bicyclist Safety

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

32

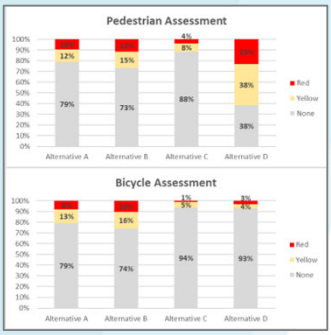
32

Design Flag Worksheets

33

33

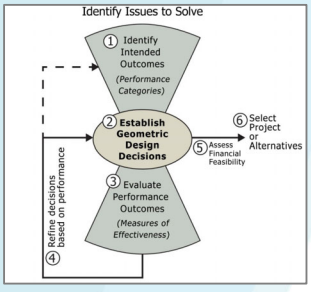
Comparing Alternatives



34

34

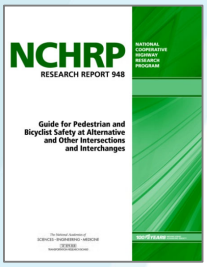
Performance-Based, Context-Sensitive Design



35

35

Questions & Discussion



36

Safety by the Numbers:

Measuring the Pedestrian and Bicyclist Experience at Intersections from Alternatives Analysis Through Final Design

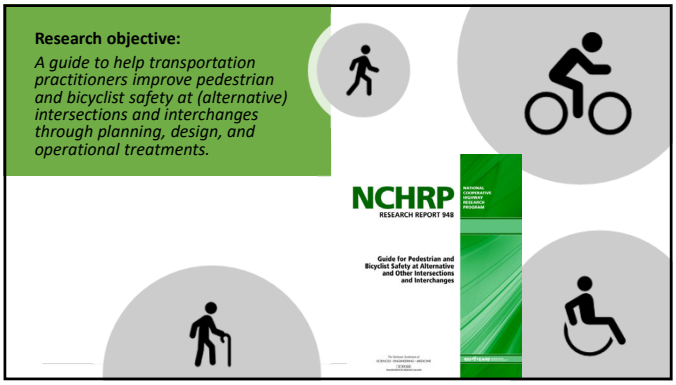
Shannon Warchol & Mike Alston
Kittelson and Associates

June 22, 2023

1

Research objective:

A guide to help transportation practitioners improve pedestrian and bicyclist safety at (alternative) intersections and interchanges through planning, design, and operational treatments.



2

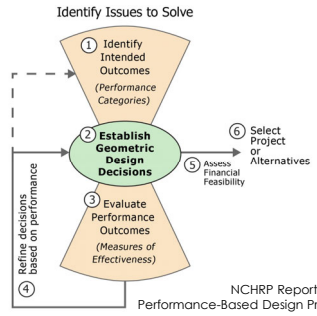
Guiding Principles

1. **Integrate** multimodal facilities into the design instead of '*accommodating*' pedestrians and bicyclists later
2. Allow **comparison** of alternative intersections and interchanges (A.I.I.) with 'conventional' designs
3. Focus on the intersection's **design elements** rather than its form
4. Follow a **performance-based** design process

3

Performance-Based Design Process

- Identify intended outcomes
- Establish geometric design decisions
- **Evaluate performance outcomes**
- Refine decisions based on performance
- Assess financial feasibility
- Select project or alternatives



NCHRP Report 785 – Performance-Based Design Process

4

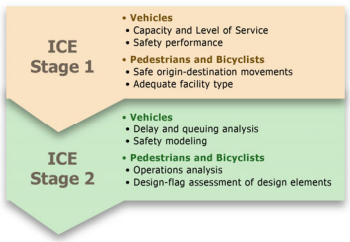
How familiar are you with **Intersection Control Evaluation**?

- Never heard of it
- Heard of it but never use it
- Use it occasionally
- Use it frequently

5

Integration with ICE

Intersection Control Evaluation



6

Slide 3

A0 Katie - all green slides should be reworked to match the black/grey scheme of the majority of the slides. Title slide can have color flourishes as desired
Author, 2023-05-17T16:07:24.556

KT1 I advise against turning this into an acronym!
Katie Taylor, 2023-06-15T17:50:02.080

Slide 4

KT0 Olga - "Performance-Based Design Process" can become a header and the rest of the text and the sidebar can go (it just repeats your visual).
Katie Taylor, 2023-06-15T17:58:11.040

Slide 6

A0 Poll for ITE
Author, 2023-05-17T16:39:05.403

Design Flag Assessment Method

20 Questions for Pedestrian and Bicyclist Safety

Motor vehicle right turns	Uncomfortable/ tight walking environment	Nonintuitive motor vehicle movements	Crossing yield or uncontrolled vehicle paths
Indirect paths	Executing unusual movements	Multilane crossings	Long red times
Undefined crossing at intersections	Motor vehicle left turns	Intersecting driveways and side streets	Sight distance for gap acceptance movements
Grade change	Riding in mixed traffic	Bicycle clearance times	Lane change across motor vehicle lane(s)
Channelized lanes	Turning motorists crossing bicycle paths	Riding between travel lanes, lane additions, or lane merges	Off-tracking trucks in multilane curves

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7

Yellow vs. Red Flags for Design Elements

Yellow Flags: Negatively affect user comfort or experience.

Red Flags: Safety concern for pedestrians or bicyclists.

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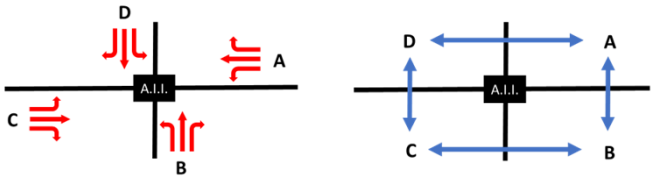
8

Applying Design Flag Checks



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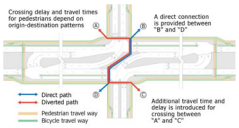
9

Applying the Methodology: Red vs. Yellow Flags

Example:
Design Flag 5 – Indirect Paths



Yellow Flags: Negatively affect user comfort or experience

Threshold:
- 90-134 feet out-of-direction travel (pedestrians)
- 450-674 feet out-of-direction travel (bicyclists)

Red Flags: Safety concern for pedestrians or bicyclists.

Threshold:
- ≥135 feet out-of-direction travel (pedestrians)
- ≥675 feet out-of-direction travel (bicyclists)

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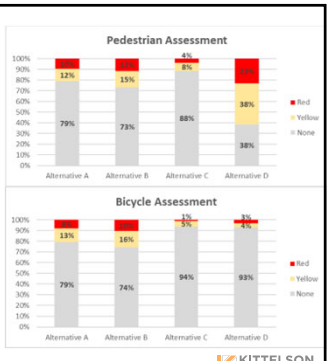
10

Flag Worksheet

KITTELSON & ASSOCIATES

11

Comp



KITTELSON & ASSOCIATES

12

Slide 7

KT0 This is a lot to take in on a single slide. Since I'm not sure what is most important, I can't make any suggestions, so just flagging it with this note.
Katie Taylor, 2023-06-15T18:08:48.990

Slide 10

KT0 Shannon and Mike--it is unclear how this figure relates to the flags. Can the figure be enlarged to fill the slide and the yellow flags/red flags be applied to it as markers where these phenomena are happening?
Katie Taylor, 2023-06-15T18:22:24.446

Slide 11

KT0 It is really hard to look at both of these on a slide. Is it necessary for the audience to see the entirety of both sheets? If so, consider doing them one to a slide.
Katie Taylor, 2023-06-15T18:25:52.426

Design Keys to Success

1. **Integrate** multimodal facilities early in the design process
2. Identify **project priorities** and understand that tradeoffs will be necessary
3. **Assess the design at each stage** to minimize flag count.

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13

After the Analysis – Mitigation Strategies

Iterate the concept
Select an alternative
Treatments and Techniques
- Segments
- Intersections
- Crossings
- Flag-Specific

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14

Intersection Treatments

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15

The 20 Design Flags

Applicability to Alternative and Conventional Intersections

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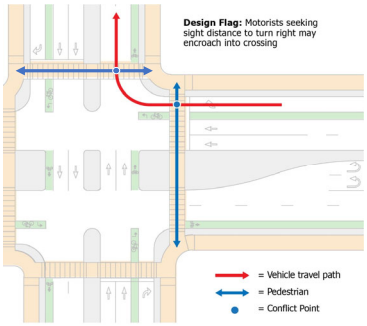
16

Design Flag 1:

Motor Vehicle Right Turns



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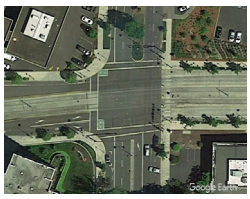
17

Design Flag 1 at Conventional Intersections



Vehicles permitted to turn right across marked crosswalks

Intersection with channelized turn lanes

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Slide 14

SW0 Mike - Please edit as desired
Shannon Warchol, 2023-05-22T14:50:06.987

MA0 0 Ok, added some options and some speaker notes
Mike Alston, 2023-06-07T21:10:41.535

SW1 Katie - Please update design to match rest of PPT
Shannon Warchol, 2023-05-22T14:50:21.851

Slide 15

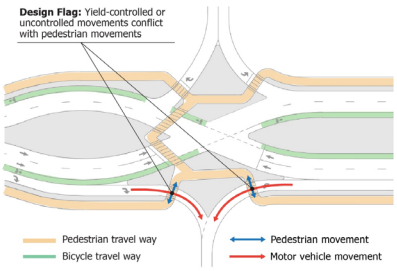
SW0 Mike - please edit as necessary
Shannon Warchol, 2023-05-22T14:51:16.428

MA0 0 Seems good to me
Mike Alston, 2023-06-07T21:13:31.092

SW1 Katie - please update to match other slides
Shannon Warchol, 2023-05-22T14:51:31.515

D

Crossing Yield- or Uncontrolled Vehicle Paths



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Design Flag 4 a

Yield controlled channelized turn lanes

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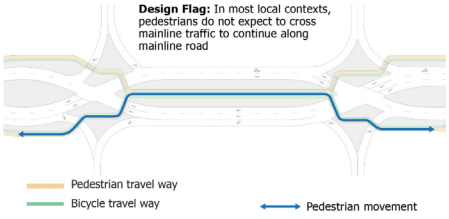
20

Design Flag 6: Executing Unusual Movements



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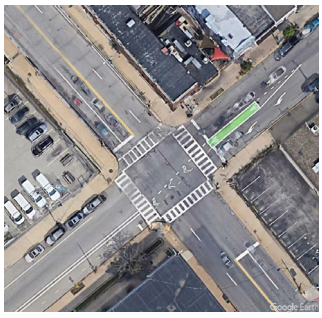
Design Flag 6



Bike lane developing between motor vehicle travel lanes

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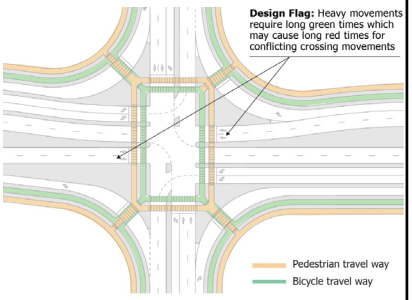
22

Long Red Times



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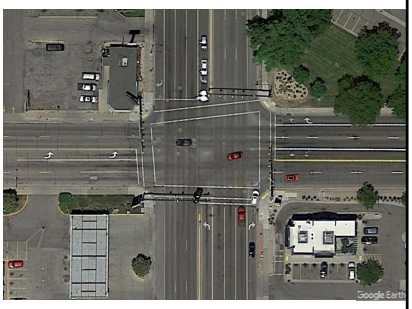
Design Flag 8



Relatively large intersections with possible long red times

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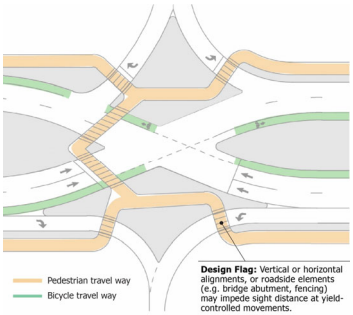
Design Flag 12:

Sight Distance for Gap Acceptance Movements



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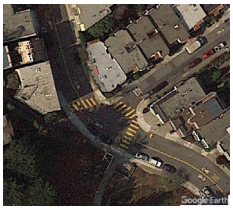
Design Flag 12 at Conventional Intersections



Profile and plan views of intersections with significant vertical and horizontal curves, limiting sight distance

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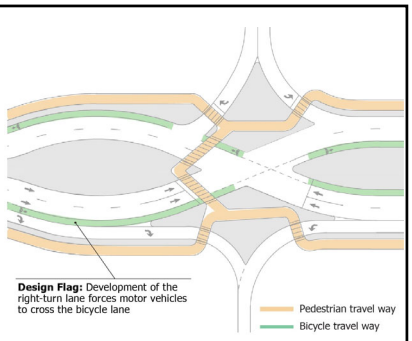
26

Design Flag 18:

Turning Motorists Crossing Bicycle Path



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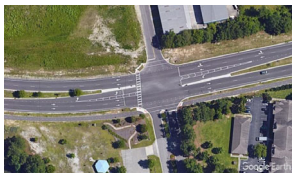
27

Design Flag 18 at Conventional Intersections

Right-turning vehicles crossing bicycle lane with exclusive right turn lane



Right-turning vehicles crossing bicycle lane with shared through-right lane

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Case Study Application

The 20-Flag Method in Use

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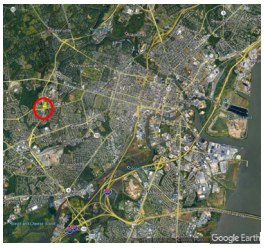
Case Study Application:

Faulkland Rd (34) at Centre Rd. (141), Wilmington, DE



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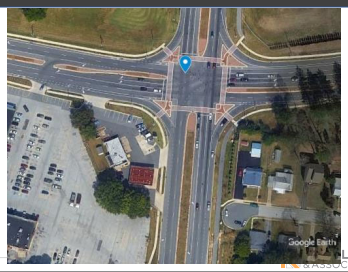
30

Results: Existing Conditions

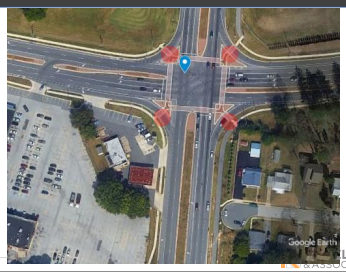
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



31

Results: Existing Conditions

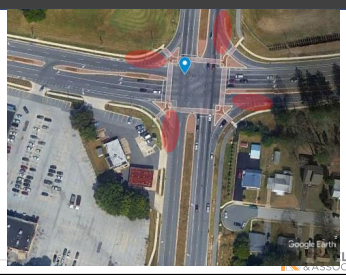
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



32

Results: Existing Conditions

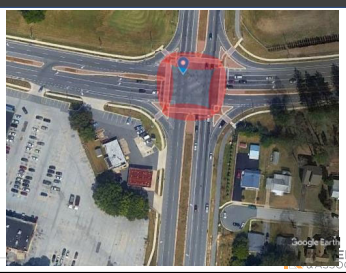
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



33

Results: Existing Conditions

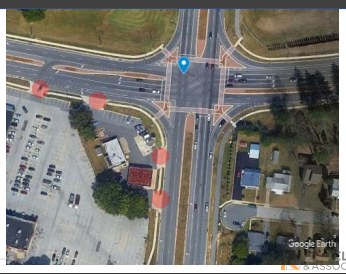
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



34

Results: Existing Conditions

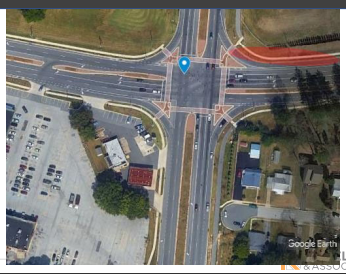
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



35

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



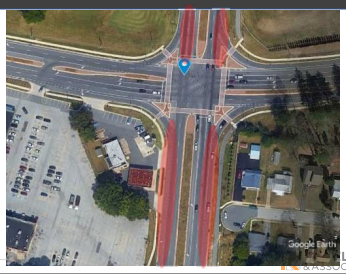
36

Slide 31

SW0 Note for Katie: Slides 30-51 have heavy animation, so please avoid resizing the graphics as it would require re-placing all of the animated objects. If you reposition the graphic, please ensure you've selected all of the objects overlaid on the graphic.
Shannon Warchol, 2023-06-08T12:39:48.899

Results: Existing Conditions

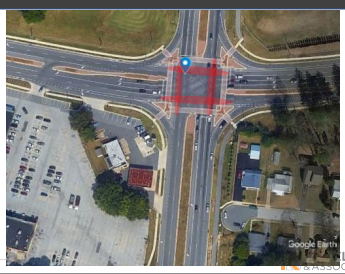
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



37

Results: Existing Conditions

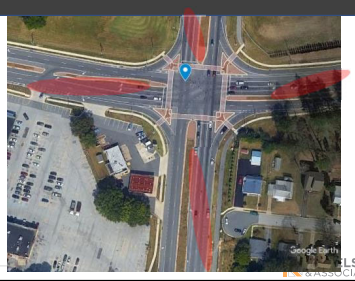
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



38

Results: Existing Conditions

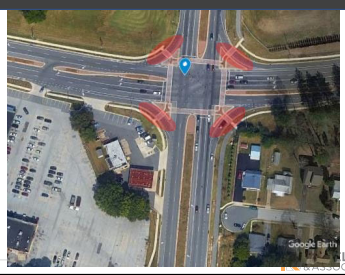
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



39

Results: Existing Conditions

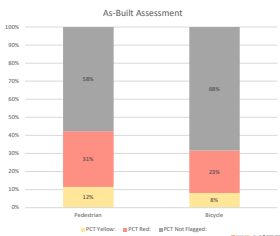
- Motor vehicle right turns
- Tight walking environment
- Crossing yield control path
- Multilane crossing
- Long red times
- Intersecting driveways
- Sight distance
- Riding in mixed traffic
- Bicycle clearance times
- Lane change across vehicle lanes
- Channelized lanes
- Motorist crossing bike path
- Riding between travel lanes



40

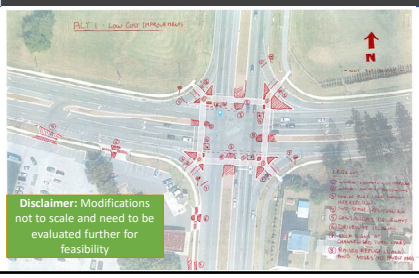
Results: Existing Conditions

- 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



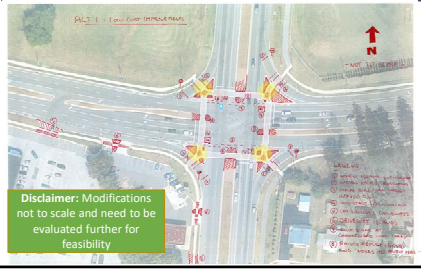
41

Assessment: Alt. 1 – Low-Cost Strategies



42

Assessment: Alt. 1 – Low-Cost Strategies



1. Widen island cut-throughs

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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Assessment: Alt. 1 – Low-Cost Strategies

1. Widen island cut-throughs
2. Install raised crosswalks

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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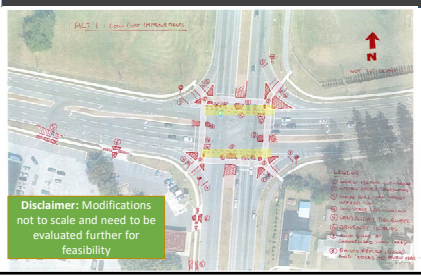
44

Assessment: Alt. 1 – Low-Cost Strategies



1. Widen island cut-throughs
2. Install raised crosswalks
3. Stripe bike-lane through intersection

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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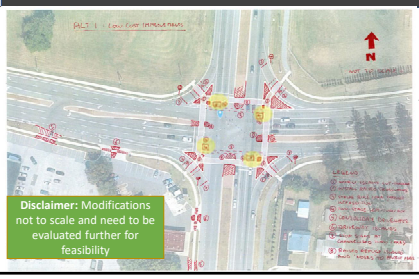
Assessment: Alt. 1 – Low-Cost Strategies



1. Widen island cut-throughs
2. Install raised crosswalks
3. Stripe bike-lane through intersection
4. Add two-stage left-turns

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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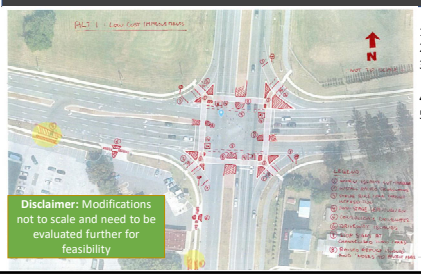
Assessment: Alt. 1 – Low-Cost Strategies



1. Widen island cut-throughs
2. Install raised crosswalks
3. Stripe bike-lane through intersection
4. Add two-stage left-turns
5. Consolidate driveways

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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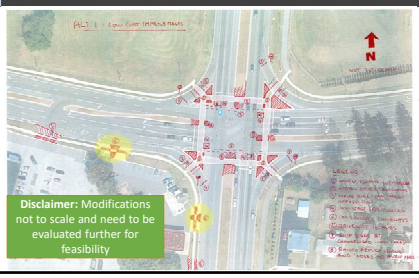
Assessment: Alt. 1 – Low-Cost Strategies



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

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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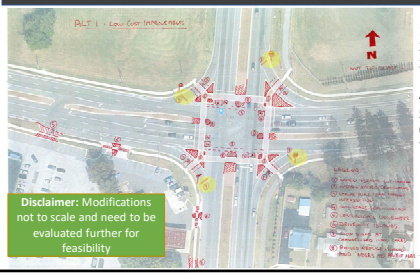
Assessment: Alt. 1 – Low-Cost Strategies



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

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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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

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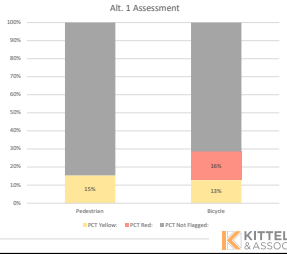
Results: Alt. 1 – Low-Cost Strategies

- ~~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



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Assessment: Alt. 2 – Median U-Turn (MUT)

Disclaimer: Modifications not to scale and need to be evaluated further for feasibility

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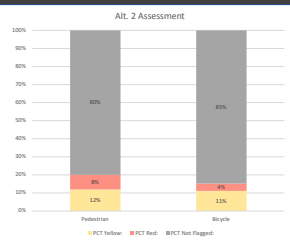
Results: Alt. 2 – Median U-Turn (MUT)

- **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~~
- Motorist crossing bike path
- Riding between travel lanes

*Mitigated but not eliminated



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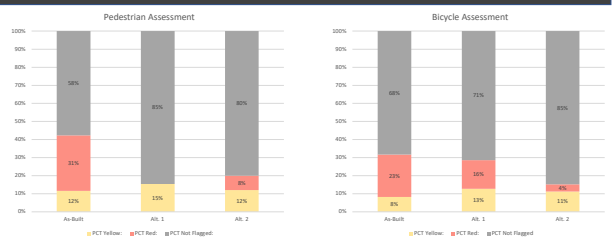
Results



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Wrap-Up

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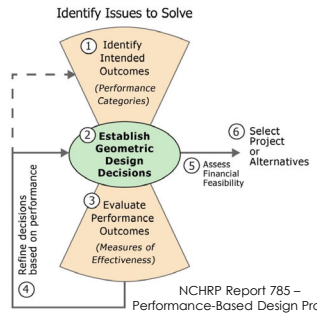
Performance-Based Design Process

- Identify intended outcomes
- Establish geometric design decisions
- **Evaluate performance outcomes**
- Refine decisions based on performance
- Assess financial feasibility
- Select project or alternatives



NCHRP Report 785 – Performance-Based Design Process

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Shannon Warchol
swarchol@kittelson.com

Mike Alston
malston@kittelson.com

Looking for More?

Check out the Links Pod!

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Slide 56

KT0 Olga - same note as on slide 4
Katie Taylor, 2023-06-15T18:50:40.298

Slide 57

A0 ITE to Drop Link
Author, 2023-05-17T16:39:19.378

A1 Katie - feel free to rearrange, change fonts, colors, etc
Author, 2023-05-17T16:47:55.464

SW2 Katie - feel free to rearrange, change fonts, colors, etc
Shannon Warchol, 2023-05-17T16:49:42.769

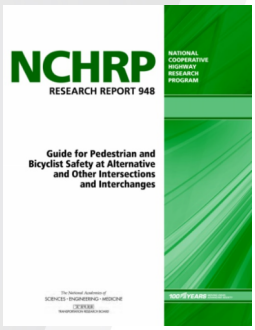
APPENDIX D – DETAILED DESIGN-FLAG SUMMARY

This appendix contains the detailed design flags, including specific guidance on application and thresholds. These slides were used as the foundation for the web-based training, and were also distributed to course participants as an in-class reference.

1

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

Design Flag Details



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1

Design Flag Assessment Method

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

2

2

Yellow vs. Red Flags

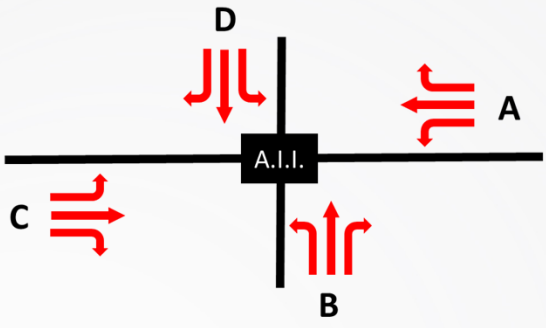
Yellow Flags, for design elements negatively affecting user comfort (in other words, increasing user stress) or the quality of the walking or cycling experience.

Red Flags, for design elements that are directly related to a safety concern for pedestrians or bicyclists.

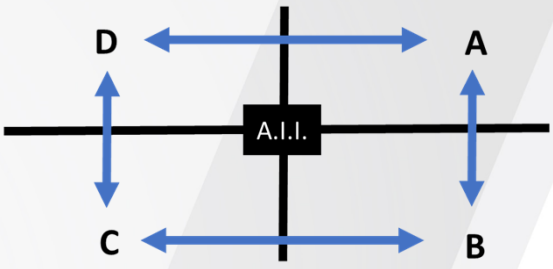
3

3

Applying Design Flag Checks



Assessment for On-Street Bicyclists follows Turning Movements



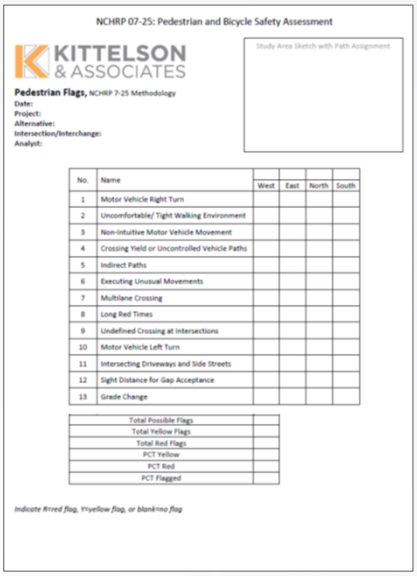
Assessment for Pedestrians (or Bicyclists pushing bikes) follows quadrant connections

4

4

Design Flag Worksheets

A four-legged intersection typically can have **up to 52 pedestrian flags**



NCHRP 07-25: Pedestrian and Bicycle Safety Assessment

KITTELSON & ASSOCIATES

Pedestrian Flags, NCHRP 7-25 Methodology

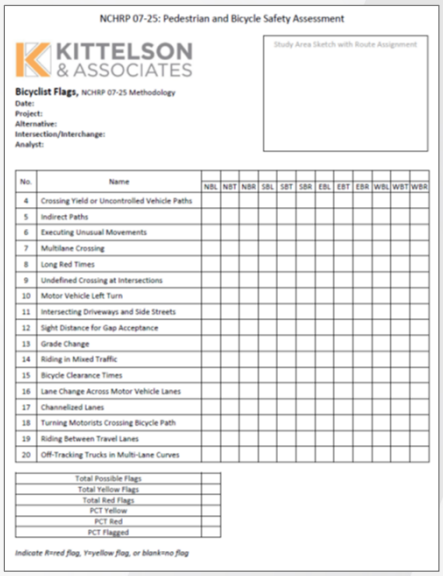
Date:
Project:
Alternative:
Intersection/Interchange:
Analyst:

Study Area Sketch with Path Assignment

No.	Name	West	East	North	South
1	Motor Vehicle Right Turn				
2	Uncomfortable/ Tight Walking Environment				
3	Non-Intuitive Motor Vehicle Movement				
4	Crossing Yield or Uncontrolled Vehicle Paths				
5	Indirect Paths				
6	Executing Unusual Movements				
7	Multilane Crossing				
8	Long Red Times				
9	Undefined Crossing at Intersections				
10	Motor Vehicle Left Turn				
11	Intersecting Driveways and Side Streets				
12	Sight Distance for Gap Acceptance				
13	Grade Change				

Total Possible Flags	
Total Yellow Flags	
Total Red Flags	
PCT Yellow	
PCT Red	
PCT Flagged	

Indicate R=red flag, Y=yellow flag, or blank=no flag



NCHRP 07-25: Pedestrian and Bicycle Safety Assessment

KITTELSON & ASSOCIATES

Bicyclist Flags, NCHRP 07-25 Methodology

Date:
Project:
Alternative:
Intersection/Interchange:
Analyst:

Study Area Sketch with Route Assignment

No.	Name	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
4	Crossing Yield or Uncontrolled Vehicle Paths												
5	Indirect Paths												
6	Executing Unusual Movements												
7	Multilane Crossing												
8	Long Red Times												
9	Undefined Crossing at Intersections												
10	Motor Vehicle Left Turn												
11	Intersecting Driveways and Side Streets												
12	Sight Distance for Gap Acceptance												
13	Grade Change												
14	Riding in Mixed Traffic												
15	Bicycle Clearance Times												
16	Lane Change Across Motor Vehicle Lanes												
17	Channelized Lanes												
18	Turning Motorists Crossing Bicycle Path												
19	Riding Between Travel Lanes												
20	Off-Tracking Trucks in Multi-Lane Curves												

Total Possible Flags	
Total Yellow Flags	
Total Red Flags	
PCT Yellow	
PCT Red	
PCT Flagged	

Indicate R=red flag, Y=yellow flag, or blank=no flag

A four-legged intersection typically can have **up to 204 bicyclist flags**

5

5

Design Flag 1: Motor Vehicle Right Turns

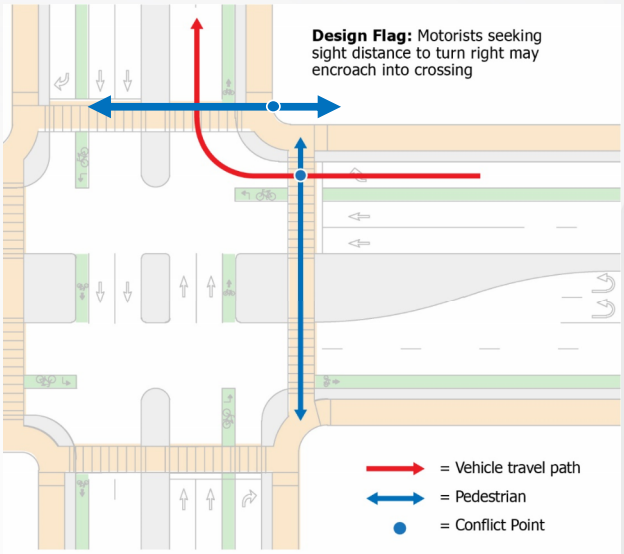


Exhibit 4-8

6

6

Flag *1: Motor Vehicle Right-Turn*

Applies to:

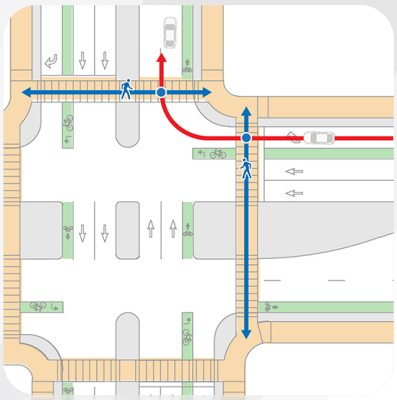
Permissive motor vehicles right-turns across pedestrian paths

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Turning Speed & Vehicle Volume	<=20 mph **AND** <= 50 veh/h	>20 mph **OR** >50 veh/h

Exceptions to Thresholds

(a) A stop-controlled crossing;
(b) A signal controlled crossing where the right turn only operated protected;
(c) A crossing with vehicle speeds below 10 mph (e.g. through the use of raised crosswalks).



7

7

Flag *1: Motor Vehicle Right-Turn*

Special Considerations

Applies to both channelized and non-channelized movements.
Applies to right turn on red and right turn on green
In absence of operating speed data, turn radius can be used to estimate vehicle speed.

Potential Mitigation Strategies

- *Providing a stop bar before the marked pedestrian crossing.*
- *Providing adequate sight distance at the intersection from the stop bar.*
- *Including space for queue storage for a vehicle to queue in-between the crossing and conflicting traffic flow, when waiting to turn right on red (providing separation between driver decisions).*
- *Restricting right-turns-on-red.*

Similar Flags

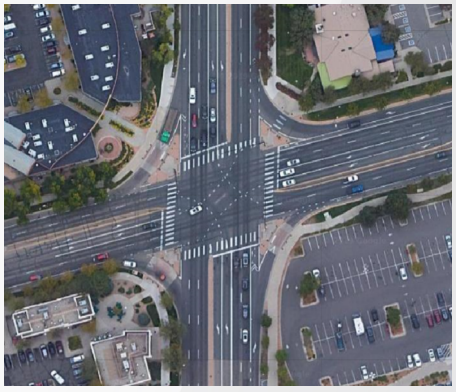
4 Yield- or Uncontrolled Vehicle Path;
18 Turning Motorist Crossing Bicycle Path

8

8

Design Flag 1 at Conventional Intersections

Vehicles permitted to turn right across marked crosswalks.

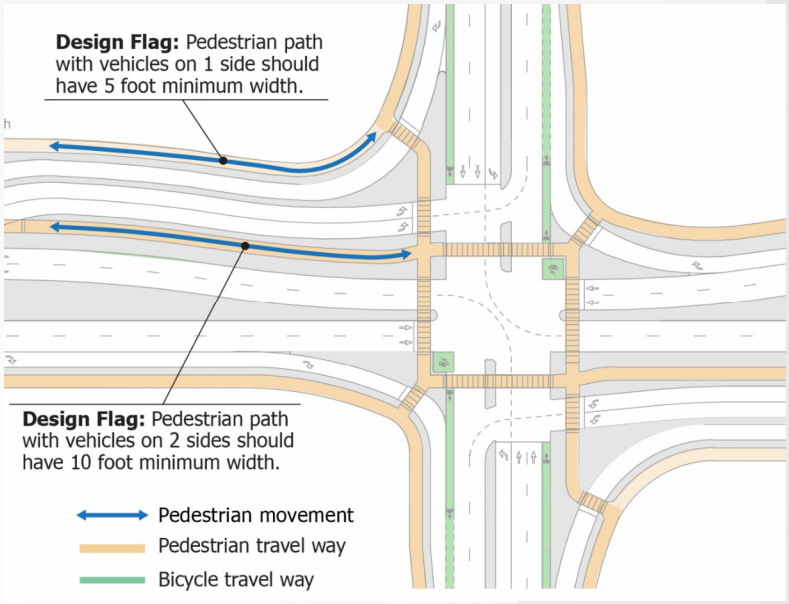


Intersection with channelized turn lanes.

9

9

Design Flag 2: Uncomfortable/ Tight Walking Environment



10

10

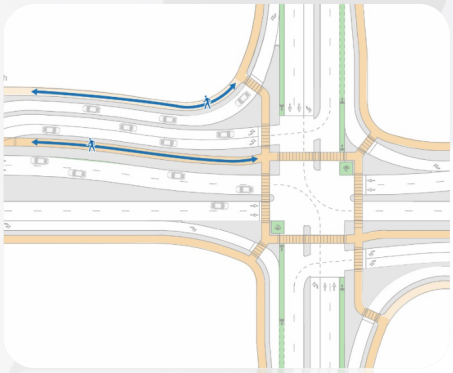
Flag *2: Uncomfortable/Tight Walking Environment*

Applies to:

Pedestrian facilities of narrow width

Flag Threshold

Measure of Effectiveness	Yellow Threshold	Red Threshold
Effective walkway width	< 5 ft if traffic present on one side; <10 ft if traffic present on two sides	N/A



Exceptions to Thresholds

N/A

11

11

Flag *2: Uncomfortable/Tight Walking Environment*

12

Special Considerations

Channelizing island is an example of an environment with traffic present on more than two sides.
ADA requirements must still be met.
If facility is a shared-use path next to a vertical object, the effective width of the path is reduced by two feet to account for the shy distance.

Potential Mitigation Strategies

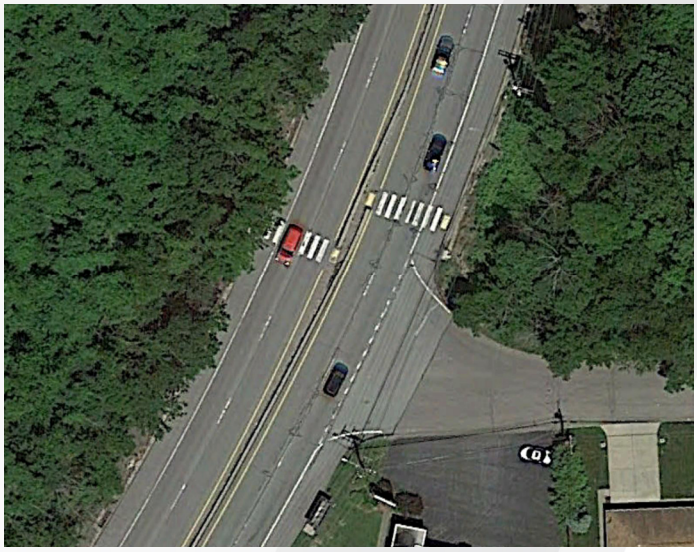
- *Widening the sidewalk.*
- *Illuminating the walking environment.*
- *Increasing the size of channelization islands and corner areas.*
- *Providing vertical separation between pedestrians and vehicles.*
- *Providing horizontal separation (buffers) between pedestrians and vehicles.*

Similar Flags

N/A

12

Design Flag 2 at Conventional Intersection

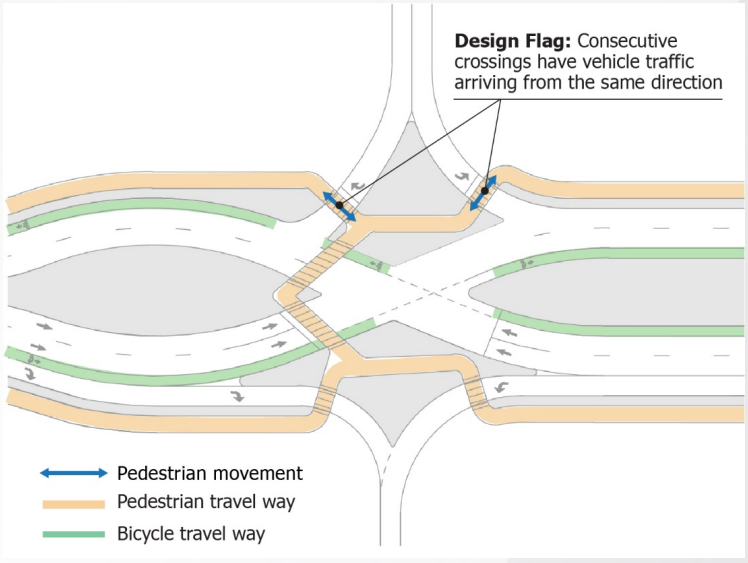


Narrow median for pedestrians crossing the road.

13

13

Design Flag 3: Nonintuitive Motor Vehicle Movements



14

14

Flag *3: Nonintuitive Motor Vehicle Movement*

Applies to:

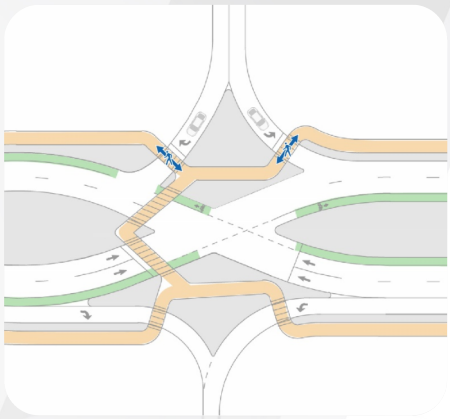
Motor vehicle movements arriving from an unexpected direction

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle acceleration profile	Vehicle decelerating	Vehicle accelerating or free-flowing

Exceptions to Thresholds

A stop-controlled crossing.



15

15

Flag *3: Nonintuitive Motor Vehicle Movement*

Special Considerations

Determining if a movement is nonintuitive likely depends on local context

Potential Mitigation Strategies

- *Designing the approaching path to face the initial direction of opposing traffic.*
- *Providing signing that is viewable and understandable to the intended users, as well as appropriate speech messages for any accessible pedestrian signals or audible information devices.*
- *Providing pavement marking at the entrance to the crossing that indicates which direction a pedestrian or bicyclist should look to view oncoming traffic.*
- *Choosing different geometric features of the design to minimize or eliminate movements from unexpected directions.*

Similar Flags

6 Executing Unusual Movement

16

16

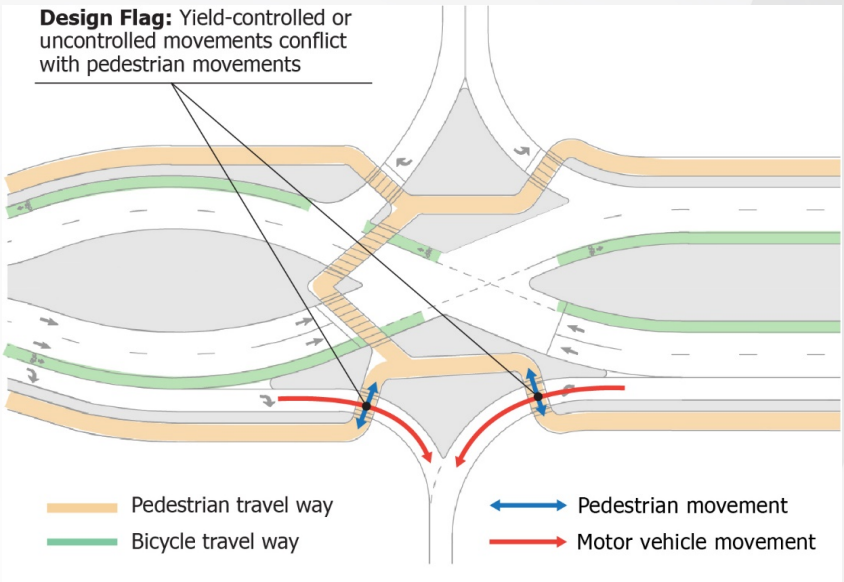
Design Flag 3 at Conventional Intersections

Pedestrian crossing N to S; vehicles approaching from the right rather than from the left.

17

17

Design Flag 4: Crossing Yield- or Uncontrolled Vehicle Paths



18

18

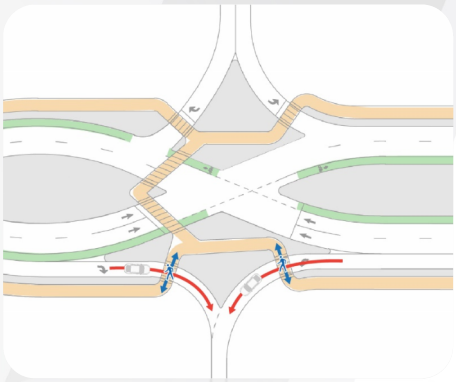
Flag *4: Yield- or Uncontrolled Vehicle Path*

Applies to:

Yield or uncontrolled pedestrian crossings

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Speed & Vehicle Volume	<=20 mph **AND** <= 50 veh/h	>20 mph **OR** >50 veh/h



Exceptions to Thresholds

Vehicles yielding to bicyclists and vehicles simultaneously (may be subject to Flag 19).

19

19

Flag *4: Yield- or Uncontrolled Vehicle Path*

Special Considerations

In absence of operating speed data, turn radius can be used to estimate vehicle speed.

Potential Mitigation Strategies

- *Providing signalized crossings.*
- *Providing stop-controlled crossings.*
- *Reducing vehicle speed through curvatures.*
- *Installing raised crosswalks to reduce vehicle speed.*

Similar Flags

1 Motor Vehicle Right-Turn;
4 Yield- or Uncontrolled Vehicle Path;
10 Motor Vehicle Left-Turn;
18 Turning Motorist Crossing Bicycle Path;
19 Riding between Travel Lanes, Lane Additions, or Lane Merges

20

20

Design Flag 4 at Conventional Intersection

Yield controlled channelized turn lanes.

21

21

Design Flag 5: Indirect Paths

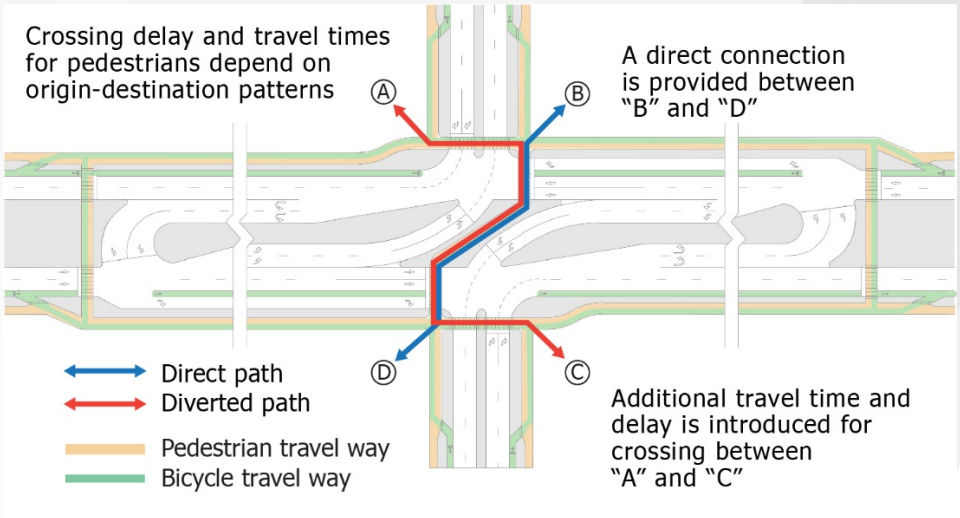


Exhibit 2-6

22

22

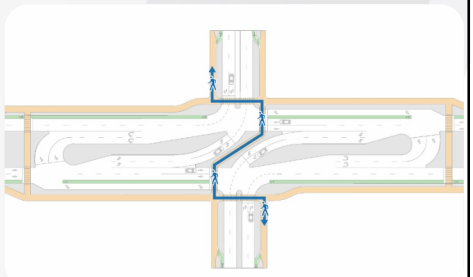
Flag *5: Indirect Path*

Applies to:

Paths resulting in out-of-direction travel

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Out-of-direction travel distance	90 ft (ped) 450 ft (bike)	135 ft (ped) 675 ft (bike)



Exceptions to Thresholds

N/A

23

23

Flag *5: Indirect Path*

Special Considerations

For approaches with more than four legs, it may be appropriate to consider desire lines across multiple approaches rather than only desires lines between adjacent approaches.

Potential Mitigation Strategies

- *Direct crossing opportunities with a dedicated pedestrian phase, if necessary.*
- *Midblock crossing before the intersection to address an otherwise indirect path.*
- *Grade-separated pedestrian and bicycle facilities, depending on the context and the origin-destination patterns for pedestrians and bicyclists.*

Similar Flags

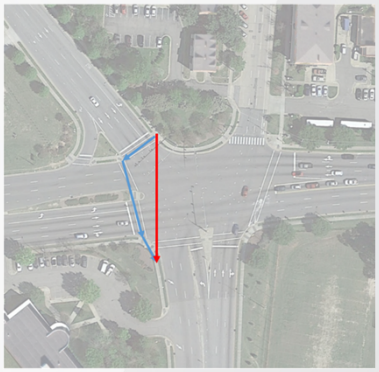
8 Long Red Time

24

24

Design Flag 5 at Conventional Intersections

Out-of-direction travel for west leg crossing.

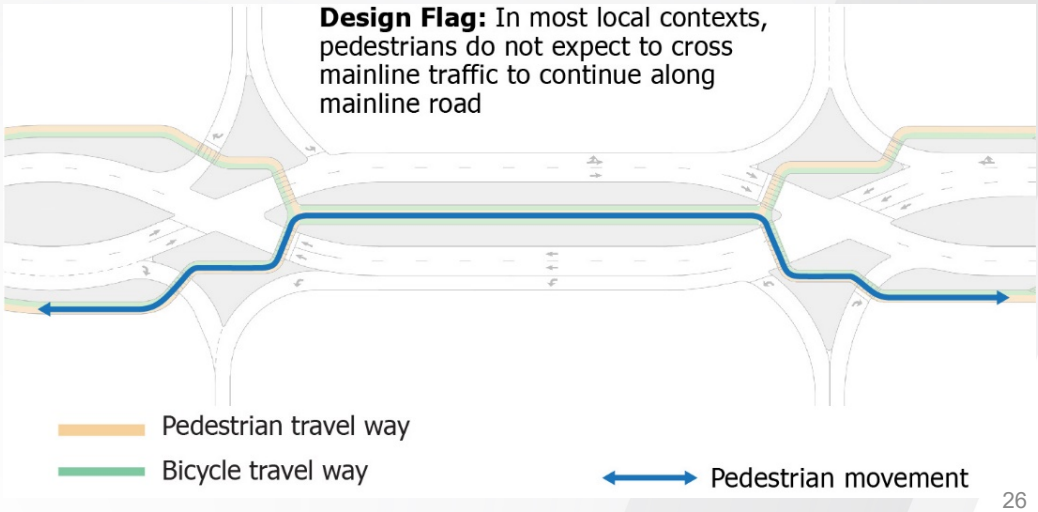


Out-of-direction travel for west leg crossing.

25

25

Design Flag 6: Executing Unusual Movements



26

26

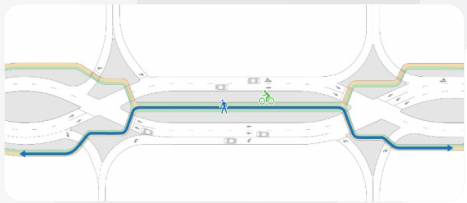
Flag *6: Executing Unusual Movement*

Applies to:

Movements that are unexpected given local context

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Local Expectation	The path does not match the expectation	N/A



Exceptions to Thresholds

N/A

27

27

Flag *6: Executing Unusual Movement*

Special Considerations

Determining if a movement is unusual likely relies on local context. It is not intended to cover common but undesirable movements.

Potential Mitigation Strategies

- *Re-aligning pedestrian/bicycle movement to make them more intuitive.*
- *Constructing dedicated pedestrian or bicycle facilities.*
- *Following the design process to meet expectations for people walking and biking.*

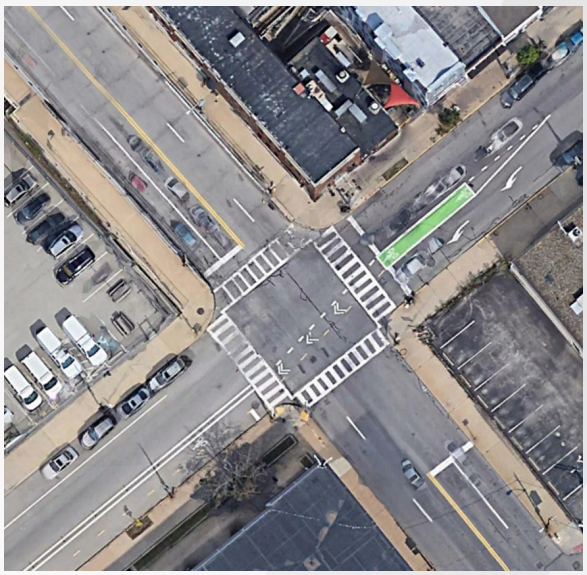
Similar Flags

3 Nonintuitive Motor Vehicle Movement;
5 Indirect Path

28

28

Design Flag 6 at Conventional Intersection

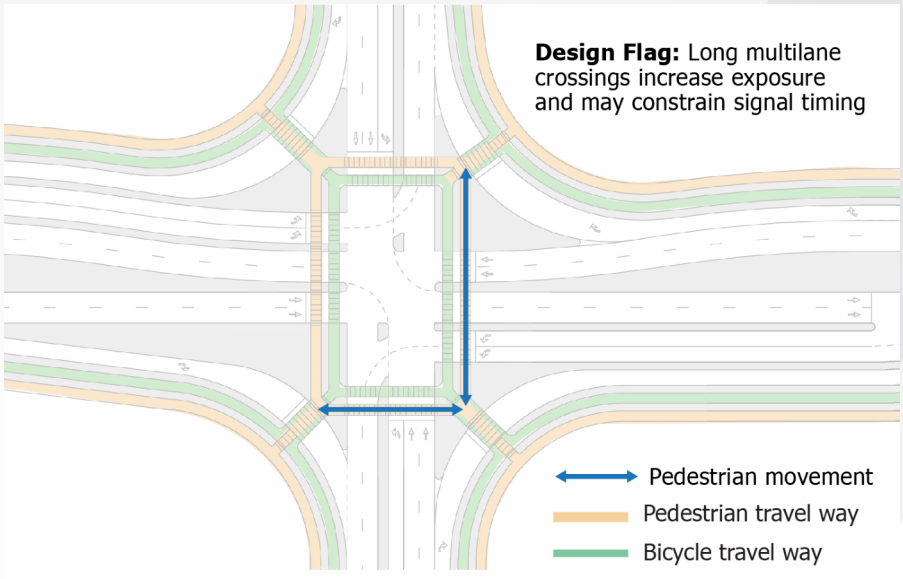


Bike lane developing between motor vehicle travel lanes.

29

29

Design Flag 7: Multilane Crossings



30

30

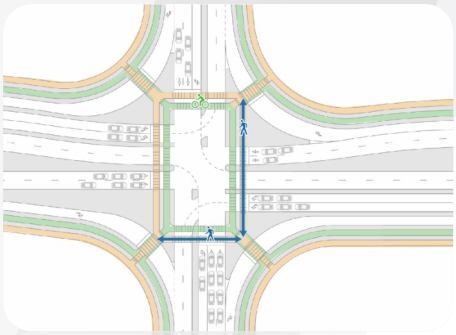
Flag *7: Multilane Crossing*

Applies to:

Crossing distances of significant length across multiple lanes

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Number of lanes without refuge	2 – 3 lanes (ped) 4 – 5 lanes (bike)	>3 lanes (ped) >5 lanes (bike)



Exceptions to Thresholds

N/A

31

31

Flag *7: Multilane Crossing*

Special Considerations

Bicycle and parking lanes are not considered in the lane count. Lane count is the maximum number of lanes of any direction, crossed between refuge areas

Potential Mitigation Strategies

- *Reducing the number of travel lanes.*
- *Providing two-stage crossings to reduce the number of lanes and travel directions crossed at one time.*
- *Providing signalized or stop-controlled crossing.*
- *Installing raised crosswalks to reduce vehicle speed.*

Similar Flags

N/A

32

32

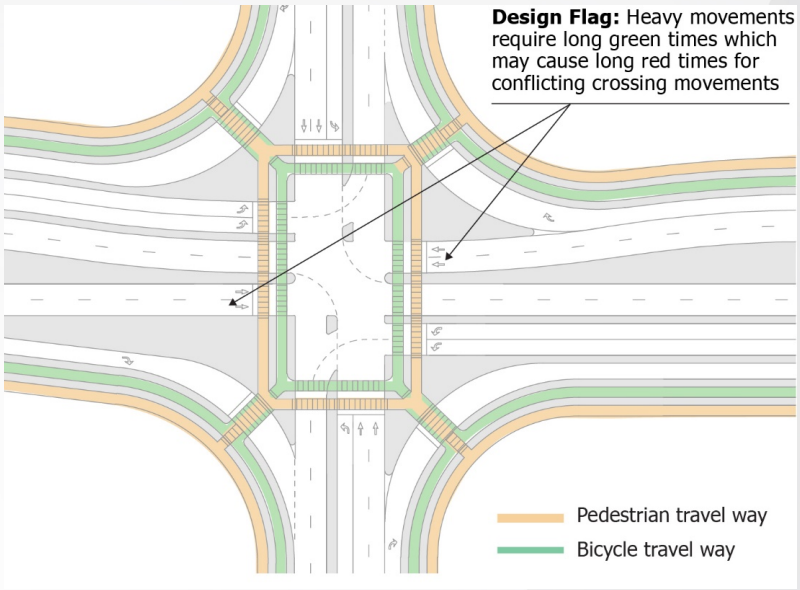
Design Flag 7 at Conventional Intersection

Pedestrian and bicycle crossings conflicting with vehicle lanes.

33

33

Design Flag 8: Long Red Times



34

34

Flag *8: Long Red Time*

Applies to:

Excessive stopped delay at signalized crossings

Flag Thresholds

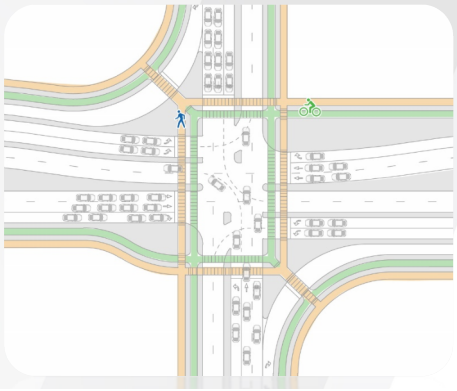
Measure of Effectiveness	Yellow Threshold	Red Threshold
Delay	30 seconds	45 seconds

Planning Level Estimation

A planning level estimation of delay can be made using the following equation and reference table on the right can be used to estimate red time.

$$Delay = \frac{r^2}{2C}$$

r = movement red time (seconds);
C = cycle length (seconds)



# Critical Phases	% Red Time of Cycle Length	
	Crossing with Major Vehicle Movement	Crossing with Minor Vehicle Movement
2	30%	70%
3	50%	75%
4	60%	85%

35

35

Flag *8: Long Red Time*

Special Considerations

Only signal delay, not extra distance traveled delay, should be included in the calculation of red time. Total time is combined across all stages for pedestrians crossing an approach which requires multiple stages (e.g. due to a short flashing don't walk indication and a median refuge) and for bicycle movements redirected to multi-stage movements (e.g. through a bike box).

Potential Mitigation Strategies

- *Reducing the overall cycle length.*
- *Modifying the phase sequence to reduce the total crossing time. (This particularly applies for priority movements because improvements in travel time for one origin-destination pattern may result in longer crossing times for other movements.)*

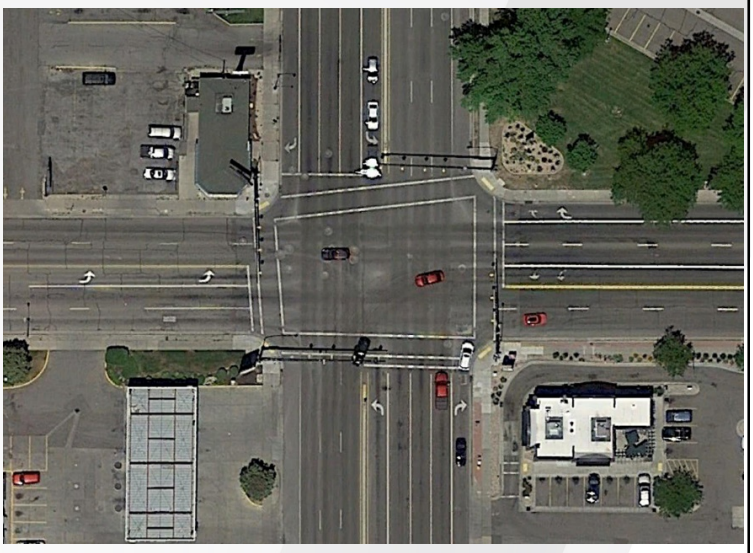
Similar Flags

5 Indirect Path

36

36

Design Flag 8 at Conventional Intersection

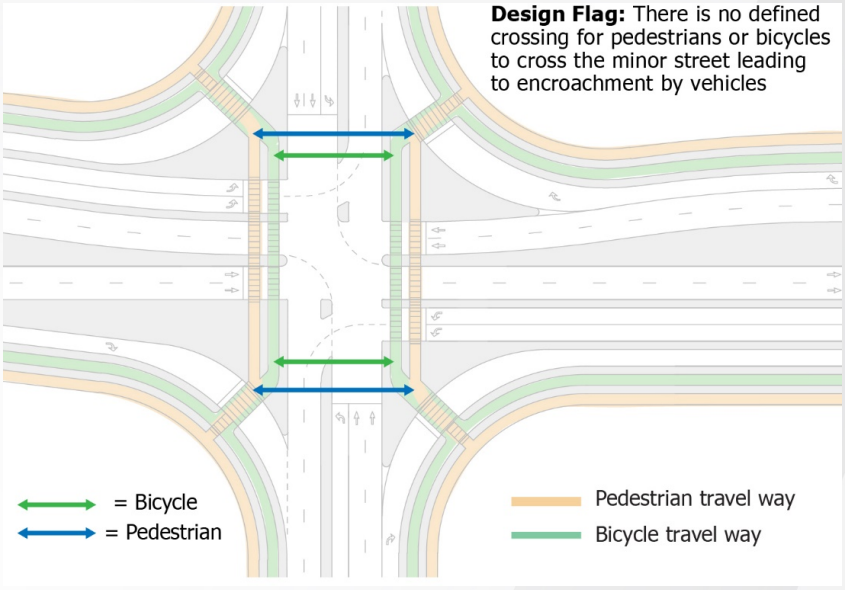


Relatively large intersections with possible long red times.

37

37

Design Flag 9: Undefined Crossings at Intersections



38

38

Flag *9: Undefined Crossing at Intersection*

Applies to:

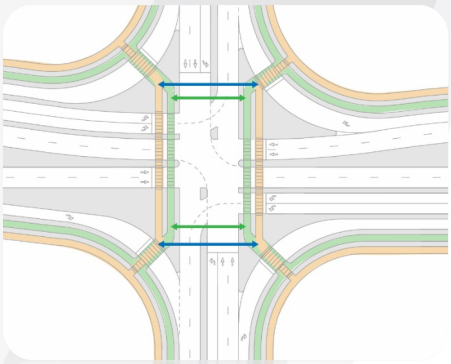
Unmarked paths through intersections

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Path Markings	Unmarked crossing	N/A

Exceptions to Thresholds

a) *Right and left turning bicycle movements;*
b) *Bicycle through movements in shared lanes with vehicles.*



39

39

Flag *9: Undefined Crossing at Intersection*

Special Considerations

N/A

Potential Mitigation Strategies

- *Striping biking pathways through an intersection to identify where drivers are entering the designated path of bike travel.*
- *Where off-street bicycling facilities are provided, placing the bike crossing and the pedestrian crossing next to one another to reduce undefined space.*
- *Designing two-stage left-turn queue boxes with queuing space for multiple bicyclists. [Two-stage turn queue boxes are allowed by and subject to FHWA Interim Approval IA-20, Optional Use of Two-Stage Bicycle Turn Boxes (8).]*

Similar Flags

14 Riding in Mixed Traffic

40

40

Design Flag 9 at Conventional Intersections

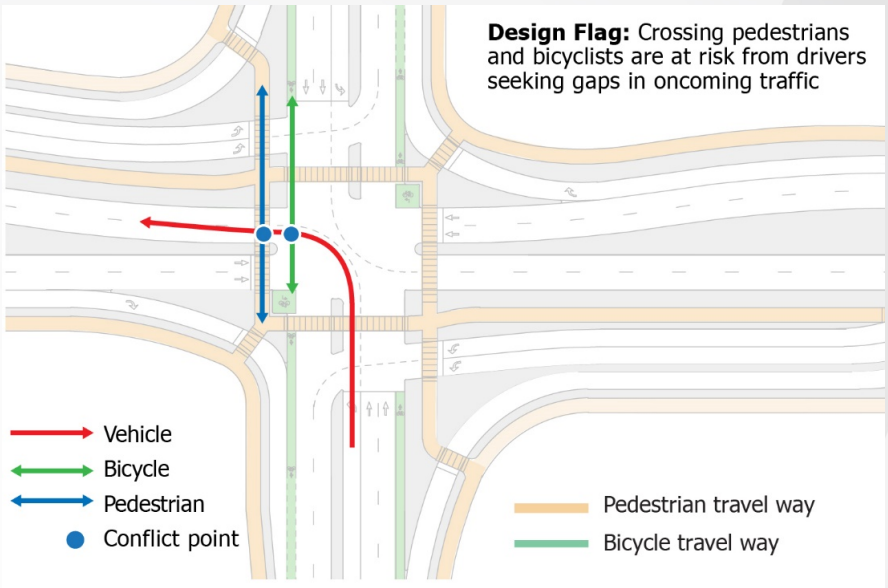
Westbound bicycle lane without intersection markings.

Undefined vehicle right turn space.

41

41

Design Flag 10: Motor Vehicle Left Turns



42

42

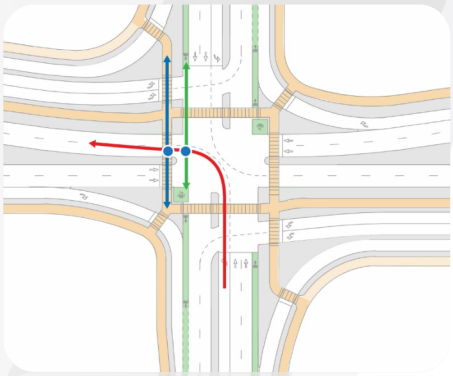
Flag *10: Motor Vehicle Left-Turn*

Applies to:

Permissive and protected left-turns across pedestrian and bicycle paths

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Turning Speed & Vehicle Volume	<=20 mph **AND** <= 50 veh/h	>20 mph **OR** >50 veh/h



Exceptions to Thresholds

A crossing with vehicle speeds below 10 mph (e.g. through the use of raised crosswalks).

43

43

Flag *10: Motor Vehicle Left-Turn*

Special Considerations

In absence of operating speed data, turn radius can be used to estimate vehicle speed.

Potential Mitigation Strategies

- *Converting permissive left-turn movements into protected left-turn movements with a dedicated signal phase. (At RCUTs, an option is to remove left-turns at the intersection.)*

Similar Flags

18 Turning Motorist Crossing Bicycle Path

44

44

Design Flag 10 at Conventional Intersections

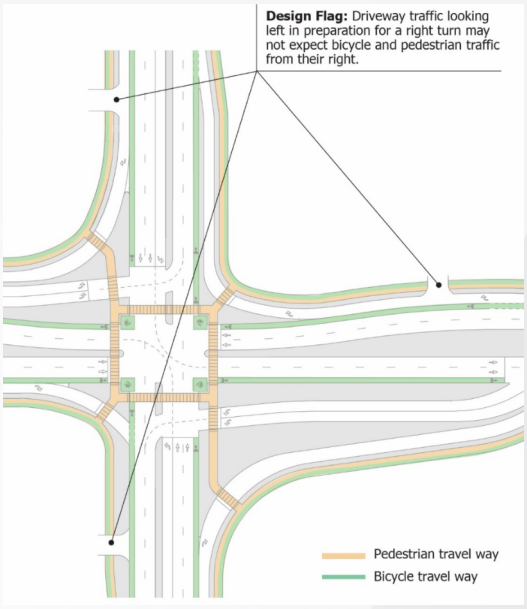
Conflict between left-turning vehicle and pedestrians.

Permissive left turns across pedestrian crossings.

45

45

Design Flag 11: Intersecting Driveways and Side Streets



46

46

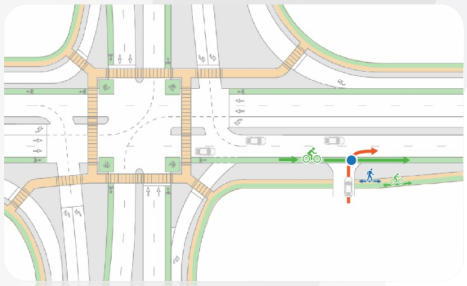
Flag *11: Intersection Driveways and Side Streets*

Applies to:

Driveways or streets within intersection area of influence

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
# of Access points in Area of Influence	1-2 (peds) 1-2 (one-way bikes)	>2 (peds) >2 (one-way bikes) >0 (two-way bikes)



Exceptions to Thresholds

N/A

47

47

Flag *11: Intersection Driveways and Side Streets*

Special Considerations

The area of influence is 250 feet from the center of the intersection.
For intersection forms with multiple nodes (e.g. RCUT), the area of influence is the entire frontage between nodes.

Potential Mitigation Strategies

- *Reducing the number of driveways through access management.*
- *Controlling vehicle speeds at driveways through curvature or vertical elements.*
- *Providing signalized or stop-controlled crossings at driveways.*

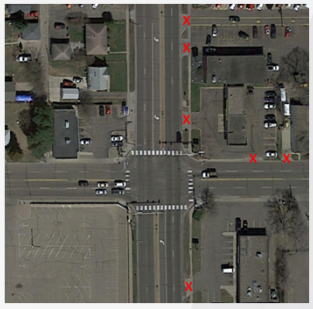
Similar Flags

N/A

48

48

Design Flag 11 at Conventional Intersections



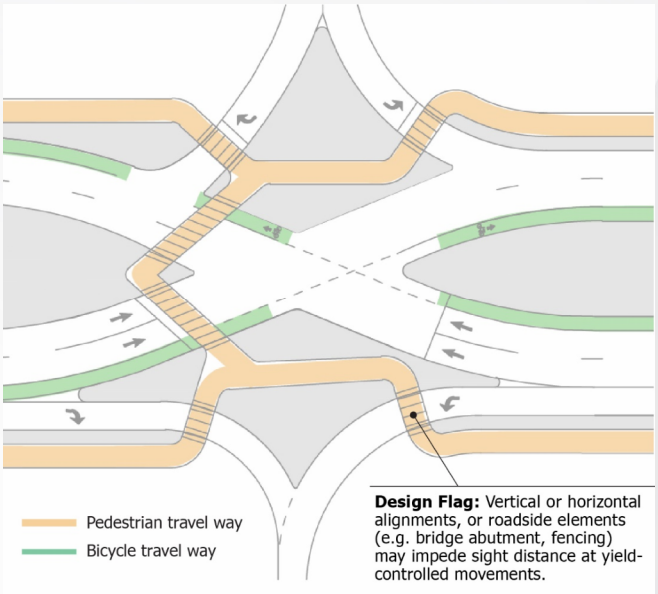
Significant driveway and side street presence adjacent to intersection.

Two-way multi-use path crossing on median-divided highway create conflicts, with specific risk for cyclists approaching from right at driveways (while drivers are looking for gaps to their left)

49

49

Design Flag 12: Sight Distance for Gap Acceptance Movements



50

50

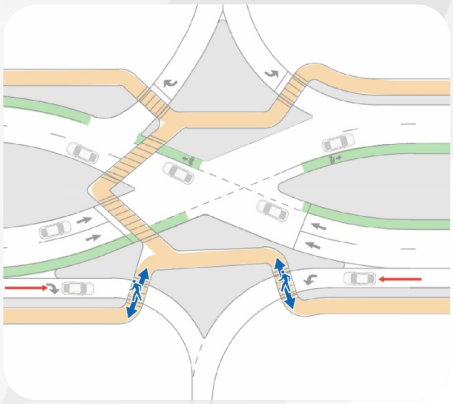
Flag *12: Sight Distance for Gap Acceptance Movement*

Applies to:

Providing adequate sight distance to conflict points

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Sight Distance	N/A	Less than required for vehicle speed



Exceptions to Thresholds

N/A

51

51

Flag *12: Sight Distance for Gap Acceptance Movement*

Special Considerations

Sight distance requirements can be found in the AASHTO Green Book and in NCHRP Report 834.

Similar Flags

N/A

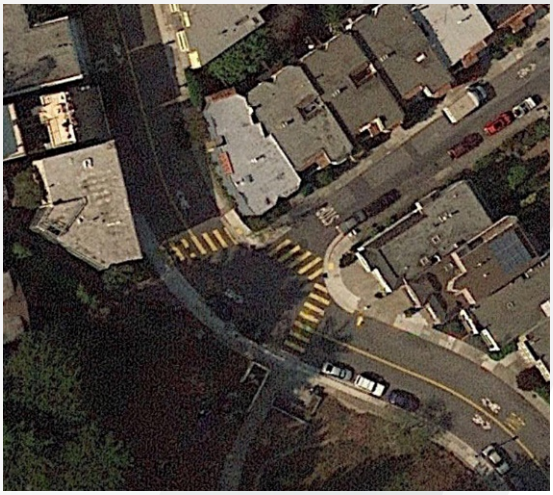
Potential Mitigation Strategies

- *Designing vertical obstructions, such as bridge abutments, tall landscaping, and signal cabinets to be positioned outside of necessary sight triangles.*
- *Establishing horizontal and vertical alignments that provide the necessary sight distance.*

52

52

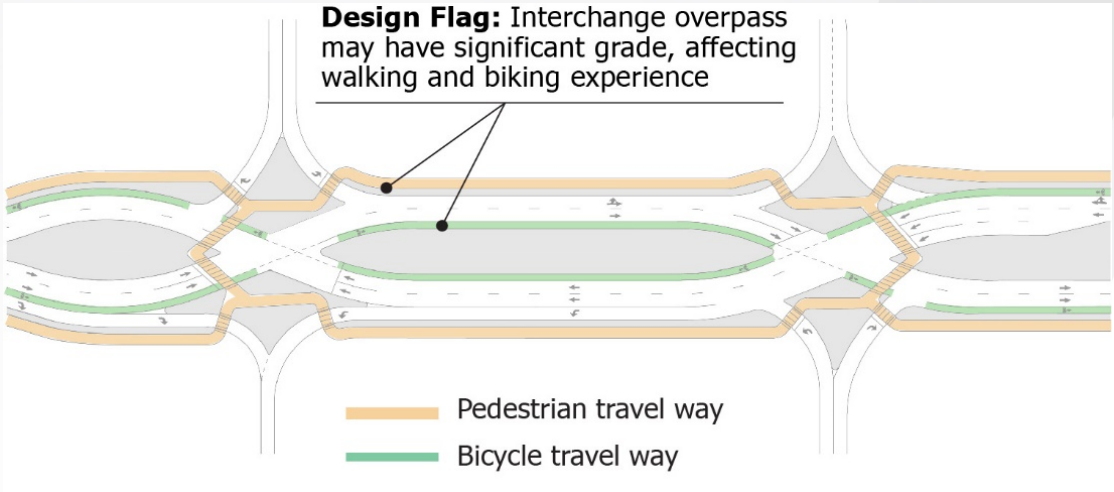
Design Flag 12 at Conventional Intersections



Profile and plan views of intersections with significant vertical and horizontal curves, limiting sight distance.

53

Design Flag 13: Grade Change



54

54

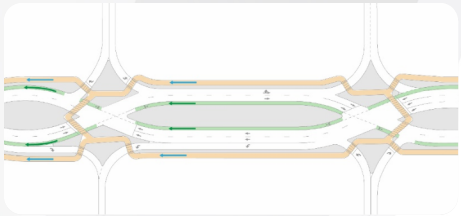
Flag *13: Grade Change*

Applies to:

Vertical curves adjacent to intersections

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
% grade	+3% to +5% **OR** -3% to -5%	<–5% **OR** >+5%



Exceptions to Thresholds

Curb ramp slopes are exempt from this flag, but should still meet ADA requirements.

55

55

Flag *13: Grade Change*

Special Considerations

N/A

Potential Mitigation Strategies

- *Constructing a dedicated protected bike lane on grade sections.*
- *Constructing a multiuse path on grade sections.*
- *Reducing vehicular speeds.*

Similar Flags

N/A

56

56

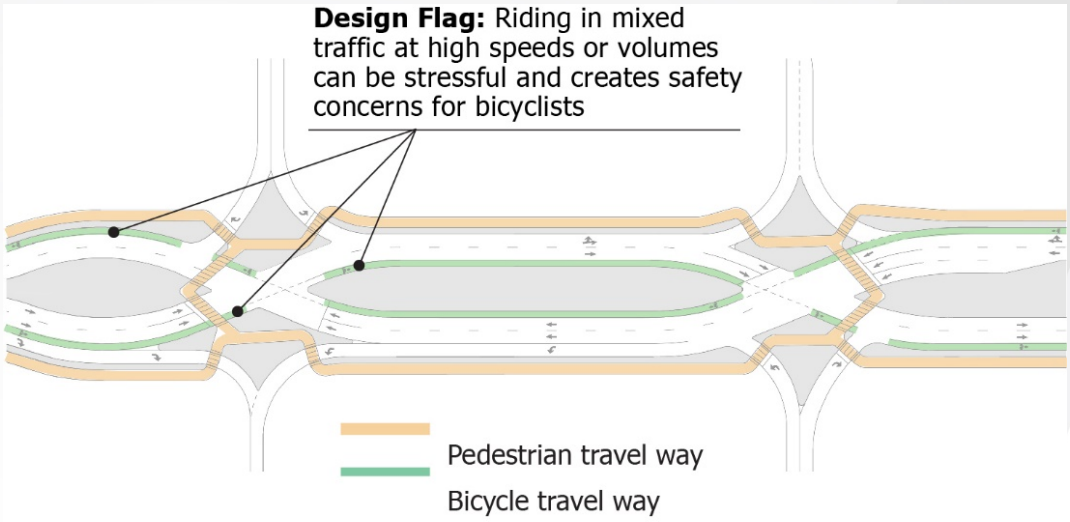
Design Flag 13 at Conventional Intersections

Significant uphill grade adjacent to an intersection.

57

57

Design Flag 14: Riding in Mixed Traffic



58

58

Flag *14: Riding in Mixed Traffic*

Applies to:

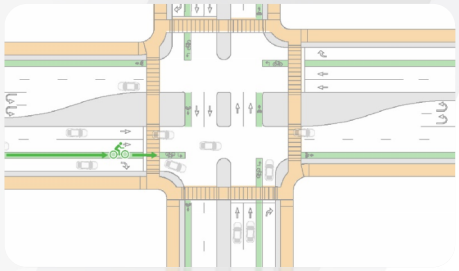
On-street bicycle facilities on high-speed/volume roads

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Speed & Vehicle Volume	25-35 mph **AND** 3,000 – 7,000 vpd	>35 mph **OR** >7,000 vpd

Exceptions to Thresholds

N/A



59

59

Flag *14: Riding in Mixed Traffic*

Special Considerations

In absence of operating speed data, design speed and engineering judgement can be used.

Potential Mitigation Strategies

- *Separating bicyclists from motor vehicles through dedicated protected lanes.*
- *Designing for lower motor vehicle speeds where bicyclists and motorists interact.*

Similar Flags

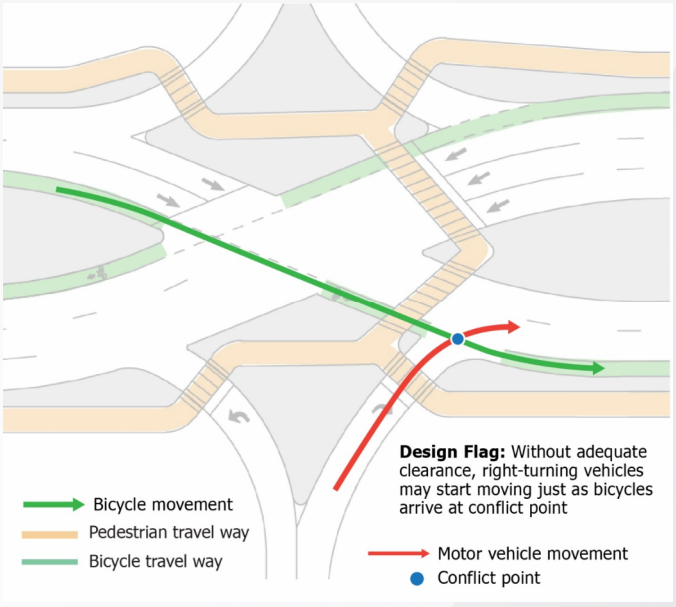
9 Undefined Crossing at Intersection

60

60

Design Flag 14 at Conventional Intersection

On-street bicycle lanes adjacent to heavy volume roadway.



Design Flag 15 – Bicycle Clearance Times

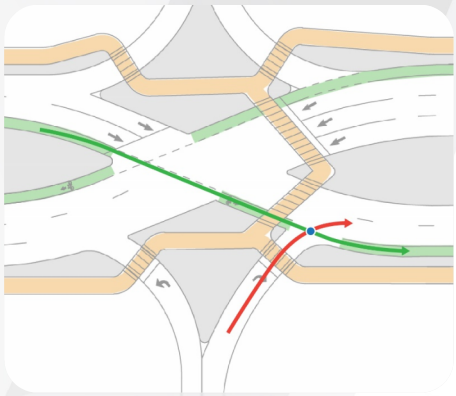
Flag *15: Bicycle Clearance Time*

Applies to:

Bicycles require longer clearance times than vehicles at signals

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Speed and Clearance Zone Length (feet)	<=35 mph and 36–72 ft **OR** > 35 mph and 24–60 ft	<=35 mph and >=72 ft **OR** > 35 mph and >=60 ft



Exceptions to Thresholds

N/A

63

63

Flag *15: Bicycle Clearance Time*

Special Considerations

Clearance zone length should include the full distance from the upstream stop bar through the furthest downstream conflicting movement.

Potential Mitigation Strategies

- *Reducing the number of lanes to cross.*
- *Reducing lane widths.*
- *Reducing median widths.*
- *Moving ramps closer to the crossover.*
- *Providing refuge for bicyclists.*
- *Installing bicycle dilemma zone detection to extend the transition of signal phases when necessary.*
- *Providing a separate bicycle signal with a dedicated indication of required clearance time.*

Similar Flags

N/A

64

64

Design Flag 15 at Conventional Intersections

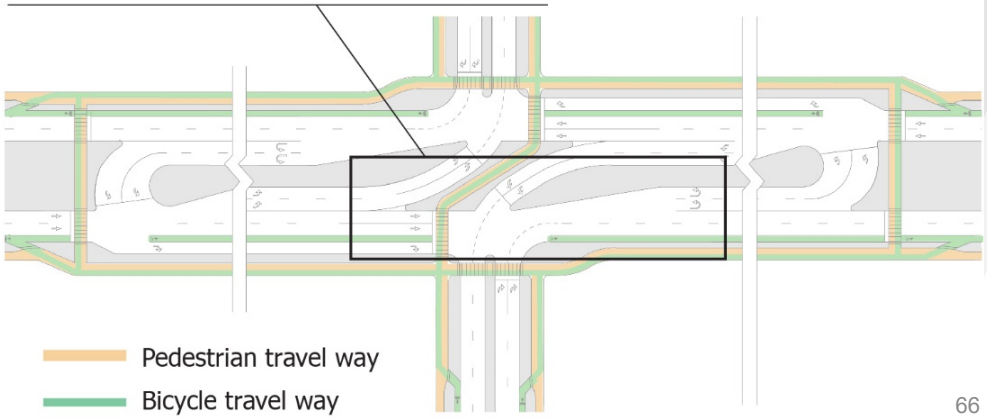
Clearance times for SE-to-NW crossing along on-street bike lane likely not long enough for bicyclist to safely clear the equivalent of 8 lanes of width across E-W road.

65

65

Design Flag 16: Lane Change Across Motor Vehicle Travel Lane(s)

Design Flag: On-street bicyclists trying to turn left would need to cross over motor vehicle travel lanes with considerable speed differential. *(Note that off-street facilities are also provided in this design, mitigating the design flag)*



66

66

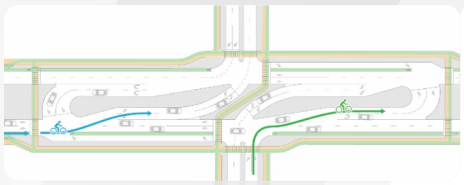
Flag *16: Lane Change Across Motor Vehicle Travel Lane*

Applies to:

Lane changes by bicycles across motor vehicle lanes

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Speed & Vehicle Volume	25–35 mph **OR** 3,000–7,000 vpd	>35 mph **OR** >7,000 vpd



Exceptions to Thresholds

Bicycles crossing vehicles lanes near- or fully perpendicularly are excluded from this flag.

67

67

Flag *16: Lane Change Across Motor Vehicle Travel Lane*

Special Considerations

This flag should not be confused with those where motor vehicles cross bicycle lanes.
In absence of operating speed data, design speed and engineering judgement can be used.

Potential Mitigation Strategies

- *Designing for bicyclists to use ramps to sidewalks or shared-use paths and cross in a crosswalk.*
- *Designing for bicyclists to use a two-stage bicycle left-turn queue box with adequate room to maneuver and wait.*
- *At RCUTs, designing for bicyclists to make a through movement with a channelized direct bicycle crossing (only feasible absent a pedestrian "Z" crossing).*
- *Clearly marking the entry to the crossover area.*
- *Design for low motorist speeds (below 20 mph) through a crossover area by reducing radii or implementing speed-reducing treatments.*

Similar Flags

18 Turning Motorist Crossing Bicycle Path

68

68

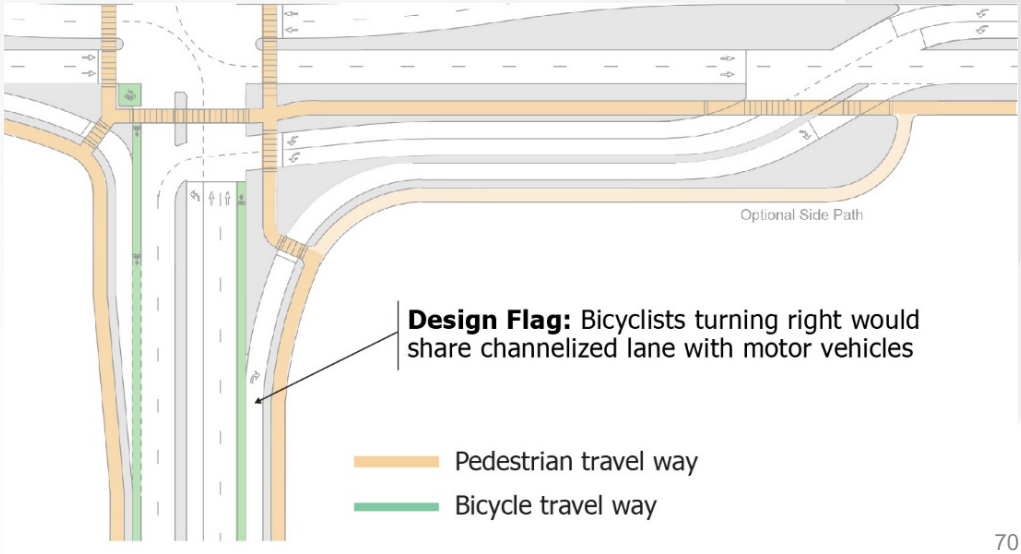
Design Flag 16 at Conventional Intersection

Bicycle path departing bike lane and crossing vehicle lane for left turn downstream.

69

69

Design Flag 17: Channelized Lanes



70

70

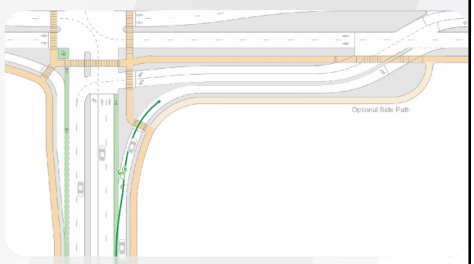
Flag *17: Channelized Lane*

Applies to:

Bicyclist Traveling in Channelized Lane Adjacent to Motor Vehicles

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Vehicle Speed & Channelization Length	25-35 mph **AND** <= 50 ft	>35 mph **OR** >50 ft



Exceptions to Thresholds

a) *Bicycle facility is in between two lanes of a multilane channelized area (may be subject to Flag 19);*
b) *Channelization is provided through striping rather than physical barriers (may be subject to Flag 19).*

71

71

Flag *17: Channelized Lane*

Special Considerations

In absence of operating speed data, design speed and engineering judgement can be used.
This flag is not intended to be used for bicycles crossing channelized movements.

Potential Mitigation Strategies

- *Designing for bicyclists to use ramps onto sidewalks or shared-use paths and cross in a crosswalk, instead of traveling as vehicles.*
- *Designing for bicyclists to use a two-stage bicycle left-turn queue box with adequate room to maneuver and wait, instead of making a direct left-turn with motorized traffic.*
- *At RCUTs, designing for bicyclists to make a through movement with a channelized direct bicycle crossing (only feasible absent a pedestrian "Z" crossing).*
- *Designing for low motorist speeds (below 20 mph) in channelized lane areas by reducing curve radii.*

Similar Flags

4 Yield- or Uncontrolled Vehicle Path

72

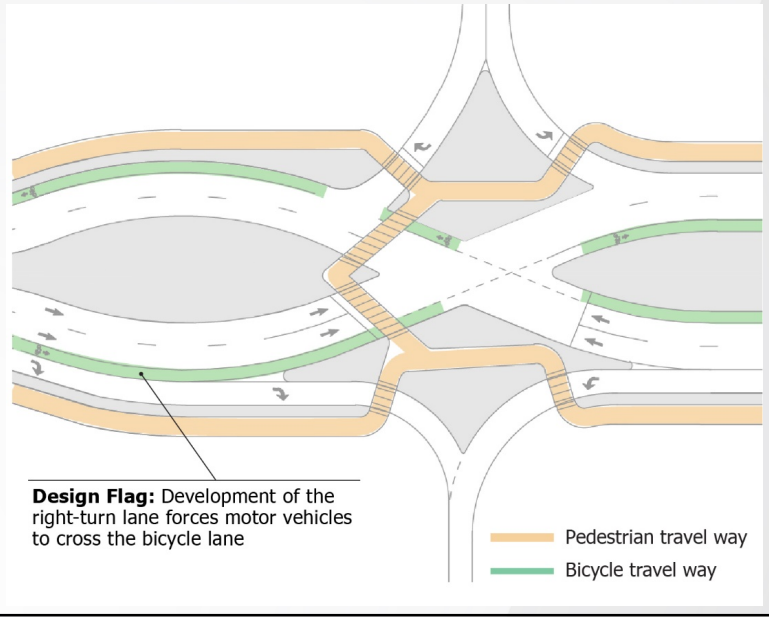
72

Design Flag 17 at Conventional Intersections

Bicyclists share space with vehicles in long channelized lanes with curb on either side.

73

Design Flag 18: Turning Motorists Crossing Bicycle Path



74

Flag *18: Turning Motorist Crossing Bicycle Path*

Applies to:

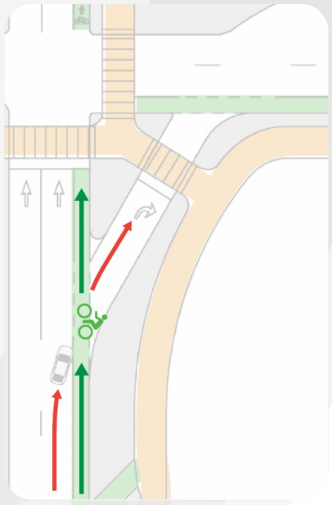
Lane changes by motor vehicles across bicycle facility

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Motor Vehicle Lane Configuration	Exclusive Turn Lane	Shared Thru & Turn Lane

Exceptions to Thresholds

Vehicles aligned directly opposite the bicycle's path are exempt from this flag.



75

75

Flag *18: Turning Motorist Crossing Bicycle Path*

Special Considerations

This flag should not be double counted with Flag 19.

Potential Mitigation Strategies

- *Providing design treatments for vehicle storage between the pedestrian crossing and vehicle merge, thereby separating driver decision points.*
- *Installing a signal to control the channelized movement.*
- *Designing channelization to manage vehicular speeds through the use of compound curves.*
- *Implementing raised crossings at the location within the channelized turn where motorist speeds are lowest.*
- *Removing channelization.*

Similar Flags

1 Motor Vehicle Right-Turn;
4 Yield- or Uncontrolled Vehicle Path;
10 Motor Vehicle Left-Turn;
16 Lane Change Across Motor Vehicle Travel Lane;
19 Riding between Travel Lanes, Lane Additions, or Lane Merges

76

76

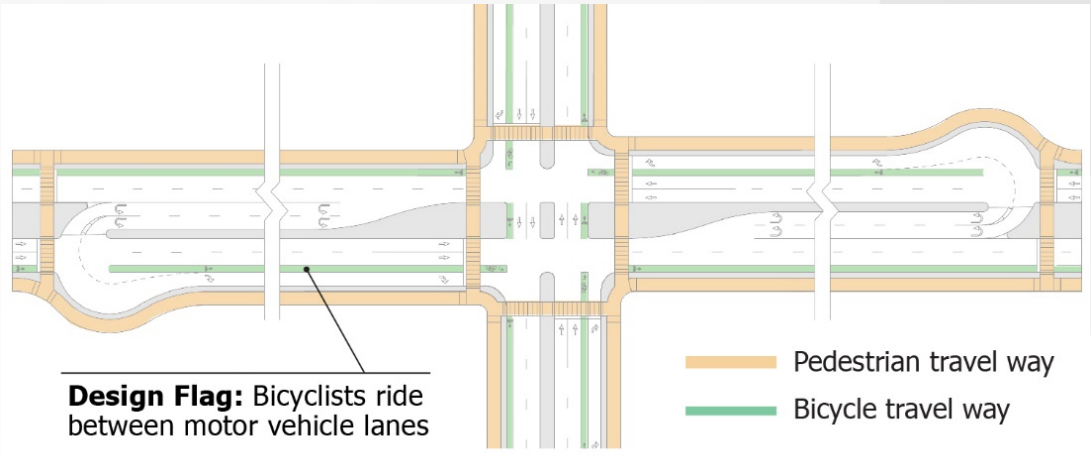
Design Flag 18 at Conventional Intersections

Right-turning vehicles crossing bicycle lane with exclusive right turn lane.

Right-turning vehicles crossing bicycle lane with shared through-right lane.

77

Design Flag 19: Riding Between Travel Lanes



78

78

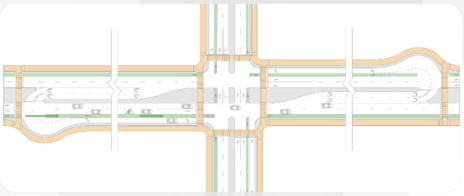
Flag *19: Riding between Travel Lanes, Lane Additions, or Lane Merges*

Applies to:

Bicycle lanes with motor vehicle lanes on both sides

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Motor Vehicle Lane Configuration	Motor vehicle lanes remain parallel or diverge	Motor vehicle lanes merge



Exceptions to Thresholds

N/A

79

79

Flag *19: Riding between Travel Lanes, Lane Additions, or Lane Merges*

Special Considerations

This flag applies regardless of the presence of striping separating two vehicular lanes (e.g. painted gore).
This flag should not be double counted with Flag 18.

Potential Mitigation Strategies

- *Replacing merge areas with stop- or yield-controlled movements.*
- *Constructing separate protected bike lanes or multiuse paths.*
- *Reducing vehicle speeds in conflict areas.*

Similar Flags

4 Yield- or Uncontrolled Vehicle Path; 18 Turning Motorist Crossing Bicycle Path

80

80

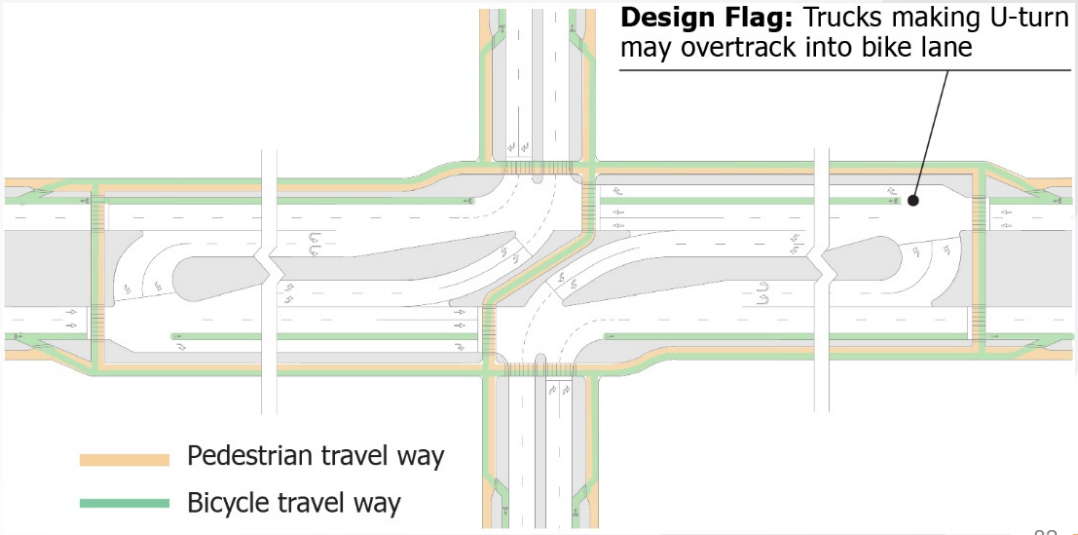
Design Flag 19 at Conventional Intersections

Westbound bicycle lane between merging motor vehicle lanes.

Eastbound bicycle lane drop as motor vehicle lane is added from the right.

81

Design Flag 20: Off-tracking Trucks in Multilane Curves



82

82

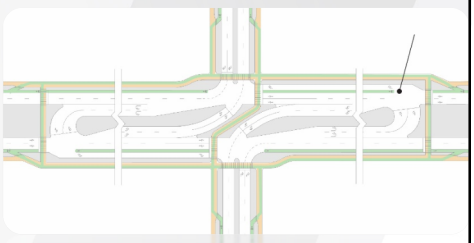
Flag *20: Off-Tracking Trucks in Multilane Curve*

Applies to:

The tendency of trucks to swing into bicycle lanes while turning

Flag Thresholds

Measure of Effectiveness	Yellow Threshold	Red Threshold
Turn Angle	Curve at 60 degrees or less	Curve at greater than 60 degrees



Exceptions to Thresholds

N/A

83

83

Flag *20: Off-Tracking Trucks in Multilane Curve*

Special Considerations

N/A

Potential Mitigation Strategies

- *Constructing separate protected bike lanes or multiuse paths.*
- *Increasing lane widths in curved areas.*
- *Using striped vane islands to separate vehicle lanes.*

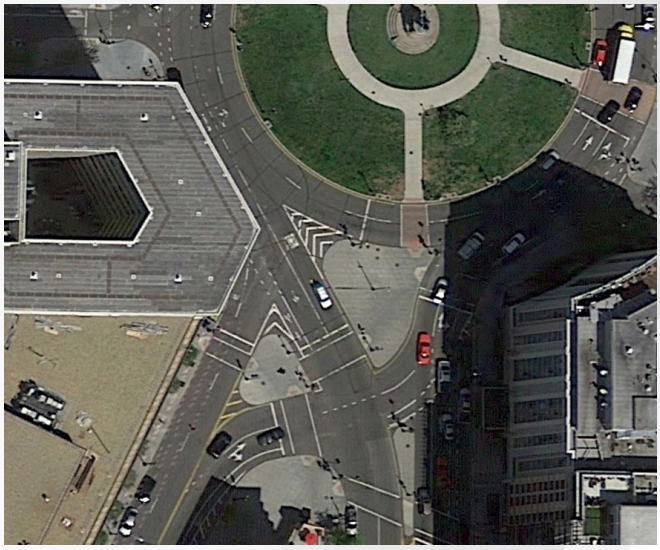
Similar Flags

N/A

84

84

Design Flag 20 at Conventional Intersection



Example application at rotary traffic circle.

85

APPENDIX E – WORKSHOP SLIDES

This appendix contains the slides for the in-person workshop. This particular set contains two additional example problems that were used in some of the classes. Future workshops can choose the example problems most relevant to local participants.

TRB

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

Module 1
Introduction and Course Overview

KITTELSON & ASSOCIATES

1

1

Course Overview

- Module 1: Introduction
  - Introductions
  - Icebreaker
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- Module 5: Pedestrian Application
- Module 6: Group Activity
- Module 7: Concluding Remarks and Questions

2

2

Agenda

Start	End	Length	Module
8:00	8:30	30 min	1. Welcome & Introductions
8:30	9:30	60 min	2. Web Training Review and A.I.I. Overview
9:30	9:45	15 min	Break
9:45	10:30	45 min	3. General Design Principles and 20-Flag Application
10:30	11:45	75 min	4. Bicycle Application – Urban Intersection
11:45	13:15	90 min	Lunch
13:15	14:30	75 min	5. Pedestrian Application – Urban Roundabout
14:30	14:45	15 min	Break
14:45	16:00	75 min	6. Group Activity – Introduce No Build Flags
16:00	16:15	15 min	Break
16:15	16:45	30 min	6. Group Activity (cont.) – Group presentations
16:45	17:00	15 min	7. Concluding Remarks and Questions

3

3

Abbreviations

- A.I.I. – Alternative Intersections and Interchanges
- ICE – Intersection Control Evaluation
- MUT – Median U-Turn
  - Also known as (aka) Michigan Left
- RCUT – Restricted Crossing U-Turn
  - aka Superstreet, Synchronized Street, Reduced Conflict Intersection, J-turn
- DLT – Displaced Left-Turn
  - aka Continuous Flow Intersection, Crossover Displaced Lefts
- DDI – Diverging Diamond Interchanges

4

4

ICEBREAKER

5

5

Icebreaker (Pick two to answer)

- Have you designed an A.I.I.?
- Have you used an A.I.I.?
  - If so, by what mode?
- What is your favorite place to walk, ride or roll?
- What do you consider as "safe" for pedestrians? For bicyclists?
- What facilities would you like to use?

6

6

7

TRB

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

Module 2
Design Flag Review and
General Design Principles

KITTELSON & ASSOCIATES

7

8

Course Overview

- Module 1: Introduction
  - Introductions
  - Icebreaker
- Module 2: Web Training Review and A.I.I. Overview
  - Questions from Web Training
  - Overview of NCHRP Report 948
  - Types of Alternative Intersections and Interchanges (A.I.I.)
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- Module 5: Pedestrian Application
- Module 6: Group Activity
- Module 7: Concluding Remarks and Questions

8

9

QUESTIONS FROM WEB TRAINING?

- What remaining questions do you have after completing the web-based training?
- What elements of the material did you find confusing?
- Are there items you disagree with or would like to discuss further?

9

10

OVERVIEW OF NCHRP RESEARCH REPORT 948

Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

10

11

This guide:

- Identifies and evaluates current practices, and emerging technologies and trends in the United States and internationally
- Describes current best practices for measuring the effectiveness of such A.I.I. treatments
- Evaluates the safety and operational outcomes of specific A.I.I. treatments
- Identifies and ranks treatments for typical types of projects

11

12

NCHRP Research Report 948
Table of Contents (1 of 2)

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NCHRP Research Report 948 Table of Contents (2 of 2)

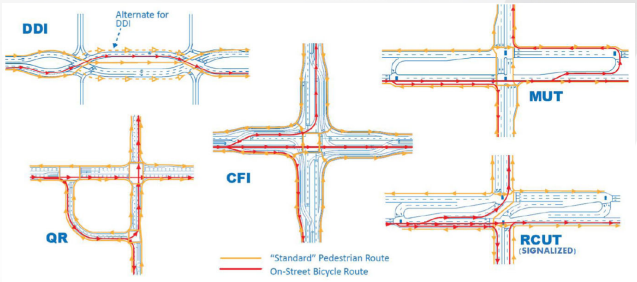
13

- **Chapter 5 Generalized Design Treatments**
  - General Segment, Intersection, & Crossing Treatments
  - Design Flag Treatments and Techniques
- **Chapter 6 Median U-Turn (MUT) Intersections**
  - Multimodal Operations & Safety and Comfort Characteristics
  - MUT Intersection-Level Concepts
  - Detailed Design Techniques
- **Chapter 7 Restricted Crossing U-Turn (RCUT) Intersections**
  - Multimodal Operations & Safety and Comfort Characteristics
  - RCUT Intersection-Level Concepts
  - Detailed Design Techniques
- **Chapter 8 Displaced Left-Turn (DLT) Intersections**
  - Multimodal Operations & Safety and Comfort Characteristics
  - DLT Intersection-Level Concepts
  - Detailed Design Techniques
- **Chapter 9 Diverging Diamond Interchanges (DDIs)**
  - Multimodal Operations & Safety and Comfort Characteristics
  - DDI Level Concepts
  - Detailed Design Techniques

13

Moving Beyond Standard Accommodations

14

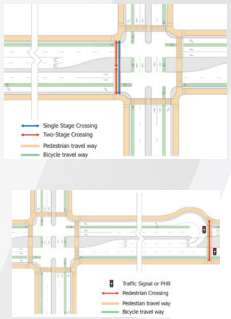


14

Multimodal Benefits of A.I.I.s

15

- Reduced conflict points
- Simplified two-phase traffic signal control
- Minimized crossing distances
- Break up long crossings
- One-directional vehicular traffic
- May feature reduced turn lanes and permissive turns
- May provide opportunities for separated paths

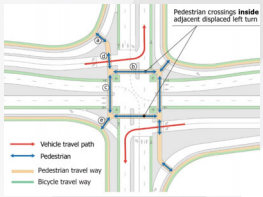


15

Multimodal Challenges of A.I.I.s

16

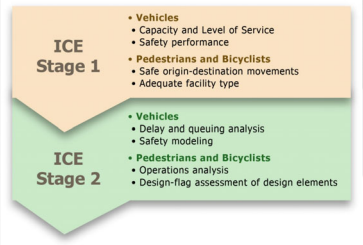
- Altered travel paths
- Channelized vehicle movements
- Traffic approaching from unexpected directions
- Unfamiliar signal phases
- Multi-stage crossings
- Uncontrolled crossing of turn lanes
- Accessibility and Wayfinding



16

Integration with ICE – Intersection Control Evaluation

17



17

Examples of A.I.I.s

18

- **MUT – Median U-Turn**
  - Also known as (aka) Michigan Left
- **RCUT – Restricted Crossing U-Turn**
  - aka Superstreet, Synchronized Street, Reduced Conflict Intersection, J-turn
- **DLT – Displaced Left-Turn**
  - aka Continuous Flow Intersection, Crossover Displaced Lefts
- **DDI – Diverging Diamond Interchanges**

18

DDI in Springfield, MO

19

DDI in Reno, NV

20

MUT Application – Birmingham, AL

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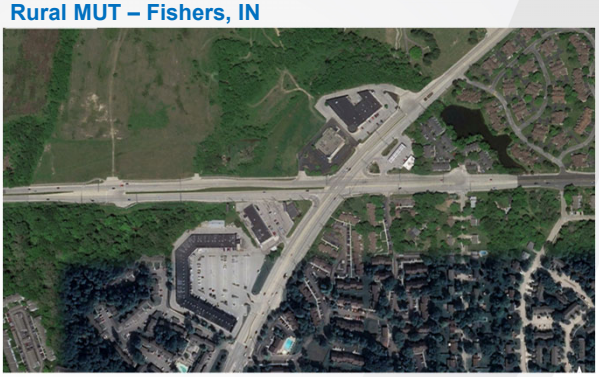
Rural MUT – Fishers, IN



22

RCUT in Leland, NC

23

RCUT in Chapel Hill, NC

24

25

DLT in Salt Lake City, UT

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26

DLT Application – Dayton, OH

26

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Questions about these Intersection Forms?

- **MUT – Median U-Turn**
  - Also known as (aka) Michigan Left
- **RCUT – Restricted Crossing U-Turn**
  - aka Superstreet, Synchronized Street, Reduced Conflict Intersection, J-turn
- **DLT – Displaced Left-Turn**
  - aka Continuous Flow Intersection, Crossover Displaced Lefts
- **DDI – Diverging Diamond Interchanges**

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SHORT BREAK

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TRB

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Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges

Module 3
Design Flag Review and General Design Principles

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Course Overview

- Module 1: Introduction
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
  - Design Principles for Pedestrian and Bicyclist Facilities
  - How to Apply Design Flag Method
- Module 4: Bicycle Application
- Module 5: Pedestrian Application
- Module 6: Group Activity
- Module 7: Concluding Remarks and Questions

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Overview of Design Principles

- **Design Principles for Pedestrian Facilities**
  - Optimize Pedestrian Routing and Delay
  - Minimize Conflicts with Motorists
  - Minimize Conflicts with Bicyclists
- **Design Principles for Bicycle Facilities**
  - Optimize Bicyclist Routing and Delay
  - Minimize Conflicts with Motorists
  - Minimize Conflicts with Pedestrians

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Optimize Pedestrian Routing and Delay (1 of 2)

- **Provide a highly visible and coherent route**
- **Consider pedestrian desire lines and reducing out-of-direction travel**
- **Minimize grade changes**
- **Minimize the use of multistage crossings**
- **Minimize pedestrian exposure to high-speed and/or high-volume traffic movements**

NCHRP 948 2.5

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Optimize Pedestrian Routing and Delay (2 of 2)

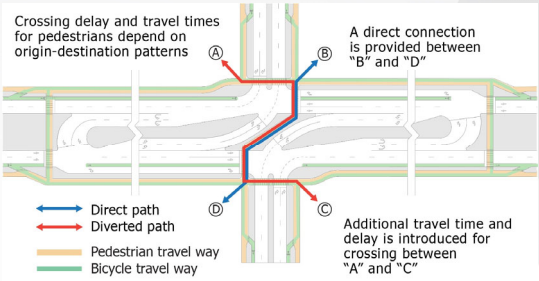

Exhibit 2-6: Pedestrian routing and delay principle

33

Minimize Conflicts with Motorists (1 of 3)

- **Maximize visibility of peds**
  - Provide crossings with clear sightlines
  - Provide crossings perpendicular to conflicting motorists
  - Provide adequate lighting at crossings
- **Reduce vehicle speeds**
  - Limit speeds to 20 mph or less at pedestrian/vehicle conflict points
  - Avoid high-speed merge lanes and free-flow traffic movements
  - Minimize corner radii
  - Use traffic calming measures

NCHRP 948 2.5

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Minimize Conflicts with Motorists (2 of 3)

- **Minimize the severity of conflicts**
  - Separate movements in time using traffic controls
  - Separate movements in space using geometry
  - Minimize exposure to conflicts with motorists by providing short crossing distances
  - Minimize vehicular speeds at conflicts
- **Provide adequate signal timing for pedestrians to clear crossings**

NCHRP 948 2.5

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Minimize Conflicts with Motorists (3 of 3)

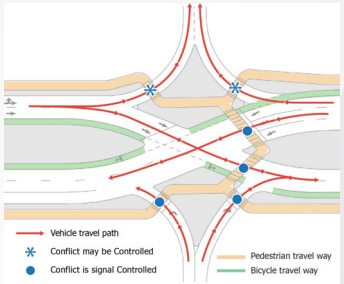

Exhibit 2-7: Minimize conflicts with motor vehicles principle

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Design Principles for Pedestrian Facilities 37

Minimize Conflicts with Bicyclists (1 of 2)

- Maximize visibility between bicyclists and pedestrians
- Provide separated bike lanes at locations with higher volumes of bicyclists or pedestrians where bicyclists are likely to operate on a sidewalk
- Separate bicyclists and pedestrians at crossings
- Ensure shared-use paths are wide enough to service anticipated volumes while minimizing conflicts
- Provide wide curb ramps that match the full width of shared-use paths

NCHRP 948 2.5

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Design Principles for Pedestrian Facilities 38

Minimize Conflicts with Bicyclists (2 of 2)

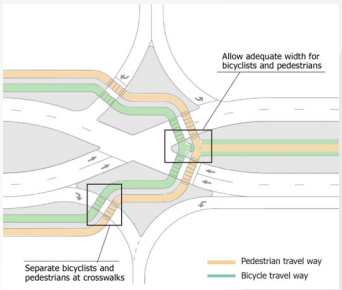

Exhibit 2-8: Minimize conflicts with bicyclists principle

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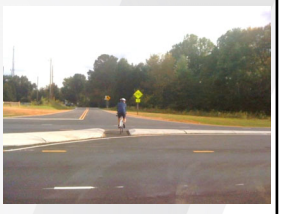
Design Principles for Bicycle Facilities 39

Optimize Bicyclist Routing and Delay (1 of 2)

- Provide a highly visible and coherent route
- Provide lane line extensions to guide bicyclists through wide intersections
- Consider bicycle desire lines and reduce out-of-direction travel
- Minimize grade changes
- Minimize the use of multistage crossings
- Minimize bicyclist exposure to high-speed and/or free-flowing traffic movements



NCHRP 948 3.4

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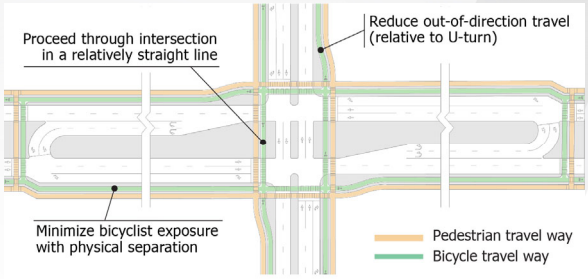
Design Principles for Bicycle Facilities 40

Optimize Bicyclist Routing and Delay (2 of 2)



NCHRP 948 3.4

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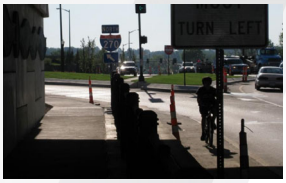
Design Principles for Bicycle Facilities 41

Minimize Conflicts with Motorists (1 of 3)

- Maximize visibility between bicyclists and motorists
  - Provide bicycle crossings that are as perpendicular to conflicting motorists
  - Provide bicycle crossings where there are clear sightlines and adequate sight distance
  - Provide adequate lighting at crossings
- Maintain separated bicycle facilities or transition bicyclists to off-street facilities near high-speed and/or high-volume conflict areas



NCHRP 948 3.4

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Design Principles for Bicycle Facilities 42

Minimize Conflicts with Motorists (2 of 3)

- Reduce motor vehicle speeds in conflict areas
  - Limit speeds at crossings
  - Minimize conflicts with high-speed merging lanes and/or high-volume traffic movements
  - Use geometry to slow speeds
  - Use traffic calming measures
- Minimize the severity of conflicts where they cannot be eliminated
  - Separate movements using traffic controls and geometric separation
  - Provide short crossing distances and physically separated bikeways
  - Avoid designs that require bicyclists to merge across multiple lanes of traffic
  - Minimize speed differential at conflict points
- Provide adequate signal timing for bicyclists

NCHRP 948 3.4

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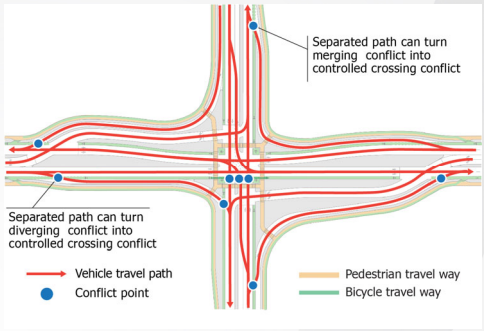
Minimize Conflicts with Motorists (3 of 3)



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Minimize Conflicts with Pedestrians (1 of 2)

- Maximize visibility between bicyclists and pedestrians
- Separate bicyclists and pedestrians at crossings
- Provide adequate width for safe passing by bicyclists and pedestrians
- Provide curb ramps that match the full width of shared-use path

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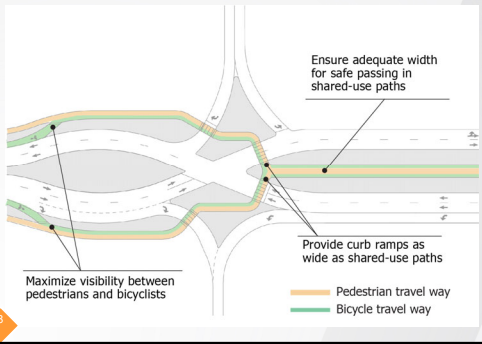
Minimize Conflicts with Pedestrians (2 of 2)



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The Design Flags ("Twenty-Flags") Method

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

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Yellow Flags 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.

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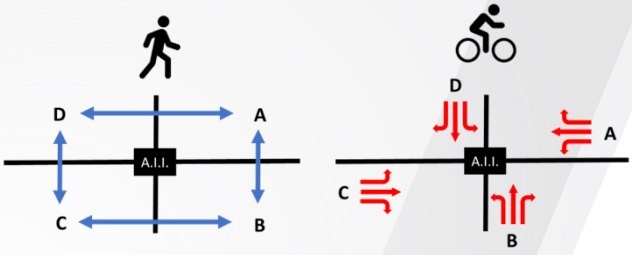
Conducting the Assessment



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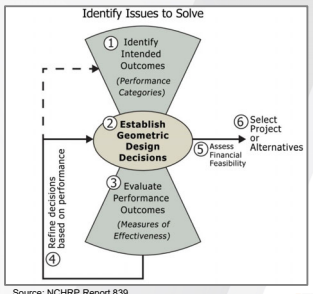
When to Use the Design Flags Method

Design Flags Method is intended to be used:

- During Alternatives Analysis
  - Intersection Control Evaluation (ICE) process
- From Preliminary through Final Design



Source: NCHRP Report 839

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Basic Steps for Applying Method

- Step 0: Obtain design drawing and/or aerial of intersection and each alternative to evaluate
- Step 1: Assign pedestrian paths and bicycle movements; Document assumptions
- Step 2: Evaluate flags for existing conditions
- Step 3: Evaluate flags for alternative configuration(s)
- Step 4: Compare results
- Step 5: Update design
- Step 6: Re-evaluate flags

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Design Flag Treatments and Techniques

1. Motor Vehicle Right-Turns
2. Uncomfortable/Tight Walking Environment
3. Nonintuitive Motor Vehicle Movements
4. Crossing Yield-Controlled or Uncontrolled Vehicle Paths
5. Indirect Paths
6. Executing Unusual Movements
7. Multilane Crossings
8. Long Red Times
9. Undefined Crossings at Intersections
10. Motor Vehicle Left Turns

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Design Flag Treatments and Techniques

11. Intersecting Driveways and Side Streets
12. Sight Distance for Gap Acceptance Movements
13. Grade Change
14. Riding in Mixed Traffic
15. Bicycle Clearance Times
16. Lane Change Across Motor Vehicle Travel Lanes
17. Channelized Lanes
18. Turning Motorists Crossing Bicycle Path
19. Riding Between Travel Lanes, Lane Additions, or Lane Merges
20. Off-Tracking Trucks in Multilane Curves

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Design Flag #1 – Motor Vehicle Right Turns

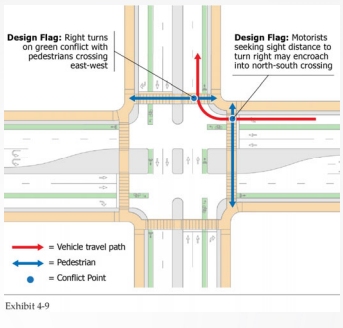

Exhibit 4-9

Design techniques and treatments can include:

- Providing a stop bar before the marked pedestrian crossing.
- Providing adequate sight distance at the intersection from the stop bar.
- Including space for queue storage for a vehicle to queue in-between the crossing and conflicting traffic flow, when waiting to turn right on red.
- Restricting right-turns-on-red.
- Timing with Leading Pedestrian Interval.
- Reduce turning speed

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Design Flag 1 at Conventional Intersections


Vehicles permitted to turn right across marked crosswalks.


Intersection with channelized turn lanes.

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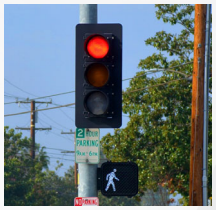
Design Flag #1: Potential Treatments

Right-Turn-on-Red Restriction



Leading Pedestrian Interval

Separating Driver Decisions & Reducing Speed

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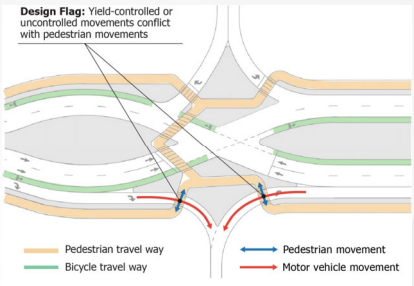
Design Flag #4 – Crossing Yield-Controlled or Uncontrolled Vehicle Paths



Design techniques and treatments can include:
- Providing signalized crossings.
- Providing stop-controlled crossings.
- Reducing vehicle speed through curvatures.
- Installing raised crosswalks to reduce vehicle speed.

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Design Flag 4 at Conventional Intersection

Yield controlled channelized turn lanes.

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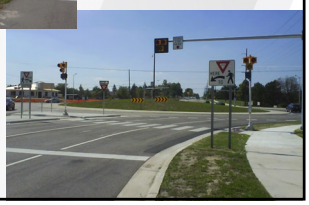
Design Flag #4: Potential Treatments

Raised Crosswalk

Rectangular Rapid-Flashing Beacon

Pedestrian Hybrid Beacon



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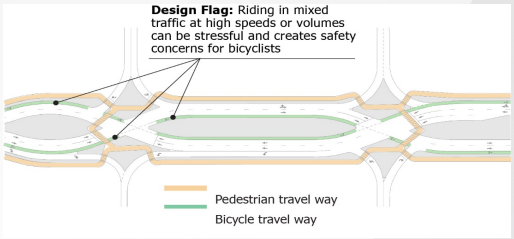
Design Flag #14 – Riding in Mixed Traffic



Design techniques and treatments can include:
- Separating bicyclists from motor vehicles through dedicated protected lanes.
- Designing for lower motor vehicle speeds where bicyclists and motorists interact.

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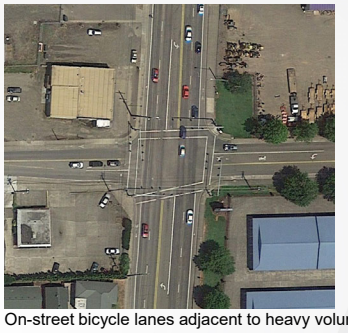
Design Flag 14 at Conventional Intersection



On-street bicycle lanes adjacent to heavy volume roadway.

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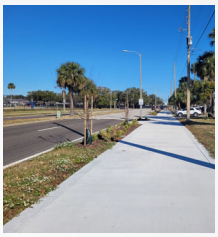
Design Flag #14: Potential Treatments

Separated Bike Lane



Shared-Use Path

Reduced Speed Environment

61

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Design Flag #16: Lane Change Across Motor Vehicle Travel Lane

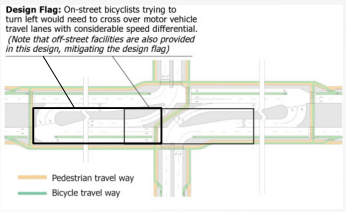

Exhibit 4-61: Design Flag 16 – Lane Change Across Motor Vehicle Travel Lane(s)

Design techniques and treatments can include:

- Using ramps to sidewalks or shared-use paths and cross in a crosswalk.
- Using a two-stage bicycle left-turn queue box with adequate room to maneuver and wait.
- At RCUTs, designing for bicyclists to make a through movement with a channelized direct bicycle crossing.
- Clearly marking the entry to the crossover area.
- Designing for low motorist speeds (below 20 mph) through a crossover area

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Design Flag 16 at Conventional Intersection

Bicycle path departing bike lane and crossing vehicle lane for left turn downstream.

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Design Flag #16: Potential Treatments

Two-Stage Left Turn Box at Intersection

Ramp to move cyclists to sidewalk level before intersection

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Module 4
Bicycle Application

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Course Overview

- Module 1: Introduction
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- Module 3: Design Principles and Design Flag Application
- **Module 4: Bicycle Application**
  - Case Study Introduction
  - Class Activity
- **Module 5: Pedestrian Application**
- **Module 6: Group Activity**
- **Module 7: Concluding Remarks and Questions**

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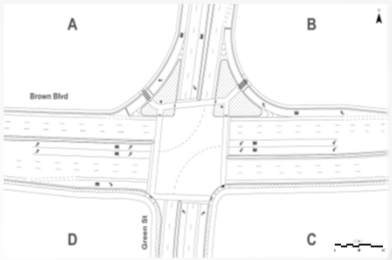
Case Study A – Conventional Signal

- *Class exercise: Bicycle Assessment*



Signalized Intersection

- Major Street AADT: 40,000
- Minor Street AADT: 10,000
  - D-factor: 0.55
  - K-factor: 0.10
  - 20% right turns
  - 10% left turns
- E-W Speed Limit 45 mph
- N-S Street Speed Limit 35 mph

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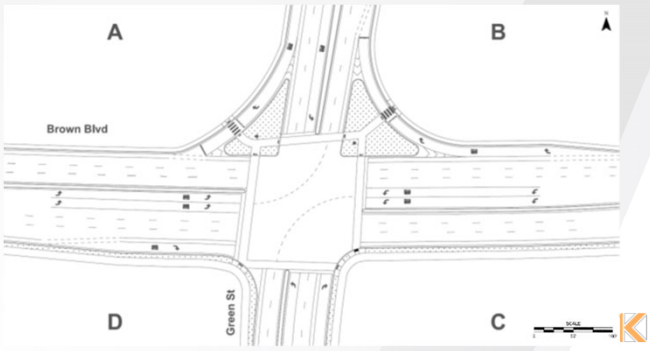
Case Study A - Signal



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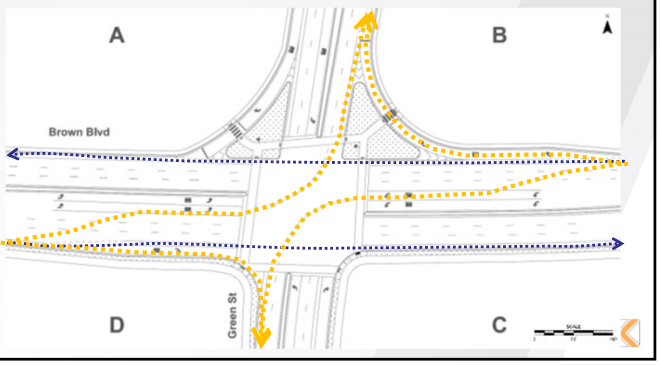
Document Assumed Bike Paths – East-West



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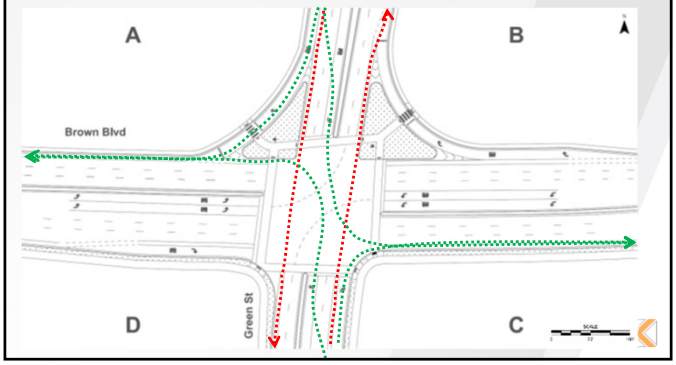
Document Assumed Bike Paths – North-South



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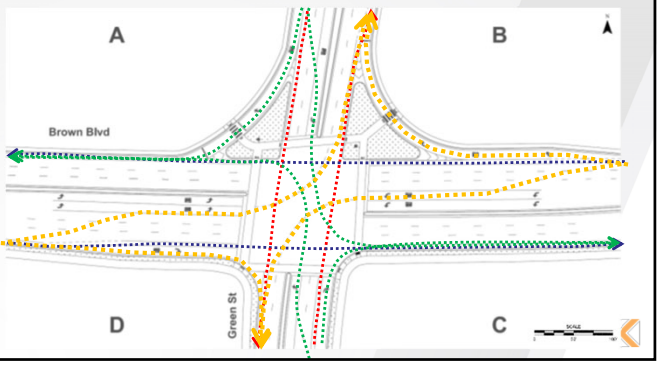
Document Assumed Bike Paths - All



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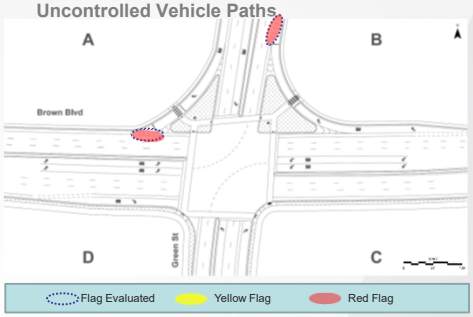
Case Study

- *Design Flag #4: Cyclists* Crossing Yield-Controlled or Uncontrolled Vehicle Paths



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

Cyclists cross yield-controlled right turns in two locations

→ Red Flag for NBT, WBT, EBL, and NBL cycling movements

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Case Study

- *Design Flag #5:* Indirect Paths

Flag Thresholds

- Yellow
  90' (ped)
  450' (bike)
- Red
  135' (ped)
  675' (bike)

Outcome

All cyclist paths are direct with no out of direction travel → No Flags

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Case Study

- *Design Flag #6:* Executing Unusual Movements

Flag Thresholds

- Yellow
  Path does not match expectation
- Red
  N/A

Outcome

All movements follow standard traffic conventions.

→ No Flags apply

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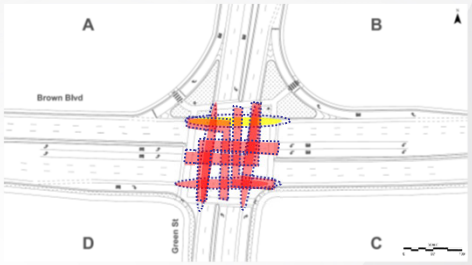
Case Study

- *Design Flag #7:* Multilane Crossing



Flag Thresholds

- Yellow
  2-3 lanes (ped)
  4-5 lanes (bike)
- Red
  >3 lanes (ped)
  >5 lanes (bike)

Outcome

N-S movements cross 8 lanes, E-W movements cross 4-6 lanes.

→ Yellow Flag for WBT
→ Red Flag for NBT, SBT, EBT, NBL, SBL, EBL, WBL

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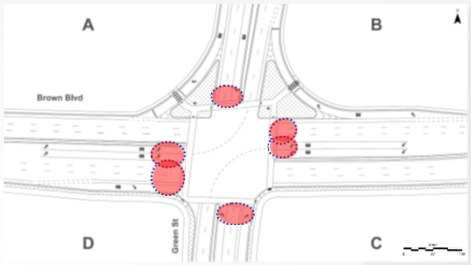
Case Study

- *Design Flag #8:* Long Red Times



Flag Thresholds

- Yellow
  30 seconds
- Red
  45 seconds

Outcome

Expect long cycle length given complex vehicle phasing. Red times likely over 60 seconds for N-S left and throughs and over 45 seconds for E-W.
→ Red Flag for WBL, WBT, EBL, EBT, NBT, NBL, SBT, SBL

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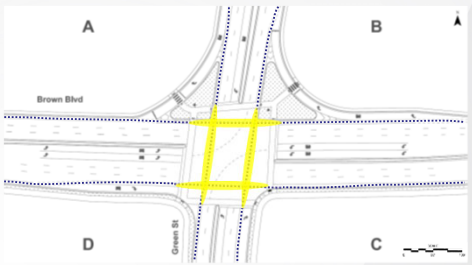
Case Study

- *Design Flag #9:* Undefined Crossings at Intersections



Flag Thresholds

- Yellow
  Unmarked crossing
- Red
  N/A

Outcome

Bike lanes are not carried through the intersection on E/W or N/S approaches

→ Yellow Flag for EBT, WBT, NBT, SBT

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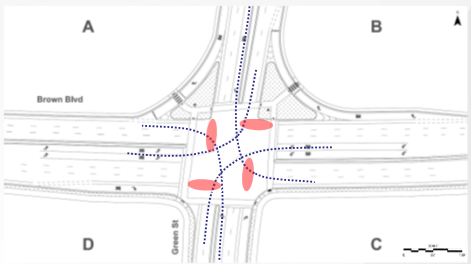
Case Study

- *Design Flag #10:* Motor Vehicle Left Turns



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

Left turn speeds and volumes high enough to trigger Red Flag. Conflicts mitigated if left turns are signalized and protected only.
→ Red Flag for NBT, SBT, EBT, WBT

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Case Study

- *Design Flag #11:* Intersecting Driveways and Side Streets

Flag Thresholds

- Yellow
  1-2 (peds)
  1-2 (one-way bikes)
- Red
  >2 (peds)
  >2 (one-way bikes)
  >0 (two-way bikes)

Outcome

No driveways in vicinity of intersection

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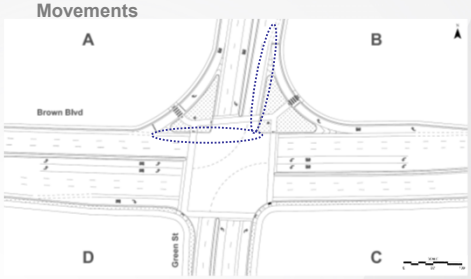
Case Study

- *Design Flag #12:* Sight Distance for Gap Acceptance Movements



Flag Thresholds

- Yellow
  N/A
- Red
  Less than required for vehicle speed

Outcome

Downstream ends of channelized lanes are gap-acceptance-based. Sight distance appears sufficient.
→ No Flags

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Case Study

- *Design Flag #13: Grade Change*

Flag Thresholds

- Yellow
  ±3-5%
- Red
  >±5%

Outcome

Assuming the ground is level, no Flags apply

82

Case Study

- *Design Flag #14: Riding in Mixed Traffic*

Flag Thresholds

- Yellow
  25-35 mph OR
  3,000 – 7,000 vpd
- Red
  >35 mph OR
  >7,000 vpd

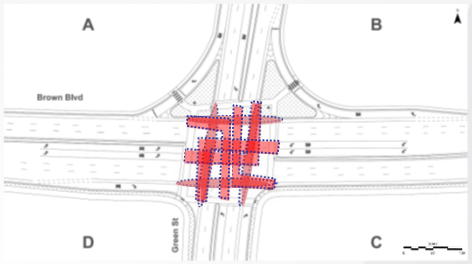
Outcome

Bike lane along both major and minor streets thus only red flag need be assessed: Red Flag because speed is over 35 mph and high AADT.
→ 12 red flags (all movements)

83

Case Study

- *Design Flag #15: Bicycle Clearance Times*



Flag Thresholds

- Yellow
  <=35 mph and 36-72 ft
  OR
  >35 mph and 24-60 ft
- Red
  <=35 mph and >=72 ft
  OR
  >35 mph and >=60 ft

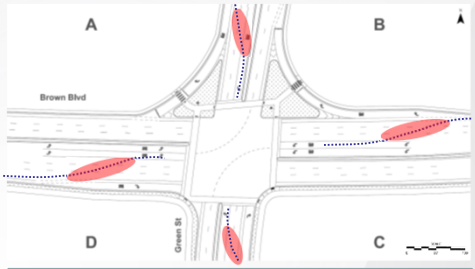
Outcome

Vehicle Speeds over 35 mi/h. E/W distance ~ 70'. N/S distance ~ 90'
→ Red Flag for EBT, WBT, NBT, SBT, EBL, WBL, NBL, SBL

84

Case Study

- *Design Flag #16: Lane Change Across Motor Vehicle Travel Lane*



Flag Thresholds

- Yellow
  25-35 mph OR
  3,000 – 7,000 vpd
- Red
  >35 mph OR
  >7,000 vpd

Outcome

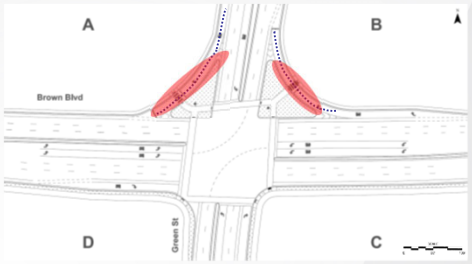
All left turns have to change across two or more vehicular travel lanes at speeds > 35 mi/h

→ Red Flag for EBL, WBL, NBL, SBL

85

Case Study

- *Design Flag #17: Channelized Lane*



Flag Thresholds

- Yellow
  25-35 mph AND
  <= 50 ft
- Red
  >35 mph OR
  >50 ft

Outcome

Channelized Right Turns on East and North approaches longer than 50'
→ Red Flags for SBR and WBR

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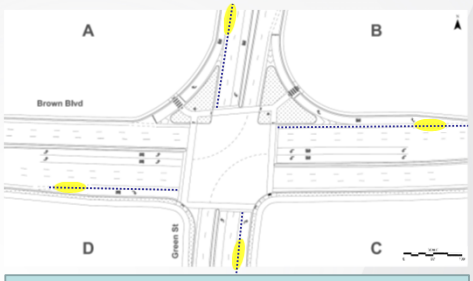
Case Study

- *Design Flag #18: Turning Motorists Crossing Bicycle Path*



Flag Thresholds

- Yellow
  Exclusive Turn Lane
- Red
  Shared Thru & Turn Lane

Outcome

All right turns have exclusive lane, resulting in lane change at higher speed differential (avoiding right hook conflict)
→ Yellow flag for WBT, EBT, NBT, SBT

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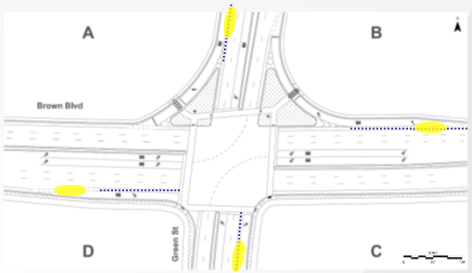
Case Study

- *Design Flag #19: Riding between Travel Lanes*



Flag Thresholds

- Yellow
  Motor vehicle lanes remain parallel or diverge
- Red
  Motor vehicle lanes merge

Outcome

Cyclists ride between travel lanes on all four approaches, but lanes remain parallel.
→ Yellow Flag for NBT, SBT, EBT, WBT

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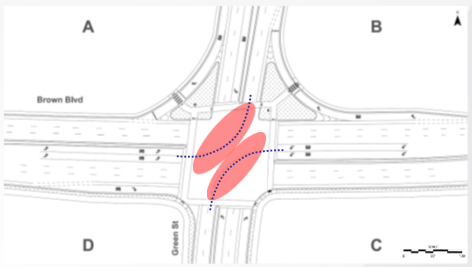
Case Study

- *Design Flag #20: Off-Tracking Trucks in Multilane Curves*



Flag Thresholds

- Yellow
  Curve at 60 degrees or less
- Red
  Curve at greater than 60 degrees

Outcome

East/West left turns are multilane with 90-degree turn
→ Red Flags for EBL and WBL

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Design Flag Assessment Summary (1 of 2)

Flag #	Flag	Bicycle Assessment											
		NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
1	Motor Vehicle Right Turn												
2	Uncomfortable/ Tight Walking Environment												
3	Non-Intuitive Motor Vehicle Movement												
4	Crossing Yield or Uncontrolled Vehicle Paths	Red	Red					Red				Red	
5	Indirect Paths												
6	Executing Unusual Movements												
7	Multilane Crossing	Red	Red		Red	Red		Red	Red		Red	Yellow	
8	Long Red Times	Red	Red		Red	Red		Red	Red		Red	Red	
9	Undefined Crossing at Intersections		Yellow			Yellow			Yellow			Yellow	
10	Motor Vehicle Left Turn		Red			Red			Red			Red	
11	Intersecting Driveways and Side Streets												
12	Sight Distance for Gap Acceptance												
13	Grade Change												
14	Riding in Mixed Traffic	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
15	Bicycle Clearance Times	Red	Red		Red	Red		Red	Red		Red	Red	
16	Lane Change Across Motor Vehicle Lanes	Red			Red			Red			Red		
17	Channelized Lanes						Red						Red
18	Turning Motorists Crossing Bicycle Path		Yellow			Yellow			Yellow			Yellow	
19	Riding Between Travel Lanes		Yellow			Yellow			Yellow			Yellow	
20	Off-Tracking Trucks in Multi-Lane Curves							Red			Red		
	Total Yellow Flags Movement	0	3	0	0	3	0	0	3	0	0	4	0
	Total Red Flags by Movement	6	6	1	5	5	2	7	5	1	6	5	2

	All	Pedestrian	Bicycle
Total Yellow Flags:	13	0	13
Total Red Flags:	51	0	51
Total No Flags:	0	0	0
Total N/A:	0	0	0
Total Possible:	256	52	204
Percent Yellow:	5%	0%	6%
Percent Red:	20%	0%	25%
Percent Not Flagged:	75%	100%	69%

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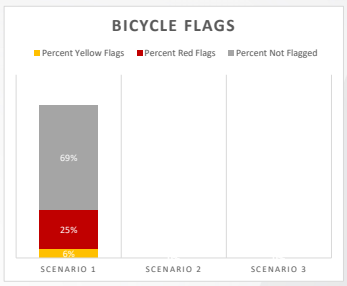
Design Flag Assessment Summary (2 of 2)



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Module 5
Pedestrian Application

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Course Overview

- Module 1: Introduction
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- **Module 5: Pedestrian Application**
  - Case Study Introduction
  - Class Activity
- Module 6: Group Activity
- Module 7: Concluding Remarks and Questions

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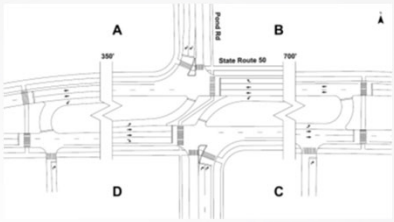
Case Study B - RCUT

- *Class exercise: Bicycle Assessment*



Signalized RCUT

- Major Street AADT: 50,000
- Minor Street AADT: 10,000
  - D-factor: 0.55
  - K-factor: 0.10
  - 20% right turns
  - 10% left turns
- Major Street Speed Limit 45 mph
- Minor Street Speed Limit 35 mph

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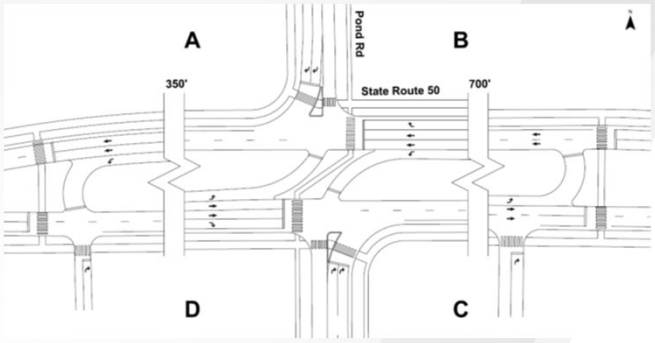
Case Study B - RCUT



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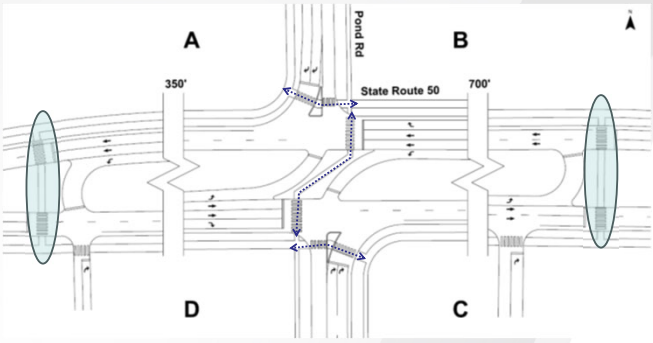
Document Assumed Pedestrian Paths



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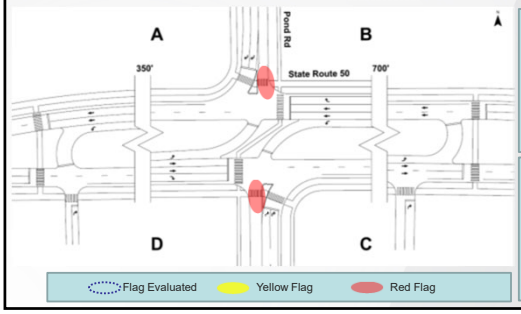
Case Study

- *Design Flag #1: Motor Vehicle Right Turns*



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome
No flag for signalized right turns

Heavy right turns onto side street result in red flag and impact all movements: A-B, B-C, C-D, and D-A

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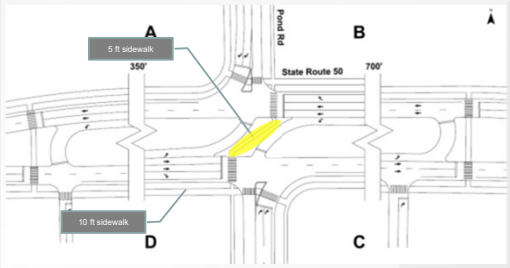
Case Study

- *Design Flag #2: Uncomfortable/Tight Walking Environment*



Flag Thresholds

- Yellow
  - < 5 ft if traffic present on one side; <10 ft if traffic present on two sides
- Red
  - N/A

Outcome

Center-island walkway is narrow for traffic on both sides

Yellow Flag for A-D and B-C movements

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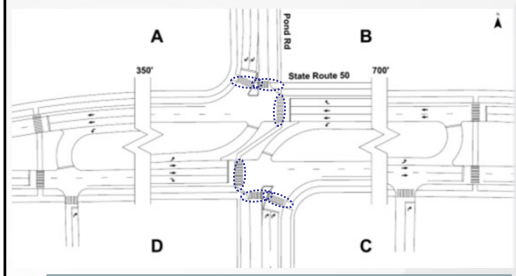
Case Study

- *Design Flag #3: Nonintuitive Motor Vehicle Movements*



Flag Thresholds

- Yellow
  - Vehicle decelerating
- Red
  - Vehicle accelerating or free-flowing

Outcome

All the vehicle movements are intuitive, so no Flags apply

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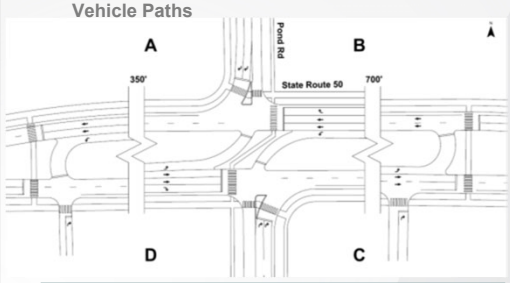
Case Study

- *Design Flag #4:* Crossing Yield-Controlled or Uncontrolled Vehicle Paths



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

All Crossings signalized (or already addressed in Flag 1) → No Flags

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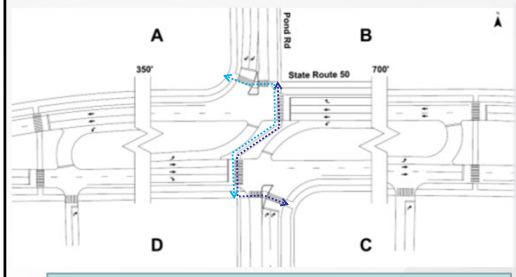
Case Study

- *Design Flag #5:* Indirect Paths



Flag Thresholds

- Yellow
  - 90 ft (ped)
  - 450 ft (bike)
- Red
  - 135 ft (ped)
  - 675 ft (bike)

Outcome

Out of direction travel due to middle Z-Crossing (~80')

Yellow Flag for B-C and A-D connections (West and East Crossing)

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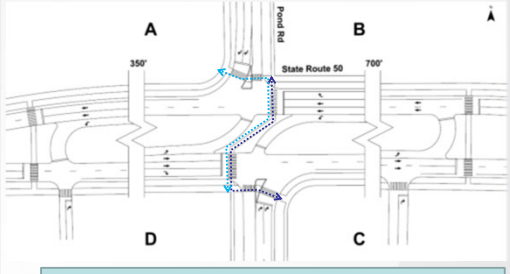
Case Study

- *Design Flag #6:* Executing Unusual Movements



Flag Thresholds

- Yellow
  - Path does not match expectation
- Red
  - N/A

Outcome

Z-Crossing is unusual

Yellow Flag for A-D and B-C connections (West and East Crossing)

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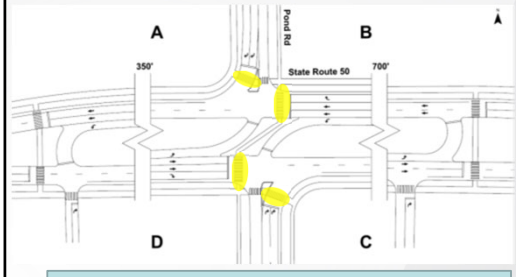
Case Study

- *Design Flag #7:* Multilane Crossing

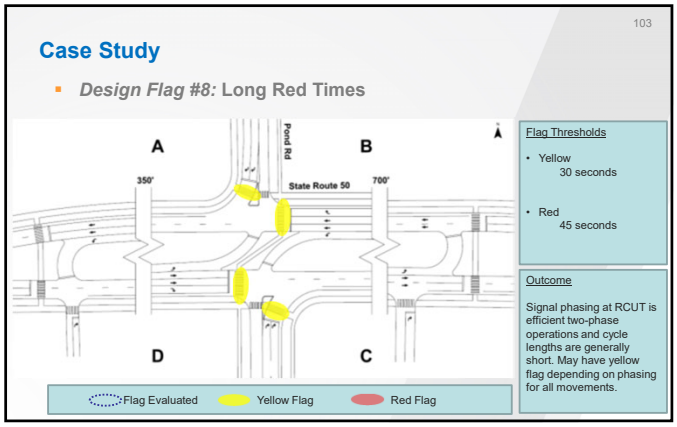


Flag Thresholds

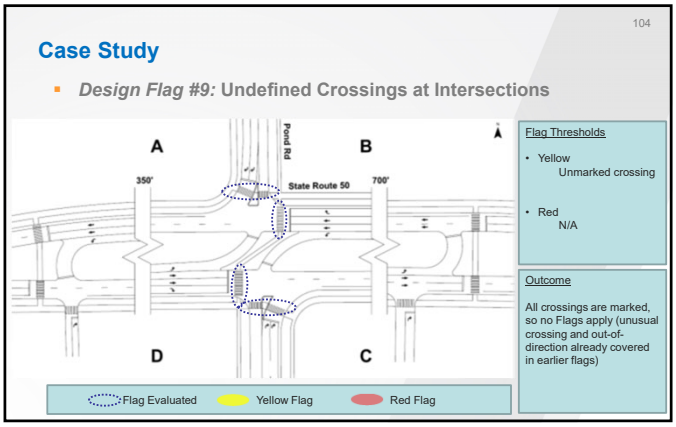
- Yellow
  - 2-3 lanes (ped)
  - 4-5 lanes (bike)
- Red
  - >3 lanes (ped)
  - >5 lanes (bike)

Outcome

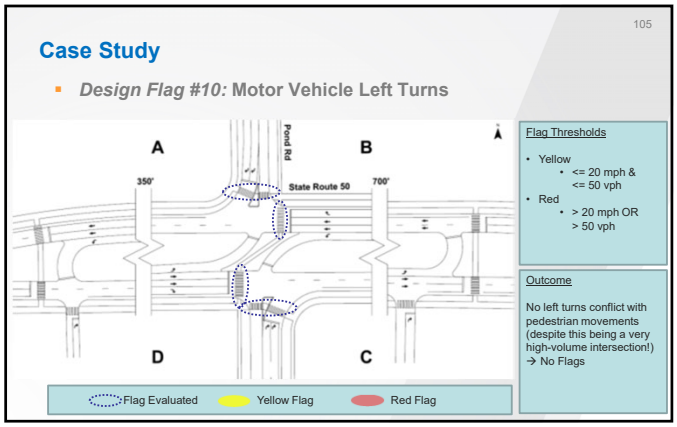
Several 2-lane and 3-lane crossings. All four movements are impacts → Yellow Flags



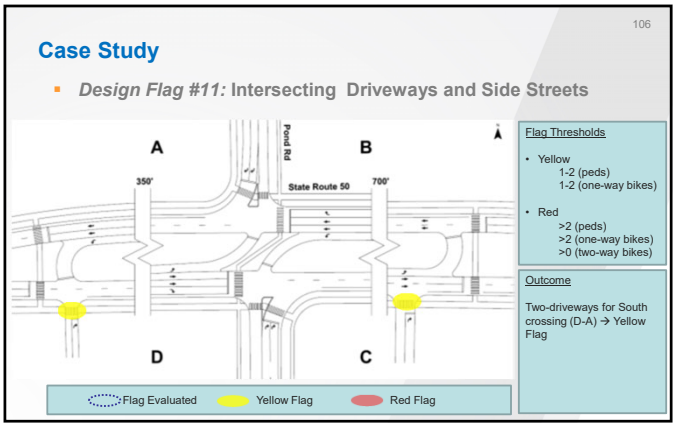
103



104



105



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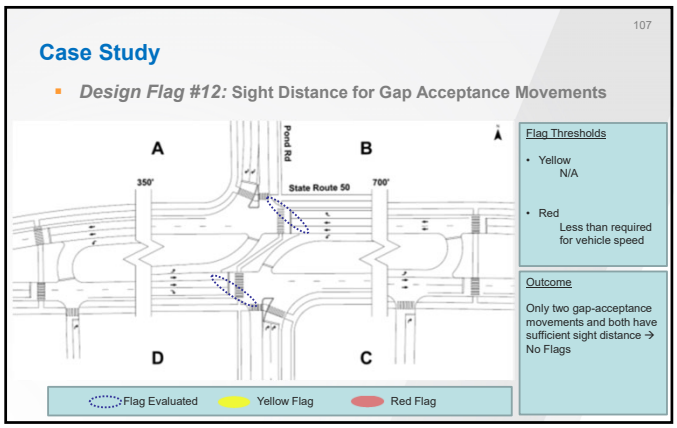
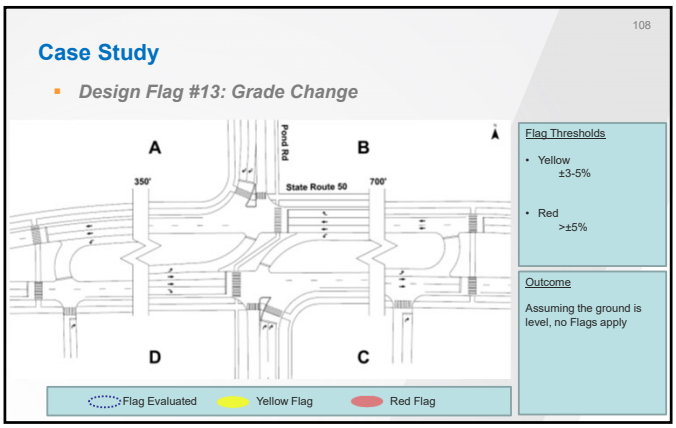


107



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Design Flag Assessment Summary (1 of 2)

		Pedestrian Assessment			
Flag #	Flag	West	East	North	South
1	Motor Vehicle Right Turn	Red	Red	Red	Red
2	Uncomfortable/ Tight Walking Environment	Yellow	Yellow		
3	Non-Intuitive Motor Vehicle Movement				
4	Crossing Yield or Uncontrolled Vehicle Paths				
5	Indirect Paths	Yellow	Yellow		
6	Executing Unusual Movements	Yellow	Yellow		
7	Multilane Crossing	Yellow	Yellow	Yellow	Yellow
8	Long Red Times	Yellow	Yellow	Yellow	Yellow
9	Undefined Crossing at Intersections				
10	Motor Vehicle Left Turn				
11	Intersecting Driveways and Side Streets			Yellow	
12	Sight Distance for Gap Acceptance				
13	Grade Change				
14	Riding in Mixed Traffic				
15	Bicycle Clearance Times				
16	Lane Change Across Motor Vehicle Lanes				
17	Channelized Lanes				
18	Turning Motorists Crossing Bicycle Path				
19	Riding Between Travel Lanes				
20	Off-Tracking Trucks in Multi-Lane Curves				
	Total Yellow Flags Movement	5	5	3	2
	Total Red Flags by Movement	1	1	1	1

	Pedestrian
Total Yellow Flags:	15
Total Red Flags:	4
Total No Flags:	0
Total N/A:	0
Total Possible:	52
Percent Yellow:	29%
Percent Red:	8%
Percent Not Flagged:	63%

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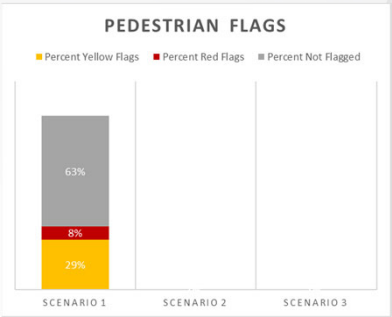
Design Flag Assessment Summary (2 of 2)



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Module 5
Group Activity

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Course Overview

- Module 1: Introduction
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- Module 5: Pedestrian Application
- **Module 6: Group Activity**
  - Local Case Study
    - **Review of No-Build**
    - **Alternatives Development**
  - Group Work Session and Presentation
- **Module 7: Concluding Remarks and Questions**

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Group Activity

- **Split into groups of 4 or 5 people**
- **Each group is given an existing intersection**
- **Identify Existing Design Flags**
- **Sketch "Build" Intersection Form**
  - Pedestrian Facilities
  - Bicycle Facilities
- **Identify Remaining Flags**
- **Modify Design**
- **Group Presentation** (*6 minutes each*)

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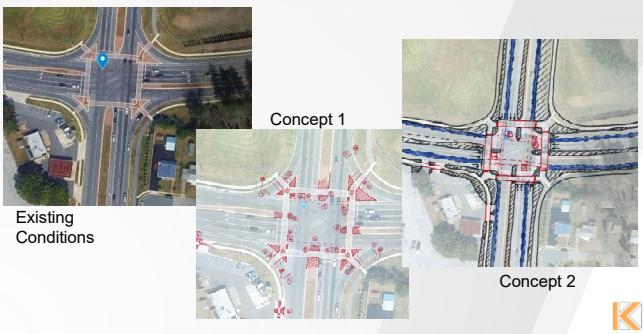
Example application (Wilmington, DE)



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Begin Group Activity

- 60-minute Group Activity
- 15-minute Break
- 30-minute Group Presentations (6 min each)

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Module 6
Concluding Remarks and Questions

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Course Overview

- Module 1: Introduction
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- Module 5: Pedestrian Application
- Module 6: Group Activity
- **Module 7: Concluding Remarks and Questions**
  - Key Take Aways
  - Questions
  - *Thank you!*

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Key Messages

- **Follow guiding principles**
- **Encourage iteration**
- **Think about pedestrian and bicycle elements early and often**

1	2	3	4
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

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QUESTIONS?

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Thank you!

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Pete Jenior: pjenior@kittelson.com
Mike Alston: malston@kittelson.com

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SUPPLEMENTAL SLIDES

The following slides with a roundabout pedestrian flag example were used in some trainings instead of the RCUT pedestrian example

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Module 5
Pedestrian Application

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Course Overview

- Module 1: Introduction
- Module 2: Web Training Review and A.I.I. Overview
- Module 3: Design Principles and Design Flag Application
- Module 4: Bicycle Application
- **Module 5: Pedestrian Application**
  - Case Study Introduction
  - Class Activity
- **Module 6: Group Activity**
- **Module 7: Concluding Remarks and Questions**

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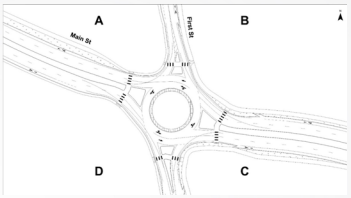
Case Study B - Roundabout

- ***Class exercise: Pedestrian Assessment***



Multilane Roundabout

- Major Street AADT: 30,000
- Minor Street AADT: 8,000
  - D-factor: 0.55
  - K-factor: 0.10
  - 25% right turns
  - 15% left turns
- Major Street Speed Limit 35 mph
- Minor Street Speed Limit 25 mph

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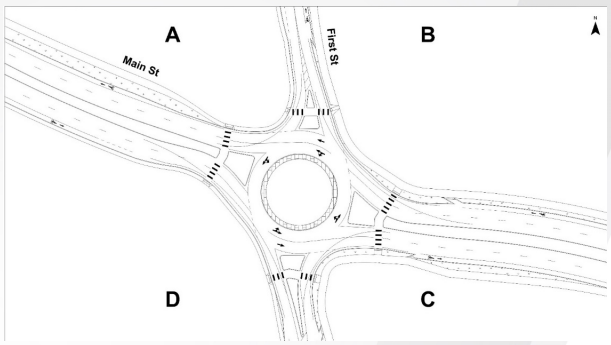
Case Study B - Roundabout



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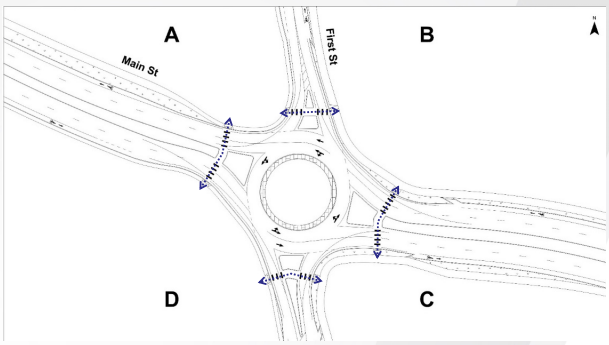
Assumed Pedestrian Paths



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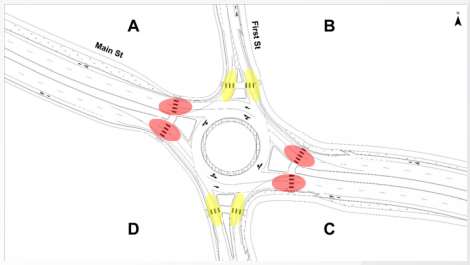
Case Study

- *Design Flag #1: Motor Vehicle Right Turns*



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

A-D and B-C movements have Red Flags, because fastest path speeds are greater than 20 mph.

A-B and D-C are yellow due to lower speed and volumes

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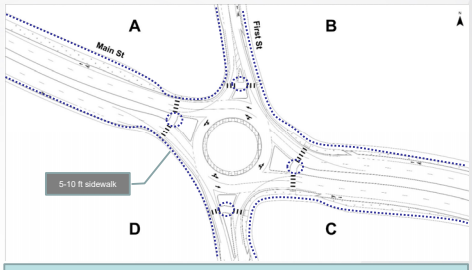
Case Study

- *Design Flag #2: Uncomfortable/Tight Walking Environment*



Flag Thresholds

- Yellow
  - < 5 ft if traffic present on one side; <10 ft if traffic present on two sides
- Red
  - N/A

Outcome

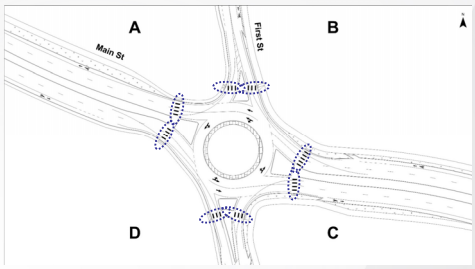
All sidewalks are at least 5 ft wide, and all center island cut-throughs are wide-enough, so no Flags apply

128

129

Case Study

- *Design Flag #3: Nonintuitive Motor Vehicle Movements*



Flag Thresholds

- Yellow
  - Vehicle decelerating
- Red
  - Vehicle accelerating or free-flowing

Outcome

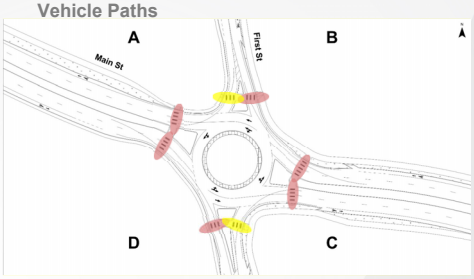
All the vehicle movements are intuitive, so no Flags apply

129

130

Case Study

- *Design Flag #4:* Crossing Yield-Controlled or Uncontrolled Vehicle Paths



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

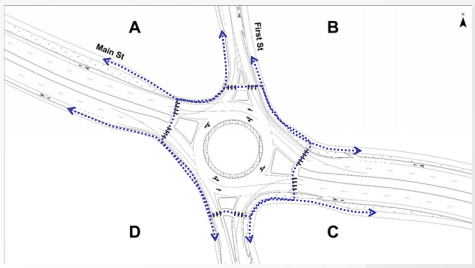
North and south entry trigger Yellow Flags. Other entry legs and all exit legs have Red Flags because speed is over 20 mph
→ All movements get Red Flags, because at least one crossing is Red

130

131

Case Study

- *Design Flag #5:* Indirect Paths



Flag Thresholds

- Yellow
  - 90 ft (ped)
  - 450 ft (bike)
- Red
  - 135 ft (ped)
  - 675 ft (bike)

Outcome

All out-of-direction travel is less than 90 ft, so no Flags apply.

131

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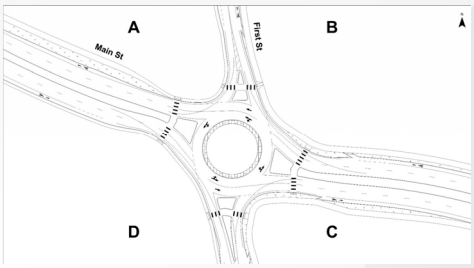
Case Study

- *Design Flag #6:* Executing Unusual Movements



Flag Thresholds

- Yellow
  - Path does not match expectation
- Red
  - N/A

Outcome

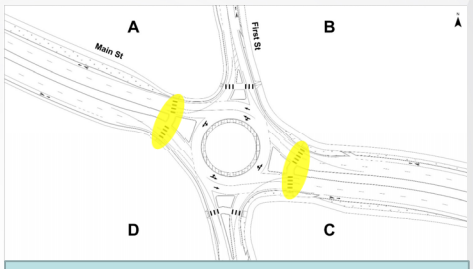
No unusual movements, so no Flags apply

132

133

Case Study

- *Design Flag #7:* Multilane Crossing



Flag Thresholds

- Yellow
  - 2-3 lanes (ped)
  - 4-5 lanes (bike)
- Red
  - >3 lanes (ped)
  - >5 lanes (bike)

Outcome

All crosswalks on Main St have Yellow Flags (A-D and B-C crossings), because peds are crossing 2 lanes

133

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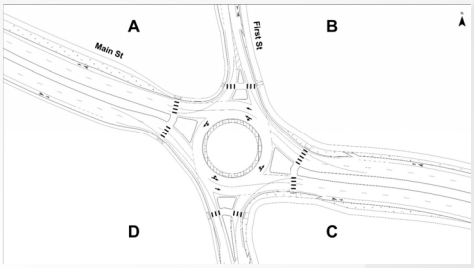
Case Study

- *Design Flag #8:* Long Red Times



Flag Thresholds

- Yellow
  - 30 seconds
- Red
  - 45 seconds

Outcome

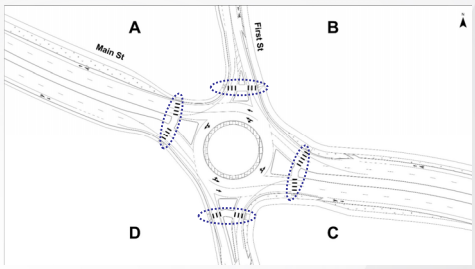
Not a signalized intersection or signalized roundabout, so no Flags apply

134

135

Case Study

- *Design Flag #9:* Undefined Crossings at Intersections



Flag Thresholds

- Yellow
  - Unmarked crossing
- Red
  - N/A

Outcome

All crossings are marked, so no Flags apply

135

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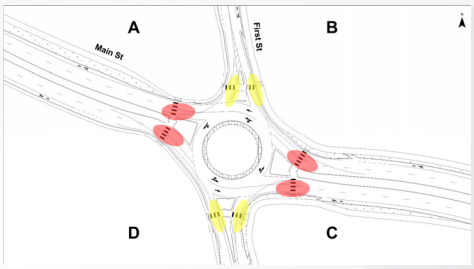
Case Study

- *Design Flag #10:* Motor Vehicle Left Turns



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

A-D and B-C movements have Red Flags, because fastest path speeds are greater than 20 mph.

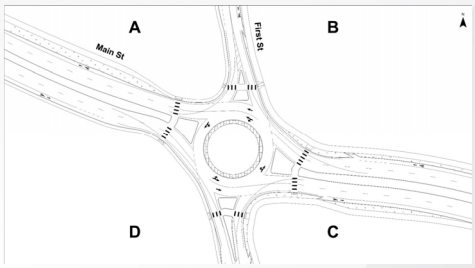
A-B and D-C are yellow due to lower speed and volumes

136

137

Case Study

- *Design Flag #11:* Intersecting Driveways and Side Streets



Flag Thresholds

- Yellow
  - 1-2 (peds)
  - 1-2 (one-way bikes)
- Red
  - >2 (peds)
  - >2 (one-way bikes)
  - >0 (two-way bikes)

Outcome

No intersecting driveway or side streets exist adjacent to the roundabout, so no Flags apply

137

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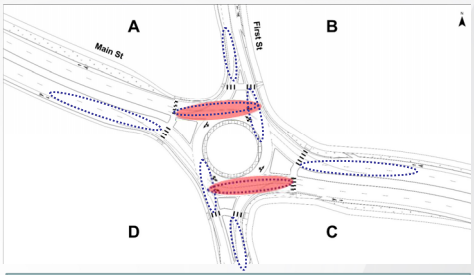
Case Study

- *Design Flag #12:* Sight Distance for Gap Acceptance Movements



Flag Thresholds

- Yellow
  - N/A
- Red
  - Less than required for vehicle speed

Outcome

Insufficient sight distance for crossings of two-lane exits → Red Flags for A-D and B-C connections

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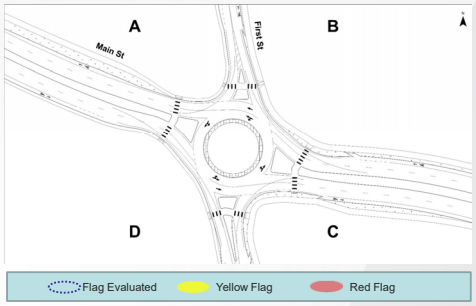
Case Study

- *Design Flag #13: Grade Change*



Flag Thresholds

- Yellow ±3-5%
- Red >±5%

Outcome

Assuming the ground is level, no Flags apply

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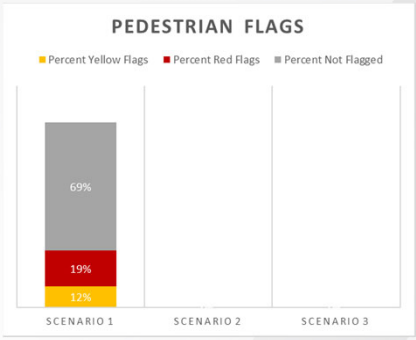
Design Flag Assessment Summary (1 of 2)

Flag #	Flag	Pedestrian Assessment West	East	North	South
1	Motor Vehicle Right Turn	Red	Red	Yellow	Yellow
2	Uncomfortable/ Tight Walking Environment				
3	Non-Intuitive Motor Vehicle Movement				
4	Crossing Yield or Uncontrolled Vehicle Paths	Red	Red	Red	Red
5	Indirect Paths				
6	Executing Unusual Movements	Yellow	Yellow		
7	Multilane Crossing				
8	Long Red Times				
9	Undefined Crossing at Intersections				
10	Motor Vehicle Left Turn	Red	Red	Yellow	Yellow
11	Intersecting Driveways and Side Streets				
12	Sight Distance for Gap Acceptance	Red	Red		
13	Grade Change				
14	Riding in Mixed Traffic				
15	Bicycle Clearance Times				
16	Lane Change Across Motor Vehicle Lanes				
17	Channelized Lanes				
18	Turning Motorists Crossing Bicycle Path				
19	Riding Between Travel Lanes				
20	Off-Tracking Trucks in Multi-Lane Curves				
	Total Yellow Flags Movement	1	1	2	2
	Total Red Flags by Movement	4	4	1	1

Pedestrian	
Total Yellow Flags:	6
Total Red Flags:	10
Total No Flags:	0
Total N/A:	0
Total Possible:	52
Percent Yellow:	12%
Percent Red:	19%

140

Design Flag Assessment Summary (2 of 2)



141

SUPPLEMENTAL SLIDES – PART 2

The following slides with an RCUT bicyclist example were used in some trainings instead of the signalized intersection bicyclist example

142

TRB

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

Module 3
Bicycle Application

KITTELSON & ASSOCIATES

143

Course Overview

- Module 1: Introduction
- Module 2: Design Flag Review and General Design Principles
- Module 3: Bicycle Application
  - Case Study
  - Group Activity
- Module 4: Pedestrian Application
- Module 5: Group Activity
- Module 6: Concluding Remarks and Questions

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Case Study A - RCUT

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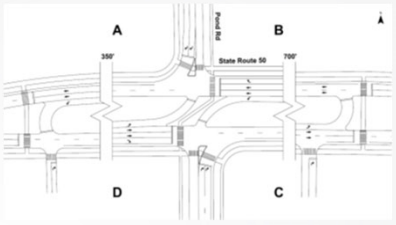
- *Class exercise: Bicycle Assessment*



Signalized RCUT

- Major Street AADT: 50,000
- Minor Street AADT: 10,000
  - D-factor: 0.55
  - K-factor: 0.10
  - 20% right turns
  - 10% left turns
- Major Street Speed Limit 45 mph
- Minor Street Speed Limit 35 mph

145

Case Study A - RCUT

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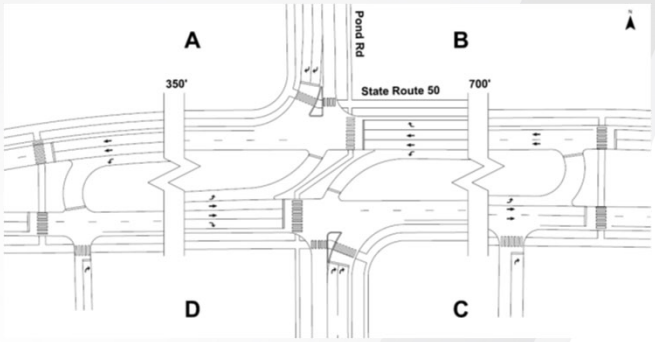
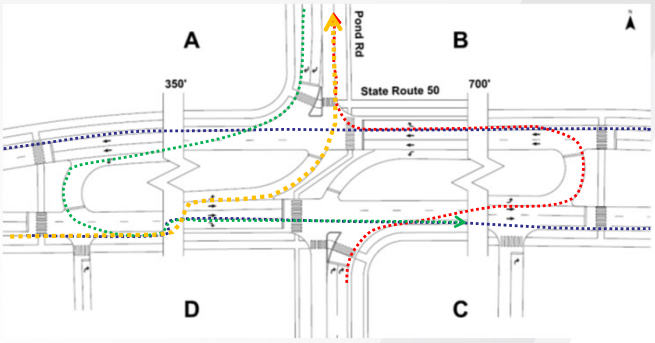


146

Document Assumed Bike Paths

147

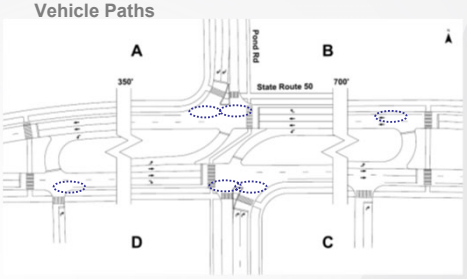


147

Case Study

148

- *Design Flag #4:* Crossing Yield-Controlled or Uncontrolled Vehicle Paths



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

None of the right turns are yield-controlled or uncontrolled, so no Flags apply.

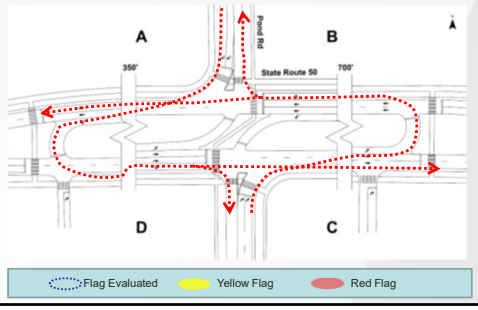
Consider RTOR conflict for right turns or U-Turns on Red (varies by state)

148

Case Study

149

- *Design Flag #5:* Indirect Paths



Flag Thresholds

- Yellow
  - 90' (ped)
  - 450' (bike)
- Red
  - 135' (ped)
  - 675' (bike)

Outcome

Out of direction distance is over 700' for SBT and SBL, so Red Flag applies

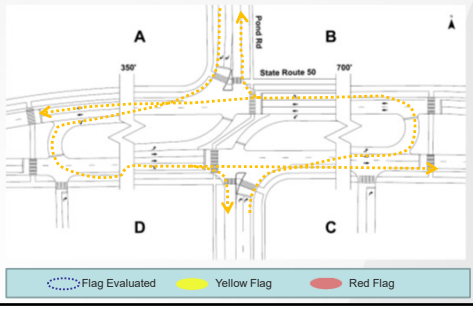
Distance is over 1,400' for NBT and NBL, so Red Flag applies.

149

Case Study

150

- *Design Flag #6:* Executing Unusual Movements



Flag Thresholds

- Yellow
  - Path does not match expectation
- Red
  - N/A

Outcome

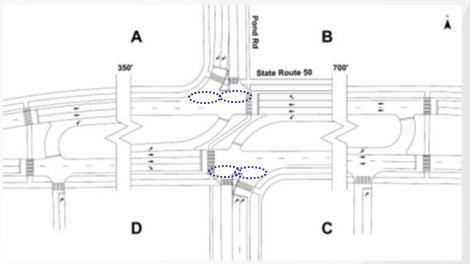
Left turns and through movements from minor street likely do not meet cyclist expectations → Yellow Flag

150

151

Case Study

- *Design Flag #7:* Multilane Crossing



Flag Thresholds

- Yellow
  2-3 lanes (ped)
  4-5 lanes (bike)
- Red
  N/A

Outcome

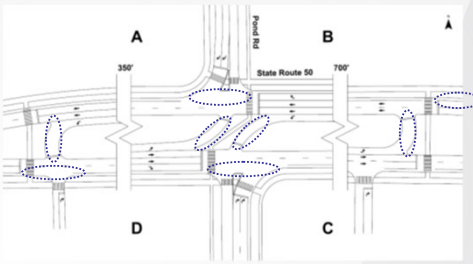
Bikes crossing 2-3 lanes, so no Flags apply

151

152

Case Study

- *Design Flag #8:* Long Red Times



Flag Thresholds

- Yellow
  30 seconds
- Red
  45 seconds

Outcome

Efficient two-phase signal of RCUT likely reduces red times to where no Flag applies.

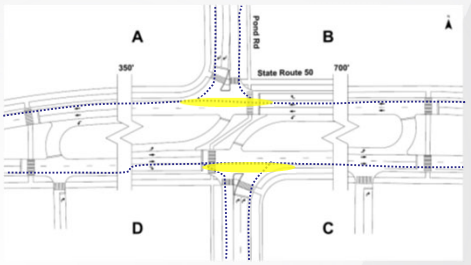
May want to re-check against actual signal timing once available.

152

153

Case Study

- *Design Flag #9:* Undefined Crossings at Intersections



Flag Thresholds

- Yellow
  Unmarked crossing
- Red
  N/A

Outcome

Bike lanes are not carried through the intersection on E/W approaches, and no bike lane exists between through and turn lanes on approaches → Yellow Flag for EBT, WBT, EBL, WBL, NBL, and SBL

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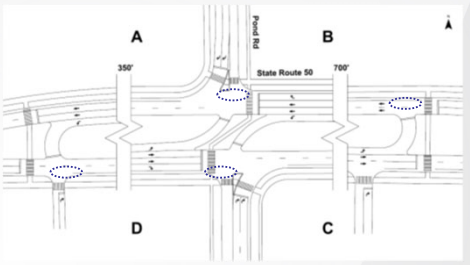
154

Case Study

- *Design Flag #10:* Motor Vehicle Left Turns



Flag Thresholds

- Yellow
  - <= 20 mph & <= 50 vph
- Red
  - > 20 mph OR > 50 vph

Outcome

Left turn speeds and volumes high enough to trigger left turns, but conflicts mitigated if all left turns are signalized and no turns on red allowed.

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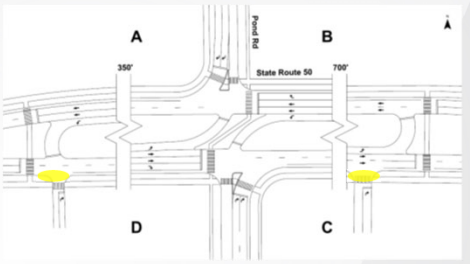
155

Case Study

- *Design Flag #11:* Intersecting Driveways and Side Streets



Flag Thresholds

- Yellow
  1-2 (peds)
  1-2 (one-way bikes)
- Red
  >2 (peds)
  >2 (one-way bikes)
  >0 (two-way bikes)

Outcome

Two driveway conflicts for W-E through movement → Yellow Flag
One driveway conflict for W-N left turn, S-E left turn, W-S right turn, and N-E right turn → Yellow Flags

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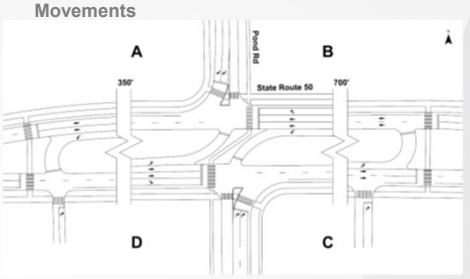
Case Study

- *Design Flag #12:* Sight Distance for Gap Acceptance Movements



Flag Thresholds

- Yellow
  N/A
- Red
  Less than required for vehicle speed

Outcome

No gap acceptance movements for bicyclists

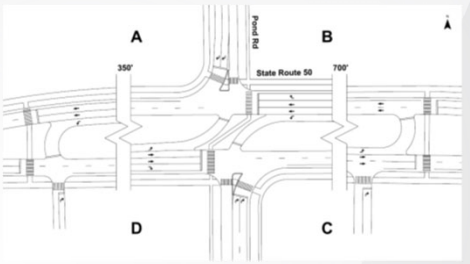
No sight distance issue, so no Flags apply.

156

157

Case Study

- *Design Flag #13: Grade Change*



Flag Thresholds

- Yellow
  ±3-5%
- Red
  >±5%

Outcome

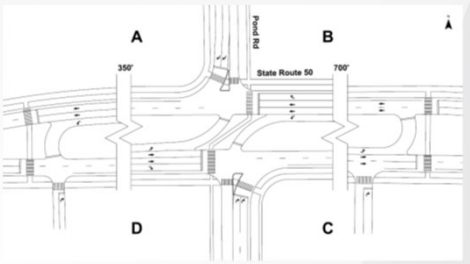
Assuming the ground is level, no Flags apply

157

158

Case Study

- *Design Flag #13: Grade Change*



Flag Thresholds

- Yellow
  ±3-5%
- Red
  >±5%

Outcome

Assuming the ground is level, no Flags apply

158

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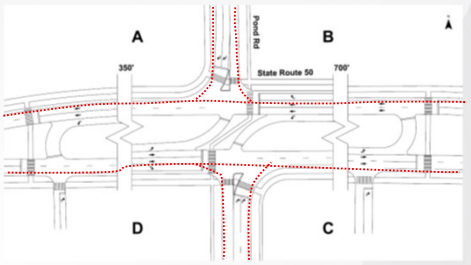
Case Study

- *Design Flag #14: Riding in Mixed Traffic*



Flag Thresholds

- Yellow
  25-35 mph OR
  3,000 – 7,000 vpd
- Red
  >35 mph OR
  >7,000 vpd

Outcome

Bike lane along major street: Red Flag because speed is over 35 mph and high AADT.
Bike path along minor street: Red Flag because AADT=10,000, even if speeds lower.
ALL MOVEMENTS RED

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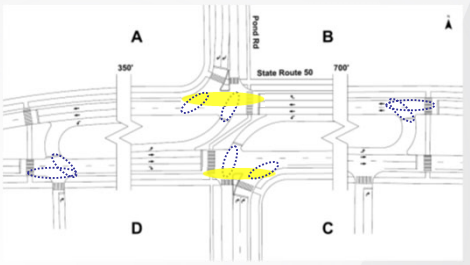
Case Study

- *Design Flag #15: Bicycle Clearance Times*



Flag Thresholds

- Yellow
  <=35 mph and 36-72 ft
  OR
  >35 mph and 24-60 ft
- Red
  <=35 mph and >=72 ft
  OR
  >35 mph and >=60 ft

Outcome

Bike paths along E-W route have Yellow Flag because the thru traffic speed is over 35 mph and clearance zone is 45-55 ft.
→ Yellow Flag for EBT, WBT, EBL, WBL, NBL, SBL

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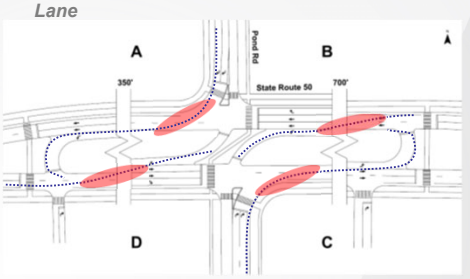
Case Study

- *Design Flag #16: Lane Change Across Motor Vehicle Travel Lane*



Flag Thresholds

- Yellow
  25-35 mph OR
  3,000 – 7,000 vpd
- Red
  >35 mph OR
  >7,000 vpd

Outcome

Six Red Flags apply where bicyclists change lane from through to left lane and vice versa with AADTs greater than 7,000.
- E-S and W-N left turns
- S-N and N-S throughs
- S-W and N-E left turns

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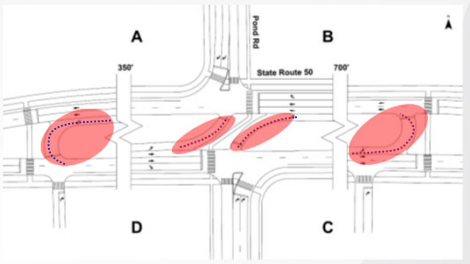
Case Study

- *Design Flag #17: Channelized Lane*



Flag Thresholds

- Yellow
  25-35 mph AND
  <= 50 ft
- Red
  >35 mph OR
  >50 ft

Outcome

Major street left-turn and U-turn bicyclists share channelized lane with motor vehicles for more than 50 ft → six Red Flags
- E-S and W-N left turns
- S-N and N-S throughs
- S-W and N-E left turns

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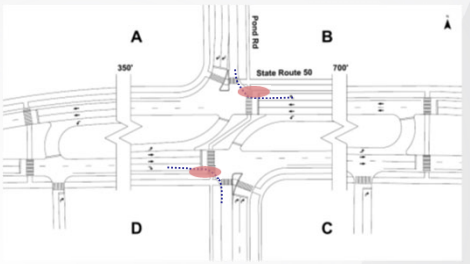
Case Study

- *Design Flag #18: Turning Motorists Crossing Bicycle Path*



Flag Thresholds

- Yellow
  Exclusive Turn Lane
- Red
  Shared Thru & Turn Lane

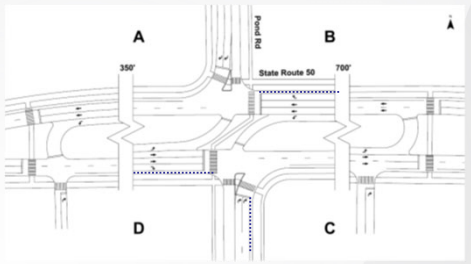
Outcome

Red Flags for right turn lanes for major-street right turns.

163

Case Study

- *Design Flag #19: Riding between Travel Lanes*



Flag Thresholds

- Yellow
  Motor vehicle lanes remain parallel or diverge
- Red
  Motor vehicle lanes merge

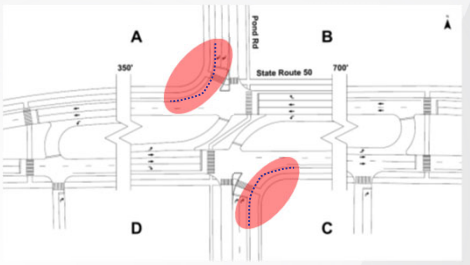
Outcome

Cyclists are on outside of turn lane, so no riding between travel lanes.

164

Case Study

- *Design Flag #20: Off-Tracking Trucks in Multilane Curves*



Flag Thresholds

- Yellow
  Curve at 60 degrees or less
- Red
  Curve at greater than 60 degrees

Outcome

Minor street approaches are multilane with 90-degree turn → Red Flags for SBR, SBT, SBL, NBR, NBT, and NBL

165

Design Flag Assessment Summary (1 of 2)

		Bicycle Assessment											
Flag #	Flag	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
1	Motor Vehicle Right Turn												
2	Uncomfortable/Tight Walking Environment												
3	Non-Intuitive Motor Vehicle Movement												
4	Crossing Yield or Uncontrolled Vehicle Paths												
5	Indirect Paths	Red	Red		Red	Red							
6	Executing Unusual Movements	Yellow	Yellow		Yellow	Yellow							
7	Multilane Crossing												
8	Long Red Times												
9	Undefined Crossing at Intersections	Yellow			Yellow				Yellow		Yellow	Yellow	Yellow
10	Motor Vehicle Left Turn												
11	Intersecting Driveways and Side Streets				Yellow				Yellow	Yellow	Yellow	Yellow	Yellow
12	Sight Distance for Gap Acceptance												
13	Grade Change												
14	Riding in Mixed Traffic	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
15	Bicycle Clearance Times	Yellow			Yellow			Yellow	Yellow		Yellow	Yellow	
16	Lane Change Across Motor Vehicle Lanes	Red	Red		Red	Red		Red			Red		
17	Channelized Lanes	Red	Red		Red	Red		Red			Red		
18	Turning Motorists Crossing Bicycle Path									Red			Red
19	Riding Between Travel Lanes												
20	Off-Tracking Trucks in Multi-Lane Curves	Red	Red	Red	Red	Red	Red						
	Total Yellow Flags Movement	3	1	0	4	1	0	1	3	1	3	3	2
	Total Red Flags by Movement	5	5	2	5	5	2	3	1	2	3	1	2

	Bicycle
Total Yellow Flags:	6
Total Red Flags:	32
Total No Flags:	0
Total N/A:	0
Total Possible:	84
Percent Yellow:	7%
Percent Red:	38%

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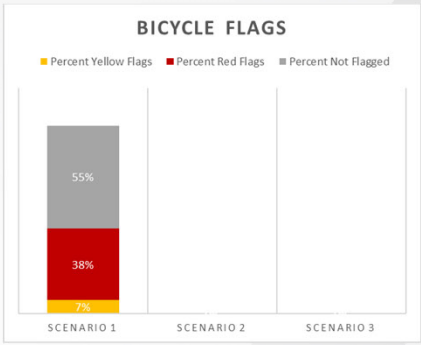
Design Flag Assessment Summary (2 of 2)



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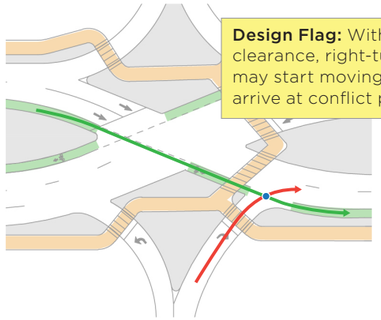
APPENDIX F – OTHER TRAINING HANDOUTS

This appendix contains other handouts given to training participants, including:

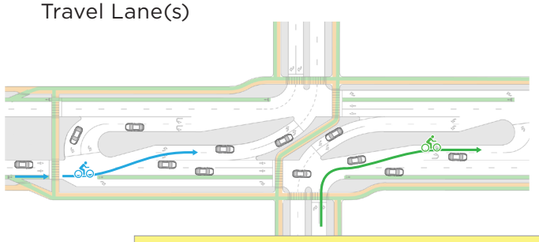
- Design flag summary (11x17 two-sided)
- Design flag threshold summary
- Design flag worksheet

15. Bicycle Clearance Times



Design Flag: Without adequate clearance, right-turning vehicles may start moving just as bicycles arrive at conflict point

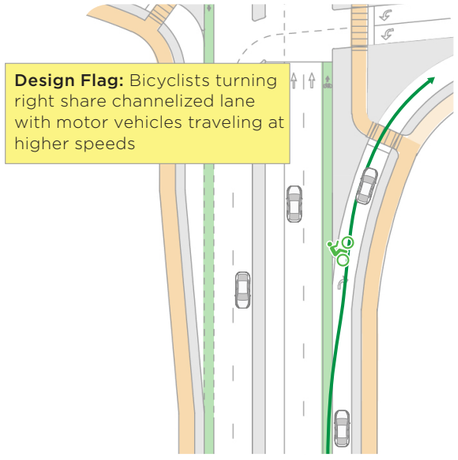
16. Bicyclist Crossing Motor Vehicle Travel Lane(s)



Design Flag: Bicyclists trying to turn left from the main line (blue) or side street (green) need to cross over motor vehicle travel lanes with considerable speed differential

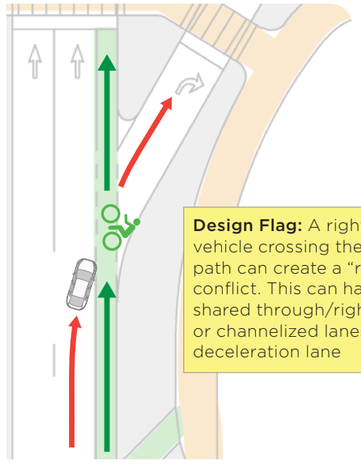
(Note that off-street facilities are also provided in this design, mitigating the design flag)

17. Channelized Lanes



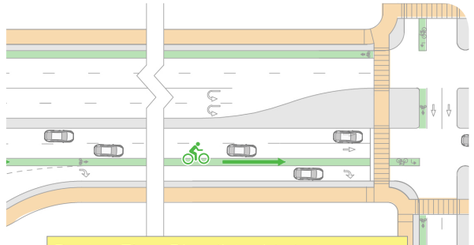
Design Flag: Bicyclists turning right share channelized lane with motor vehicles traveling at higher speeds

18. Turning Motorists Crossing Bicycle Path



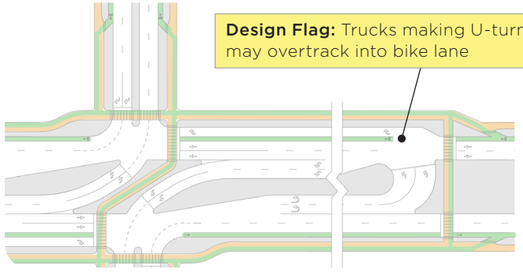
Design Flag: A right-turning vehicle crossing the bicycle path can create a "right hook" conflict. This can happen at shared through/right lanes, or channelized lanes without deceleration lane

19. Riding between Travel Lanes, Lane Additions, or Lane Merges



Design Flag: Bicyclists ride between motor vehicle lanes with faster-moving vehicle traffic on both sides.

20. Off-Tracking Trucks in Multi-Lane Curves

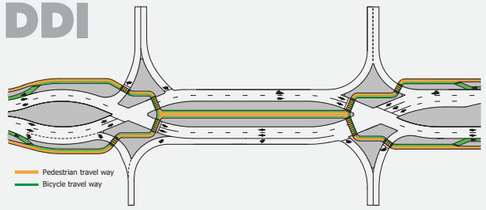


Design Flag: Trucks making U-turns may overtrack into bike lane

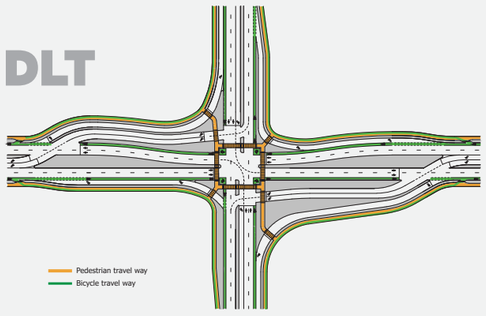
ALTERNATIVE INTERSECTION CONFIGURATIONS

- Diverging Diamond Interchange (DDI)
- Displaced Left Turn (DLT)
- Median U-Turn (MUT)
- Restricted Conflict Intersection (RCI)

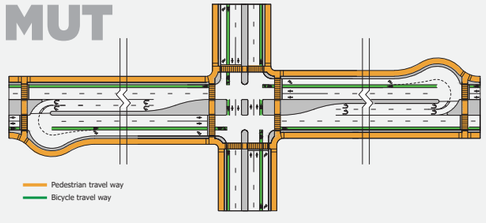
DDI



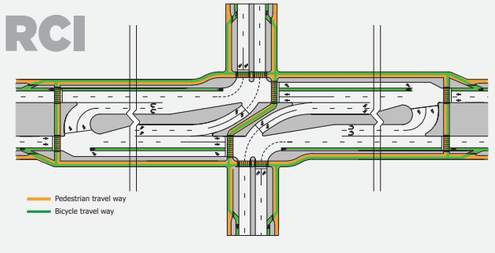
DLT



MUT

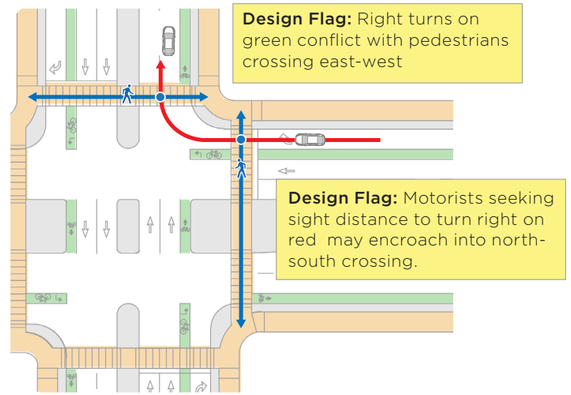


RCI



PEDESTRIAN AND BICYCLE SAFETY
DESIGN FLAGS 20

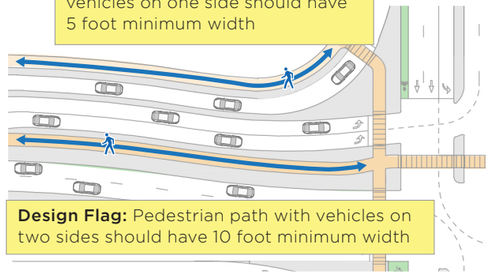
1. Motor Vehicle Right Turns



Design Flag: Right turns on green conflict with pedestrians crossing east-west

Design Flag: Motorists seeking sight distance to turn right on red may encroach into north-south crossing.

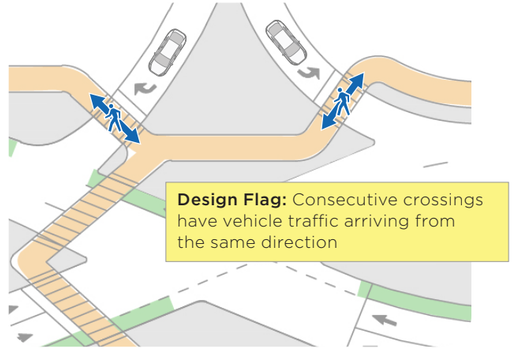
2. Uncomfortable/Tight Walking Environment



Design Flag: Pedestrian path with vehicles on one side should have 5 foot minimum width

Design Flag: Pedestrian path with vehicles on two sides should have 10 foot minimum width

3. Nonintuitive Motor Vehicle Movements



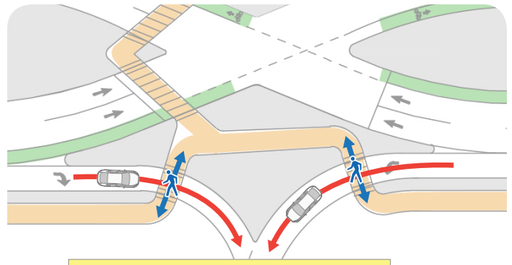
Design Flag: Consecutive crossings have vehicle traffic arriving from the same direction

20 PEDESTRIAN AND BICYCLE SAFETY

DESIGN FLAGS

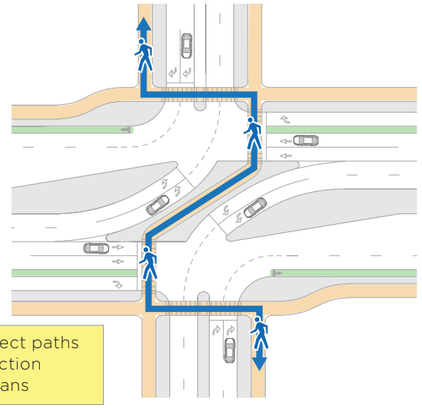
The design flag method is based on National Cooperative Highway Research Program (NCHRP) Project 07-25 on Pedestrian and Bicycle Safety at Alternative and Other Intersections and Interchanges.

4. Crossing Yield- or Uncontrolled Vehicle Paths



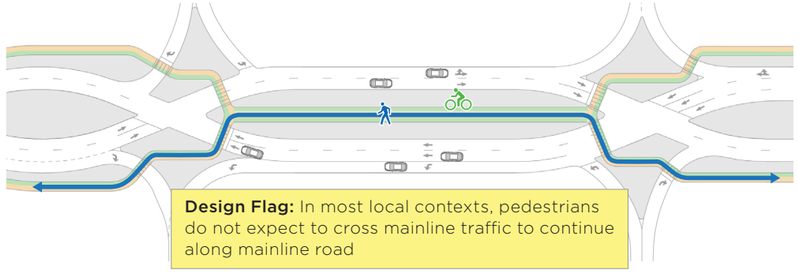
Design Flag: Yield-controlled or uncontrolled movements conflict with pedestrian movements

5. Indirect Paths



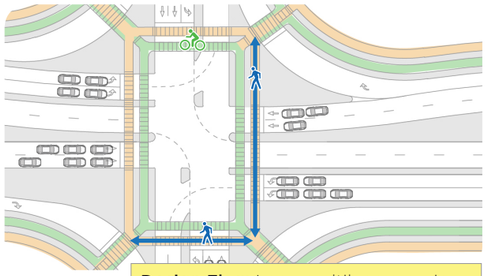
Design Flag: Indirect paths create out-of-direction travel for pedestrians

6. Executing Unusual Movements



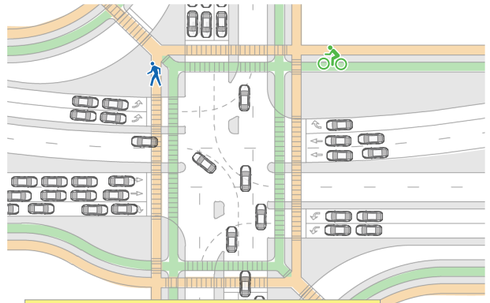
Design Flag: In most local contexts, pedestrians do not expect to cross mainline traffic to continue along mainline road

7. Multilane Crossings



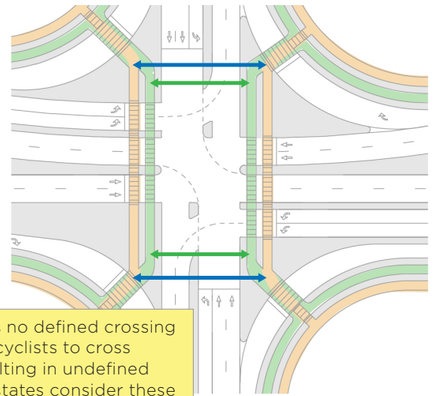
Design Flag: Long multilane crossings increase exposure and may result in multiple threat situations

8. Long Red Times



Design Flag: Large intersections with multi-phase signals and heavy vehicle movements can result in long red times and high delay for pedestrians and bicyclists

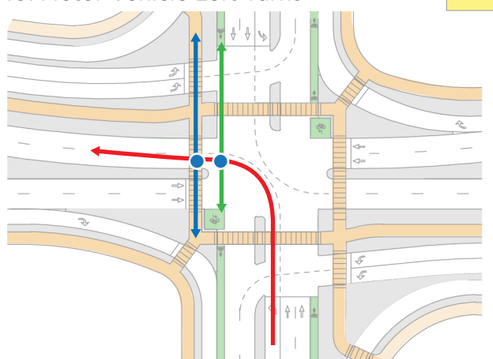
9. Undefined Crossing At Intersections



Design Flag: There is no defined crossing for pedestrians or bicyclists to cross the minor street resulting in undefined space, even if many states consider these unmarked locations “legal crossings”

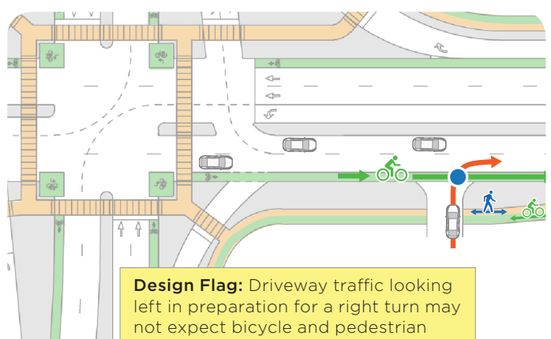
#	Flag Description	Pedestrian	Bicycle
1	Motor Vehicle Right Turns		
2	Uncomfortable/Tight Walking Environment		
3	Nonintuitive Motor Vehicle Movements		
4	Crossing Yield- or Uncontrolled Vehicle Paths		
5	Indirect Paths		
6	Executing Unusual Movements		
7	Multilane Crossings		
8	Long Red Times		
9	Undefined Crossing At Intersections		
10	Motor Vehicle Left Turns		
11	Intersecting Driveways and Side Streets		
12	Sight Distance for Gap Acceptance Movements		
13	Grade Change		
14	Riding in Mixed Traffic		
15	Bicycle Clearance Times		
16	Bicyclist Crossing Motor Vehicle Travel Lane(s)		
17	Channelized Lanes		
18	Turning Motorists Crossing Bicycle Path		
19	Riding between Travel Lanes, Lane Additions, or Lane Merges		
20	Off-Tracking Trucks in Multi-Lane Curves		

10. Motor Vehicle Left Turns



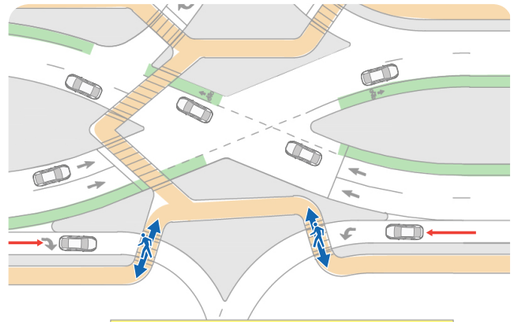
Design Flag: Crossing Pedestrians and bicyclists are at risk from left-turning drivers seeking gaps in oncoming traffic

11. Intersecting Driveways and Side Streets



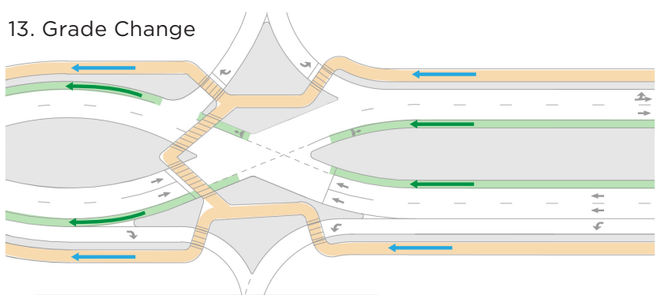
Design Flag: Driveway traffic looking left in preparation for a right turn may not expect bicycle and pedestrian traffic from their right

12. Sight Distance for Gap Acceptance Movements



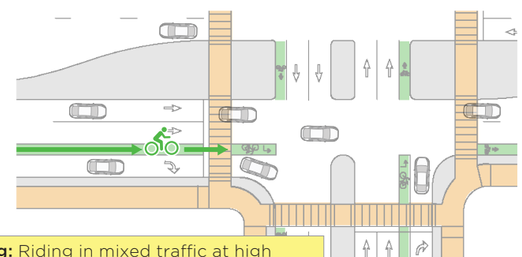
Design Flag: Unsignalized crossings should be designed with adequate sight distance for a safe crossing and for drivers to yield

13. Grade Change



Design Flag: Interchange overpass may have significant grade, affecting walking and biking experience

14. Riding in Mixed Traffic



Design Flag: Riding in mixed traffic at high speeds or volumes can be stressful and creates safety concerns for bicyclists

KITTELSON & ASSOCIATES

For more information please contact Bastian Schroeder, bschroeder@kittelson.com

NCHRP 07-25
ASSESSMENT DESIGN FLAG THRESHOLDS

No.	Flag	Applicable Mode	Measure of Effectiveness	Yellow Flag Threshold	Red Flag Threshold
1	Motor Vehicle Right Turns	Pedestrian	Vehicle Turning Speed & Vehicle Volume	<=20 mph **&** <= 50 vph	>20 mph **OR** >50 vph
2	Uncomfortable/Tight Walking Environment	Pedestrian	Walkway width	< 5' if traffic present on one side; <10' if traffic present on two sides	N/A
3	Nonintuitive Motor Vehicle Movements	Pedestrian	Vehicle acceleration profile	Vehicle decelerating	Vehicle accelerating or free-flowing
4	Crossing Yield-Controlled or Uncontrolled Vehicle Paths	Pedestrian & Bicycle	Vehicle Speed & Vehicle Volume	<=20 mph **&** <= 50 vph	>20 mph **OR** >50 vph
5	Indirect Paths	Pedestrian & Bicycle	Out of direction travel distance	90' (ped) 450' (bike)	135' (ped) 675' (bike)
6	Executing Unusual Movements	Pedestrian & Bicycle	Local Expectation	Path does not match expectation	N/A
7	Multilane Crossing	Pedestrian & Bicycle	Number of lanes without refuge	2 – 3 lanes (ped) 4 – 5 lanes (bike)	>3 lanes (ped) >5 lanes (bike)
8*	Long Red Times	Pedestrian & Bicycle	Delay	30 seconds	45 seconds
9	Undefined Crossings at Intersections	Pedestrian & Bicycle	Path Markings	Unmarked crossing	N/A
10	Motor Vehicle Left Turns	Pedestrian & Bicycle	Vehicle Turning Speed & Vehicle Volume	<=20 mph **&** <= 50 vph	>20 mph **OR** >50 vph

Continued on reverse

*To estimate delay:

$$Delay = \frac{r^2}{2C}$$

Where:

r = movement red time (seconds)

C = cycle length (seconds)

# Critical Phases	% Red Time of Cycle Length	
	(Crossing with Major Vehicle Movement)	(Crossing with Minor Vehicle Movement)
2	30%	70%
3	50%	75%
4	60%	85%

No.	Flag	Applicable Mode	Measure of Effectiveness	Yellow Flag Threshold	Red Flag Threshold
11**	Intersecting Driveways and Side Streets	Pedestrian & Bicycle	# of Access points in Area of Influence	1-2 (peds) 1-2 (one-way bikes)	>2 (peds) >2 (one-way bikes) >0 (two-way bikes)
12	Sight Distance for Gap Acceptance Movements	Pedestrian & Bicycle	Sight Distance	N/A	Less than required for vehicle speed
13	Grade Change	Pedestrian & Bicycle	% grade	±3-5%	>±5%
14	Riding in Mixed Traffic	Bicycle	Vehicle Speed & Vehicle Volume	25-35 mph **OR** 3,000 – 7,000 vpd	>35 mph **OR** >7,000 vpd
15	Bicycle Clearance Times	Bicycle	Vehicle Speed and Clearance Zone Length (feet)	<=35 mph and 36-72’ **OR** > 35 mph and 24’-60’	<=35 mph and >=72’ **OR** > 35 mph and >=60’
16	Lane Change Across Motor Vehicle Travel Lane	Bicycle	Vehicle Speed & Vehicle Volume	25-35 mph **OR** 3,000 – 7,000 vpd	>35 mph **OR** >7,000 vpd
17	Bicyclist Crossing Motor Vehicle Travel Lane	Bicycle	Vehicle Speed & Vehicle Volume	25-35 mph **OR** 3,000 – 7,000 vpd	>35 mph **OR** >7,000 vpd
18	Turning motor vehicles crossing bike path	Bicycle	Motor Vehicle Lane Configuration	Exclusive Turn Lane	Shared Thru & Turn Lane
19	Riding between lanes	Bicycle	Motor Vehicle Lane configuration	Motor vehicle lanes remain parallel or diverge	Motor vehicle lanes merge
20	Off-Tracking Trucks in Multi-Lane Curves	Bicycle	Turn Angle	Curve at 60 degrees or less	Curve at greater than 60 degrees

** The area of influence is the greater of:

- 250 feet in both directions from the center of the main intersection (for a total of 500 feet)
- the entire frontage area along the traveled path through the intersection

NCHRP 07-25: Pedestrian and Bicycle Safety Assessment

KITTELSON & ASSOCIATES

Pedestrian Flags, NCHRP 7-25 Methodology
Date:
Project:
Alternative:
Intersection/Interchange:
Analyst:

Study Area Sketch with Path Assignment

No.	Name				
		West	East	North	South
1	Motor Vehicle Right Turn				
2	Uncomfortable/ Tight Walking Environment				
3	Non-Intuitive Motor Vehicle Movement				
4	Crossing Yield or Uncontrolled Vehicle Paths				
5	Indirect Paths				
6	Executing Unusual Movements				
7	Multilane Crossing				
8	Long Red Times				
9	Undefined Crossing at Intersections				
10	Motor Vehicle Left Turn				
11	Intersecting Driveways and Side Streets				
12	Sight Distance for Gap Acceptance				
13	Grade Change				

Total Possible Flags	
Total Yellow Flags	
Total Red Flags	
PCT Yellow	
PCT Red	
PCT Flagged	

Indicate R=red flag, Y=yellow flag, or blank=no flag

NCHRP 07-25: Pedestrian and Bicycle Safety Assessment

KITTELSON & ASSOCIATES

Study Area Sketch with Route Assignment

Bicyclist Flags, NCHRP 07-25 Methodology
Date:
Project:
Alternative:
Intersection/Interchange:
Analyst:

No.	Name	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
4	Crossing Yield or Uncontrolled Vehicle Paths												
5	Indirect Paths												
6	Executing Unusual Movements												
7	Multilane Crossing												
8	Long Red Times												
9	Undefined Crossing at Intersections												
10	Motor Vehicle Left Turn												
11	Intersecting Driveways and Side Streets												
12	Sight Distance for Gap Acceptance												
13	Grade Change												
14	Riding in Mixed Traffic												
15	Bicycle Clearance Times												
16	Lane Change Across Motor Vehicle Lanes												
17	Channelized Lanes												
18	Turning Motorists Crossing Bicycle Path												
19	Riding Between Travel Lanes												
20	Off-Tracking Trucks in Multi-Lane Curves												

Total Possible Flags	
Total Yellow Flags	
Total Red Flags	
PCT Yellow	
PCT Red	
PCT Flagged	

Indicate R=red flag, Y=yellow flag, or blank=no flag