A SAFE SYSTEM-BASED FRAMEWORK AND ANALYTICAL METHODOLOGY FOR ASSESSING INTERSECTIONS

Winter Workshop

A Community of Transportation Professionals

ite

FLORIDA PUERTO RICO

DISTRICT

February 17, 2022

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FHWA Resource Center

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U.S. Department of Transportation

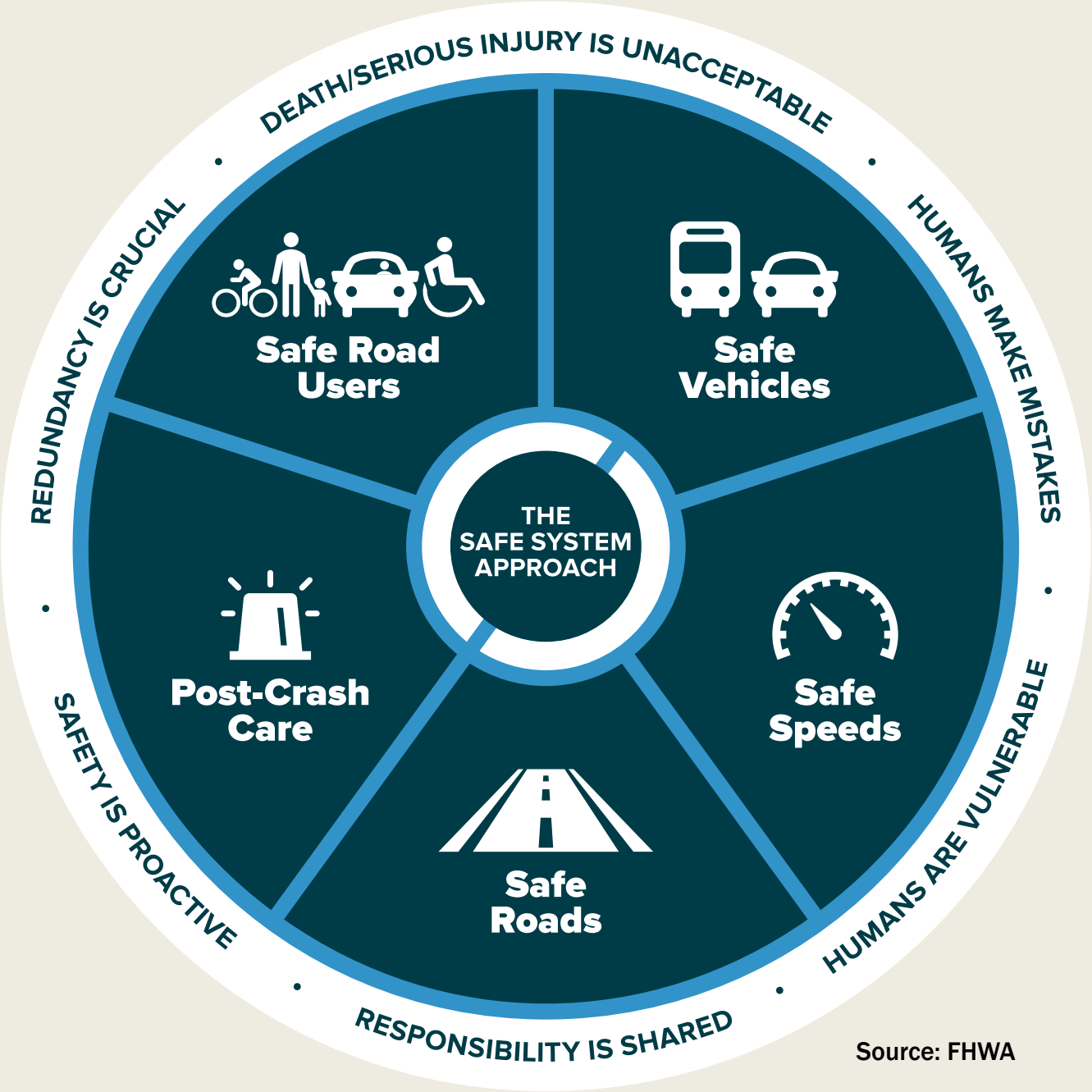
Federal Highway Administration

THE SAFE SYSTEM APPROACH

Death/serious injury is unacceptable

Humans make mistakes

Humans are vulnerable



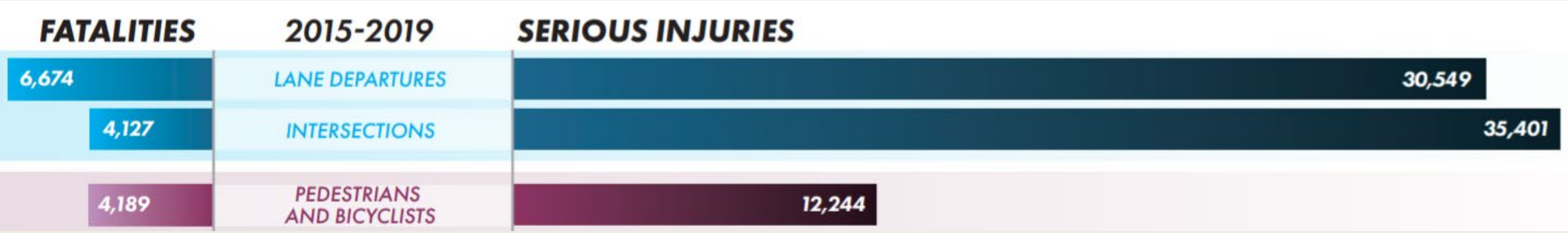
Source: FHWA

Responsibility is shared

Safety is proactive

Redundancy is crucial

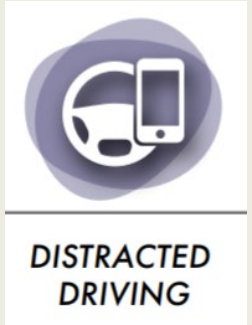
Why Intersections?



Source: Florida Strategic Highway Safety Plan
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/safety/shsp-2021/shsp_mar21.pdf?sfvrsn=5452dad_0

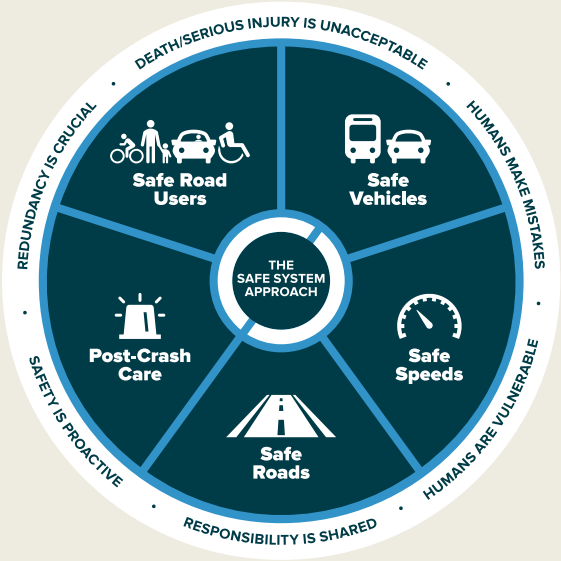
Why are People Killed at Intersections?

"Many intersection crashes in Florida involve aging road users, distracted drivers, teen drivers, motorcyclists, pedestrians, or bicyclists. Making left turns, changing lanes, and navigating through intersections can be difficult for aging road users who experience declines in visual, cognitive, or physical abilities."



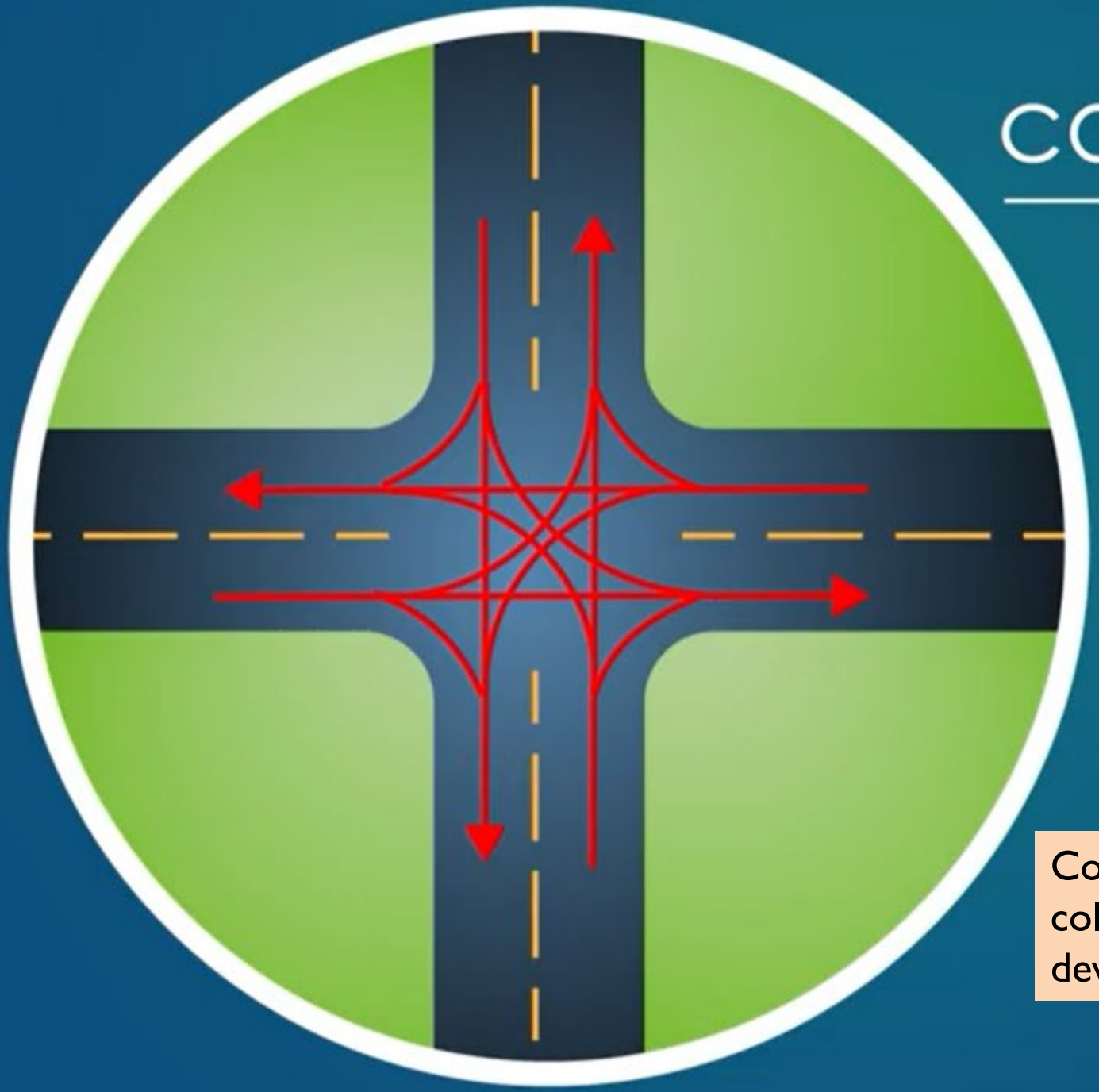
Why are People Killed and Seriously Injured on the Roads?

People are killed and seriously injured on the roads when the collision forces transferred onto the human body exceed tolerable thresholds.



" In road injury epidemiology, kinetic energy is the pathogen "

Robertson LS. *Injury epidemiology*. Oxford: Oxford University Press, 1992



conflict points

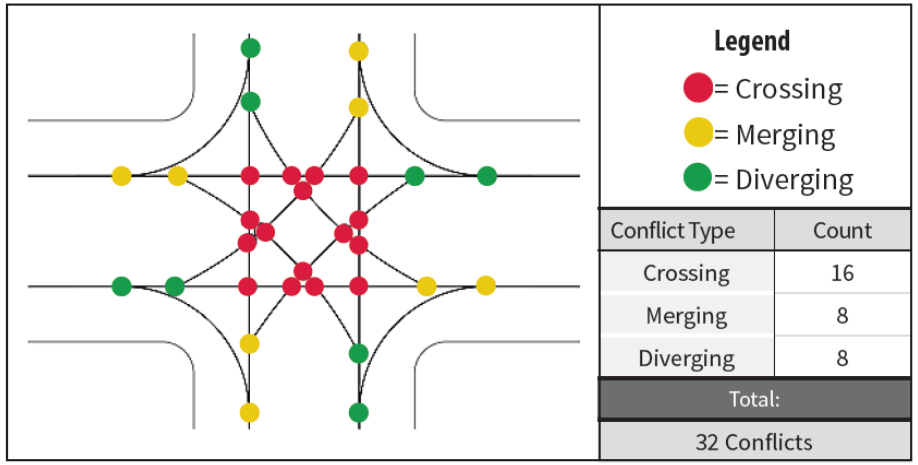
Intersection Conflict Point - locations where the typical paths of road users coincide

Traffic Conflict - a traffic event involving the interaction of two or more users where taking evasive action is needed to avoid a collision

Conflict points represent the "potential" for collisions if users violate the traffic control device or make a mistake in judgement

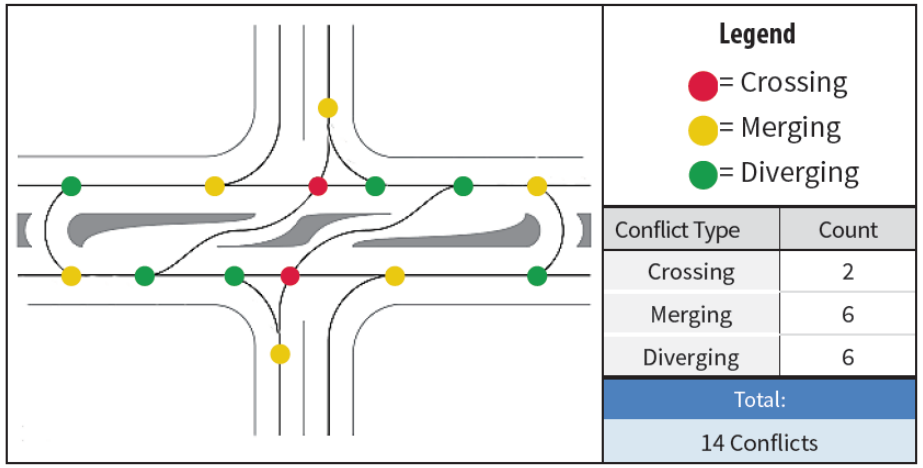
INTERSECTION CONFLICT POINTS

Conventional Intersection: Conflict Points



Conflict Type	Count
Crossing	16
Merging	8
Diverging	8
Total:	
32 Conflicts	

RCUT Intersection: Conflict Points



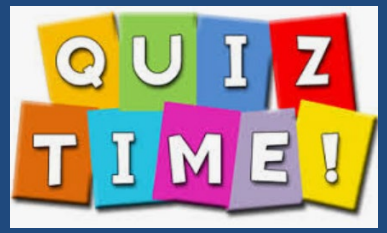
Conflict Type	Count
Crossing	2
Merging	6
Diverging	6
Total:	
14 Conflicts	

Intersections are "planned" areas of traffic conflict with concentrated groupings of conflict points:

- Crossing
- Merging
- Diverging
- Non-motorized

Intersection geometrics can reduce the number of conflicts and/or change the types of conflicts

QUIZ QUESTION



Of the three intersection choices below, which is more likely to have better safety performance?

1

Conflict Type	Count
Crossing	2
Merging	8
Diverging	8

2

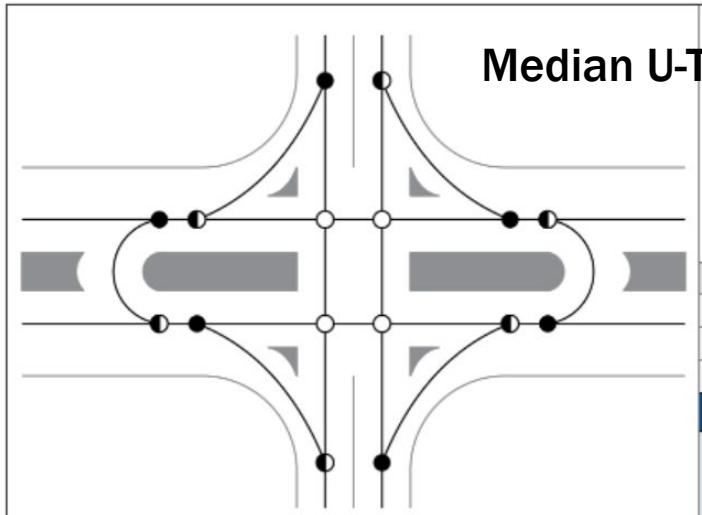
Conflict Type	Count
Crossing	0
Merging	4
Diverging	4

3

Conflict Type	Count
Crossing	16
Merging	8
Diverging	8

Correct Answer: 2

CONFLICT POINTS AS A SAFETY SURROGATE



Legend

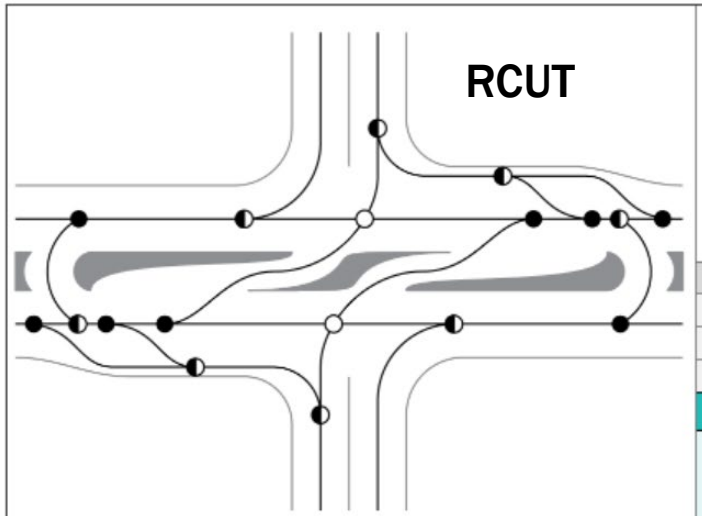
● = Diverging

◑ = Merging

○ = Crossing

Conflict Type	Count
Crossing	4
Merging	6
Diverging	6
Total:	

16 Conflicts



Legend

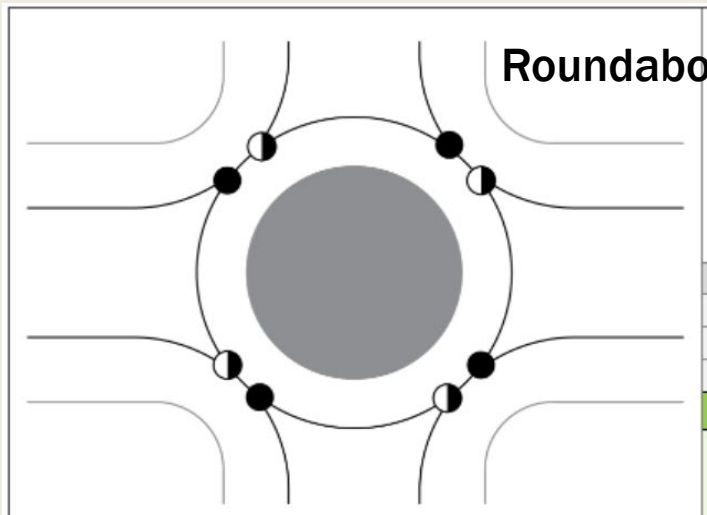
● = Diverging

◑ = Merging

○ = Crossing

Conflict Type	Count
Crossing	2
Merging	8
Diverging	8
Total:	

18 Conflicts



Legend

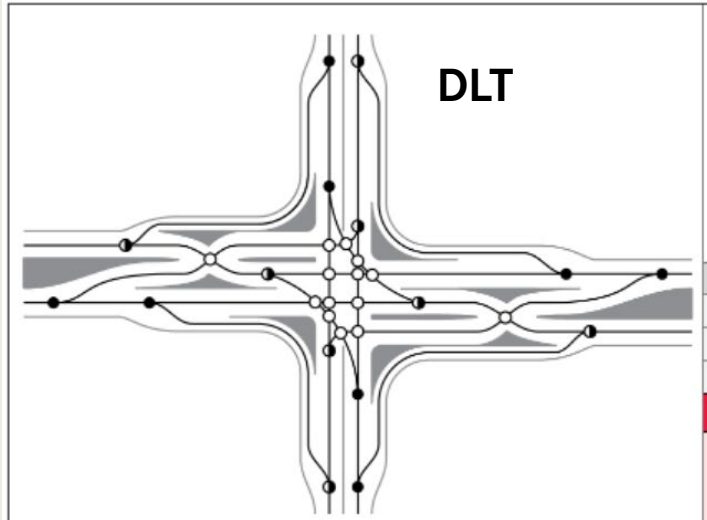
● = Diverging

◑ = Merging

○ = Crossing

Conflict Type	Count
Crossing	0
Merging	4
Diverging	4
Total:	

8 Conflicts



Legend

● = Diverging

◑ = Merging

○ = Crossing

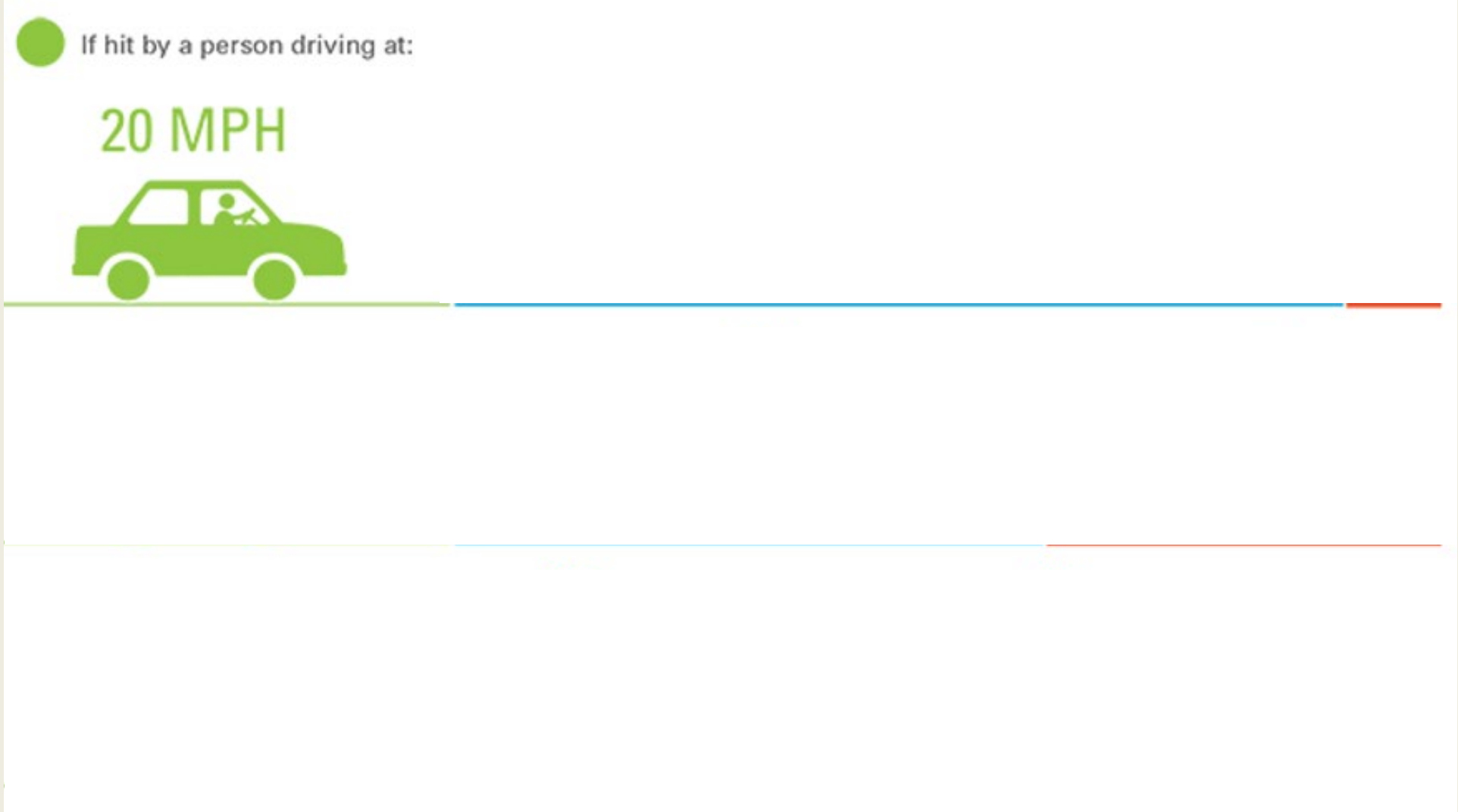
Conflict Type	Count
Crossing	14
Merging	8
Diverging	8
Total:	

30 Conflicts

But what about ....?

- Differing Speeds
- Differing Volumes
  - Pedestrian and Vehicular
- Differing Contexts
  - Intersection “Complexity”
- Differing Geometry
  - Corner radii, Skew angles, etc.

Pedestrian Fatality Risk Based on Vehicle Speed



Source: ITE adapted from AAA Foundation for Traffic Safety data

Prevention through Design (PtD)

Hierarchy of Control

Eliminate
Physically remove the hazard

Substitute
Replace the hazard with option that lowers severity

Engineering Controls
Operate the system to reduce exposure

Administrative Controls
Education, legislation & policies to change behavior

Personal Protective Equipment
PPE, protective gear

Prevention through Design

Initiative led by the National Institute for Occupational Safety and Health (NIOSH)

Aim is to prevent or reduce occupational injuries, illnesses, and fatalities through efforts that anticipate and "design out" hazards to workers.

Hierarchy of controls is a PtD strategy.
https://www.cdc.gov/niosh/topics/ptd/

Adapted from National Institute for Occupational Safety and Health - https://www.cdc.gov/niosh/topics/hierarchy/default.html

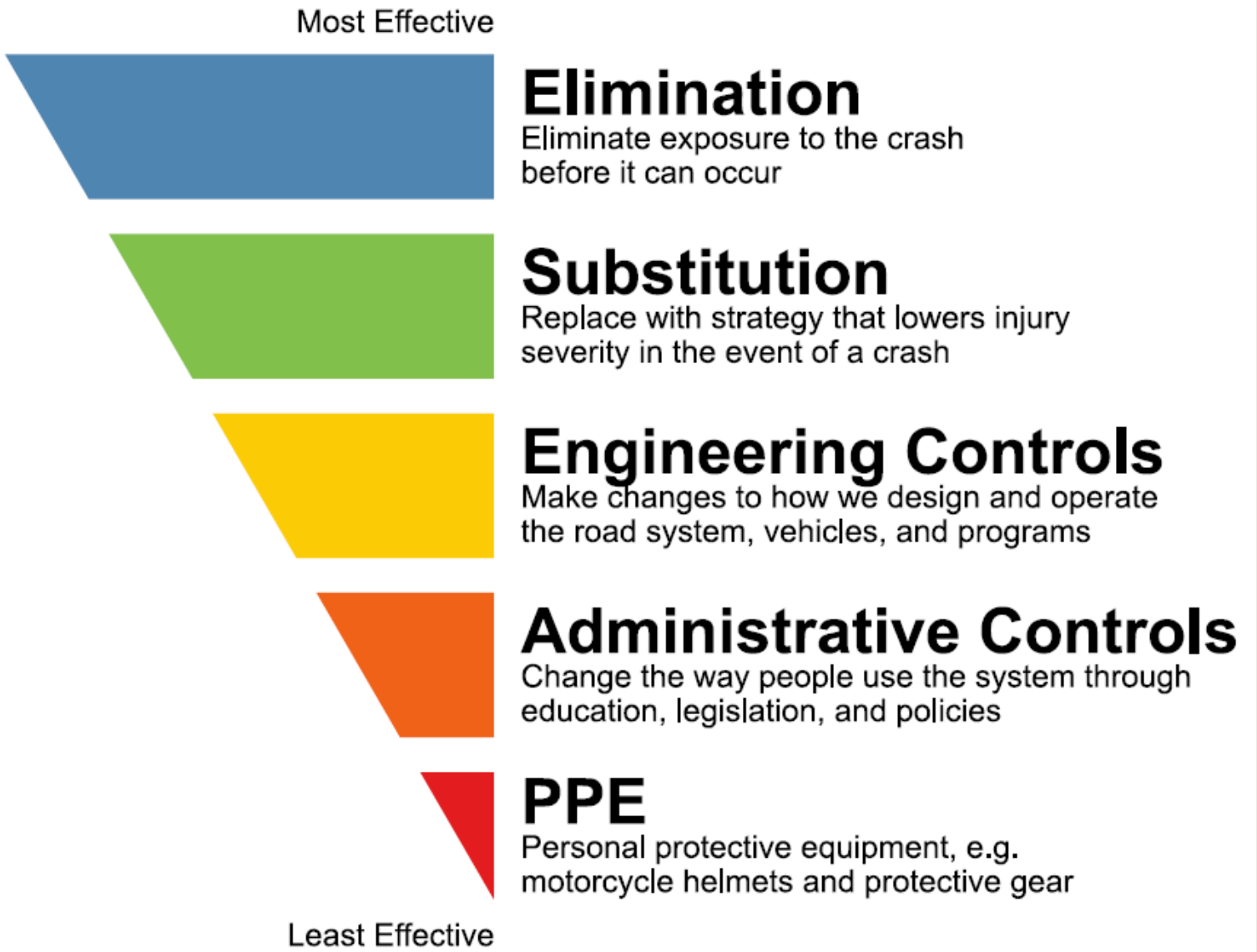


Illustration. Hierarchy of Controls for Traffic Safety.

(Source: Washington Traffic Safety Commission)

Washington State Strategic Highway Safety Plan:

Target Zero 2019

http://targetzero.com/wp-content/uploads/2020/03/TargetZero2019_Lo-Res.pdf

Intersection Fatality and Serious Injury Prevention thru Design

REDUCE RISK OF ERROR

- Eliminate exposure by physical separation of user conflicts
- Reduce exposure by conflict separation in time
- Increase user attentiveness & awareness

MANAGE CRASH ENERGY

- Reduce exposure to incompatible speed
- Reduce exposure to severe angles of impact
- Personal protection & road features that manage energy distribution

Separating users in space

Separating users in time

Increasing attentiveness and awareness

Source: Fehr & Peers

Manage speed

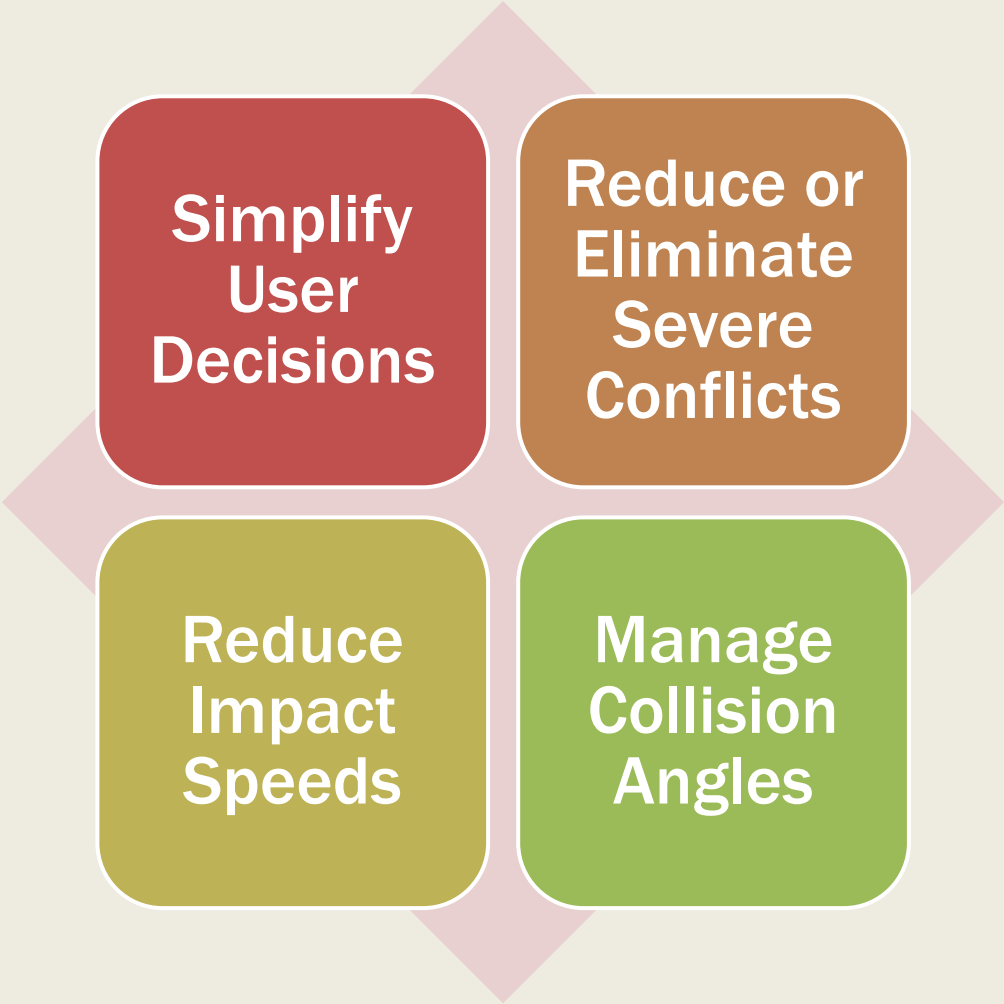
Source: City of Carmel, IN

Manage impact angles

Source: Fehr & Peers

Manage impact energy distribution

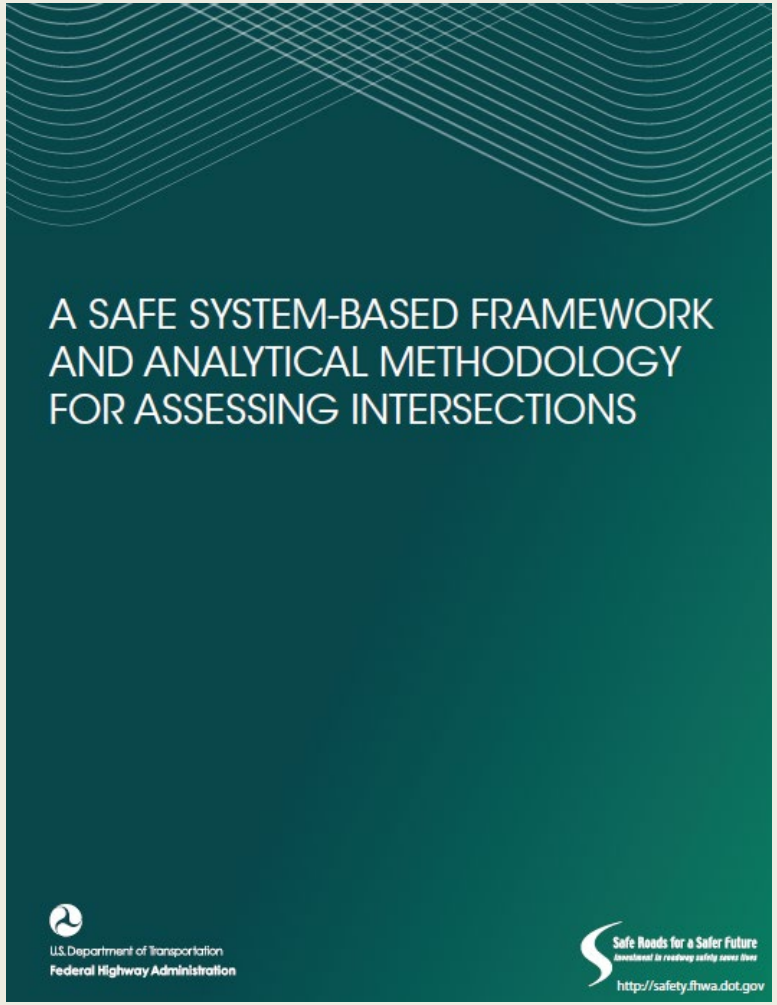
SAFE SYSTEM FOR INTERSECTIONS FRAMEWORK



A SAFE SYSTEM-BASED FRAMEWORK AND ANALYTICAL METHODOLOGY FOR ASSESSING INTERSECTIONS

SAFE SYSTEM FOR INTERSECTIONS (SSI) FRAMEWORK

- Objectives:
  - Readily implementable
  - Common project-level data inputs
  - Stage I ICE (scoping phase)



Full report and Tech Brief available at
https://safety.fhwa.dot.gov/intersection/ssi/index.cfm
Report Number FHWA-SA-21-008

SAFE SYSTEM FOR INTERSECTIONS (SSI) FRAMEWORK (VERSION 1.0)

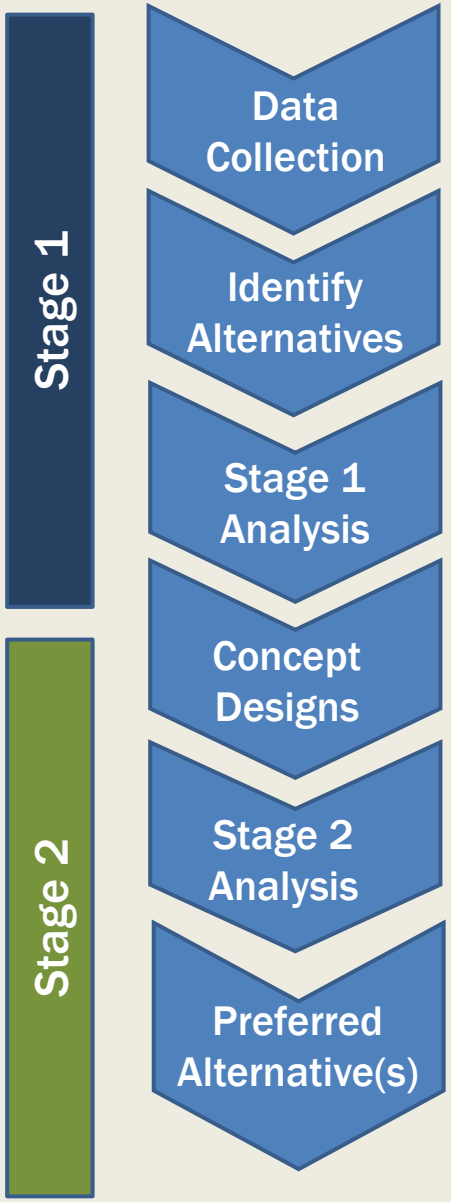
- A technical basis by which practitioners can apply Safe System principles to inform intersection planning and design decisions
- SSI (version 1.0) focuses on alternatives screening (ICE Stage 1)

Source: FHWA

https://safety.fhwa.dot.gov/intersection/ice/

General Process

Intersection Control Evaluation



Stage I is a scoping stage

- Initially consider a full array of options
- Use screening tools that consider operational and safety goals, project needs, and practicality
- Develop a short list of alternatives that merit further consideration and analysis to be carried into Stage II

Stage II is an alternative development & selection stage

- Objectively differentiates among the alternatives brought forward from the Stage I scoping analysis
- Preferred alternative(s) determined based on more detailed evaluations
  - Multimodal provisions
  - Safety performance
  - Operational performance
  - Lifecycle benefits and costs
  - Environmental, utility, and right-of-way impacts

Now part of Florida's Manual on Intersection Control Evaluation

FDOT

Florida Department of Transportation

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KEVIN J. THIBAULT, P.E.
SECRETARY

TRAFFIC ENGINEERING AND OPERATIONS BULLETIN 21-07

DATE: November 1, 2021

TO: District Traffic Operations Engineers, District Safety Administrators, District Design Engineers, District Project Development Engineers and Administrators

FROM: Trey Tillander
Director, Traffic Engineering and Operations

DocuSigned by: Trey Tillander D749973004EE41F... 10/28/2021

COPIES: Will Watts, Tim Lattner, Jennifer Marshall, State Traffic Engineering and Operations Office

SUBJECT: **Manual on Intersection Control Evaluation (ICE)**

This bulletin announces the release of the 2022 Manual on Intersection Control Evaluation (ICE) which is available on the State Traffic Engineering and Operations website: https://www.fdot.gov/traffic/trafficservices/intersection-operations.shtm

SUMMARY OF REVISIONS

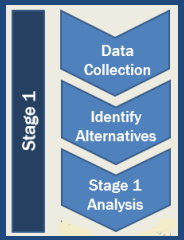
- **Chapter 2 Intersection Control Evaluation**
  - **Section 2.2:** Updated with the 2021 Strategic Highway Safety Plan (SHSP) and new intersection crash data. Added references to the FDOT Design Manual (FDM) and context classification and included ramp terminal intersections in SPICE.
  - **Section 2.3:** Updated to specifically exempt signalization at midblock crosswalk from ICE analysis.
  - **Section 2.4:** Updated with the reference to the 2021 FDOT Traffic Analysis Handbook.
  - **Section 2.5:**
    - Added language and Metrics in Stage 1, 2 and Table 3 and 4 regarding the addition of the Safe System for Intersections (SSI) safety analysis in SPICE.
    - Introduced new thru-cut intersection to ICE analysis.
    - Added further discussion on FDOT ICE Tool's Stage 2 form to include both with and without benefit-cost analysis and updated how to set up forms.
    - Added language regarding Stage 1 and Stage 2 ICE analysis in a PD&E Study and updated tables.
    - Added and modified tools and resources for ICE in Table 6.

Section 2.5:

- Added language and Metrics in Stage 1, 2 and Table 3 and 4 regarding the addition of the Safe System for Intersections (SSI) safety analysis in SPICE.

Appendix B FDOT ICE Forms

- Added thru-cut intersection to Stage 1 ICE Form (at-grade intersection).
- Added new Stage 1 ICE forms for ramp terminal intersections.
- Added discussion on setting up form for "At-Grade Intersection" or "Ramp Terminal Intersection" and then choosing the "Project Funding Source" in Stage 1 Form.
- Added new information required for "Ramp Terminal Intersections".
- Expanded the Screening Evaluation section for considerations in comparing SPICE's crash prediction to the SSI analysis and rank.
- Added SSI discussion under Safety Performance in Stage 2 ICE Form.



SPICE

SPICE
Safety Performance for Intersection Control Evaluation

Federal Highway Administration (FHWA)

Safety Performance for Intersection Control Evaluation Tool

Introduction	Overview
The Safety Performance for Intersection Control Evaluation (SPICE) Tool was developed to provide an easy-to-use tool that automates the predictive safety analysis of intersections. This tool will allow analysts conducting Intersection Control Evaluations (ICE) to be equipped with necessary safety information during the decision-making process, without having to research a myriad of crash modification factors (CMFs) and Safety Performance Functions (SPFs) in multiple sources. The SPICE tool will perform a comparative predictive safety analysis of different intersection control strategies. The results – crash frequency and severity for each alternative – will then enable safety performance of alternatives to be considered quantitatively like traffic operations, construction cost, maintenance cost, or other factors.	The SPICE Tool performs safety analysis of at-grade intersection forms/control types and ramp terminal intersections of diamond interchanges. This user-friendly tool requires only data inputs that are readily available to the analyst. In addition, the SPICE tool has an option to conduct planning level analysis, wher the tool assumes default values for data inputs that are challenging to obtain in the early stages of a project and/or have a very minor impact on the results. The SPICE tool assumes that certain attributes c the intersection – AADT, facility type, and number of legs – are the same for all alternatives. If they are not, users will be required to use the tool twice to get results. The tool will not allow simultaneous evaluation of at-grade intersections and ramp terminal intersections. For projects where analysis of both intersections and interchanges is needed, users are required use the tool twice to get results.

Worksheets

Project Information: Provide general project information for reference purposes only.
Definitions: Reference sheet with additional information related to inputs for the SPICE tool.
Control Strategy Selection: Choose between At-Grade or Ramp Terminal intersection types to be included in the SPICE analysis.
At-Grade Inputs: SPF and Part C CMF inputs for At-Grade intersections (hidden if Ramp Terminals are being analyzed).
Ramp Terminal Inputs: SPF and Part C CMF inputs for Ramp Terminal intersections (hidden if At-Grade intersections are being analyzed).
Calibration: Input optional override values for SPF calibration factors from locally-developed or updated information.
Results: Summary of opening year and (if applicable) design year and total project life cycle crash frequency and crash severity.
Additional Worksheets: Additional worksheets to support the underlying Macros. Not to be updated by users unless updating future tool versions.

SPICE
Safety Performance for Intersection Control Evaluation

Maintenance	Input Legend	
Version: SPICE Tool 1.0		Required data entry field
Maintained By: TBD		Optional data entry field
Contact Information: TBD		Planning-Level Default Input
Disclaimer		Data entry field not used

Introduction | Project Information | Definitions | Control Strategy Selection | At-Grade Inputs | Calibration | Historical | Results | Notes | User Selections | Labels

http://www.fdot.gov/traffic/trafficservices/Studies/MICE/SPICE_FDOT_V1_RAB.xlsm

SPICE FDOT V4.0

Safe System Intersection (SSI) Inputs

Specify the geomtric, exposure, severity, and conflicting traffic complexity inputs required for an SSI analysis.

1. Roadway Geometry	Lanes
Major number thru lanes (one direction)	2
Minor number thru lanes (one direction)	2

Optional Major Street Designation	
Select major street direction	N-S

	Required Inputs
	Default Available, Override Optional
	Planning-Level Default Input
	Computed Value, Override Optional
	Computed Value - No Override
	Disabled Cell (Often based on input selections)

2. Complete the "Exposure" inputs. These inputs will apply to all interesections selected for analysis.

3. Complete the "Severity" inputs

4. Complete the "Conflicting Traffic Complexity" inputs

2. Exposure - All Intersections

Average Daily Traffic (veh/day)	Open	Design
Major	--	--
Minor	--	--

ADT Directional Split	
Major	0.50
Minor	0.50

Nonmotorized Total ADT (ped/day)	Activity Level	ADT Val
Open Year Total Intersection NM	Medium (700)	7
Design Year Total Intersection NM	Medium (700)	7

(or overwrite ped movement ADTs below)

Nonmotorized Movement ADT (ped/day)	Open	Des
Major NM 1 (NM mvmt crossing Maj1)	175	1
Major NM 2	175	1
Minor NM 1	175	1
Minor NM 2	175	1

Are turning movement ADT values are available?	No	If "Yes", input values in Table 2-A
Are peak hour turning movement counts available?	No	If "Yes", input values in Table 2-B

If no turning movment volumes or counts are available, a user can optionally override the planning-level default turning movment proportions in Table 2-C

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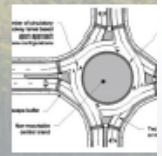
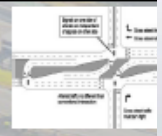
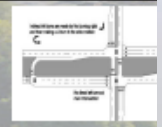
Introduction | Project Information | Definitions | Control Strategy Selection | At-Grade Inputs | SSI Inputs | Calibration | Historical | Results | SSI Results ...

SSI LIBRARY OF INTERSECTION TYPES

- Traditional:
  - Minor-road stop control (MRSC)
  - Signalized
  - All-way stop control (AWSC)
- Roundabout:
  - 1 x 1 (one entering lane, one circulating lane)
  - 2 x 1
  - 1 x 2
  - 2 x 2
- Restricted crossing U-turn (RCUT):
  - MRSC
  - Signalized
- Median U-turn (MUT)
- Bowtie
- Jughandle
- Quadrant roadway
- Partial displaced left turn (PDLT)
- Full displaced left turn (FDLT)

“Menu” of Intersection Alternatives

Title	Image	Description	Key Safety Benefits	Key Operational Benefits	Design/Applications	Tradeoffs
Single Lane Roundabout		Counterclockwise flow, yield at entry, low speed NCHRP-672 2nd Edition	Veh-veh conflicts reduced from 32 to 8; Veh-veh crossing conflicts eliminated; CRF range for severe crashes 78 to 82%	Speed reduction, reduces stops and approach delays (primarily off peak); access management limiting driveways near intersection	90-180 ft inscribed circle diameter; 25,000 vpd; traversable apron may better handle large vehicles with smaller radii	Site specific-typically low
Multilane Roundabout						Traffic control device (signs/markings) should be thoroughly planned to decrease lane changing or violating design lane use & be consistent with geometry and education efforts; somewhat larger than traditional intersection footprint
Restricted Cross-ing U-Turn (RCUT) (J-Turn, Super-street)						Heavy throughs and lefts from side street can marginalize main street timing benefits if signalized Accommodating emergency vehicle making crossing or left turn from minor street; see note 1.
Median U-Turn (MUT) (Michigan U-Turn)						Operations of restricting left turns at prima-ry intersections; need sufficient median widths; potential need for added signals at U -turn locations; Sufficient median width and loon for design vehicle; control left turn violations; pedestrian crossing may be to-staged depending on cycle
Thru-U Turn (Express Left)						Insignificant other than a secondary signal if justified
Displaced Left Turn (DLT) (Continuous Flow Intersection)						Increases intersection footprint; require-ment for signalized intersection upstream of primary intersection; disservice to nearby access (need for right-in right-out driveways); need for turn lane storage at both upstream and displaced locations; see note 1.

SECRET MENU

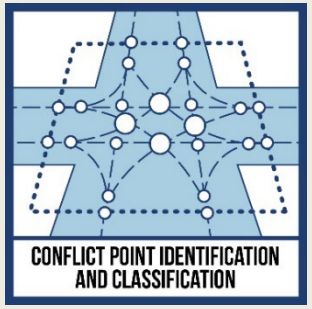
The Short Order *Menu of Innovative Intersections and Interchanges* provides a quick glance at more common intersection and interchange designs. All these designs have proven to reduce crashes and improve operations. Motorists, pedestrians, and bicyclists face greater mobility challenges and safety risks at both intersections and interchanges as traffic volumes grow and congestion worsens. Agencies need safer, more balanced designs that keep people moving. Innovative designs, such as the few highlighted here, offer many safety and operational benefits, and are being built more often because they can deliver more for less. The Menu is compiled from multiple sources by the Resource Center; all rights reserved. For more in depth information visit Fhwa's Office of Safety website at: https://safety.fhwa.dot.gov/interssection/ ; Alternative Intersections/Interchange Report (AIIR) FHWA-HRT-09-060

Notes: 1) Meeting pedestrian needs and accommodations can differ from traditional intersections. Refuge areas, detection location, APS, multistage crossings are common considerations Where the number of phases are reduced, as with alternative designs, more time is often an added benefit for pedestrians. 2) Loon-a widened pavement, arc-shaped area designed for turning paths of vehicles making a U-turn oftentimes incorporating a shoulder or throat of a street or road; a bulb-out. 3) A sketch analysis planning tool, Capacity Analysis for Planning for Junctions is available through FHWA and is useful in preliminary assessment and selection of an alternative intersection

SSI METHOD OVERVIEW

1. Conflict point identification and classification

Crossing, merging, diverging, nonmotorized



2. Conflict point exposure

Volumes (vehicular and nonmotorized)

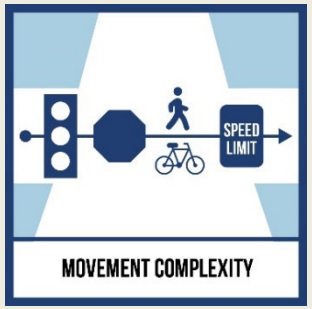
3. Conflict point severity (probability of FSI)

Vehicle-vehicle: speeds and conflict angles

Nonmotorized: speeds

4. Movement Complexity

- Conflicting traffic
- Traffic control devices
- Additional complexity for nonmotorized users

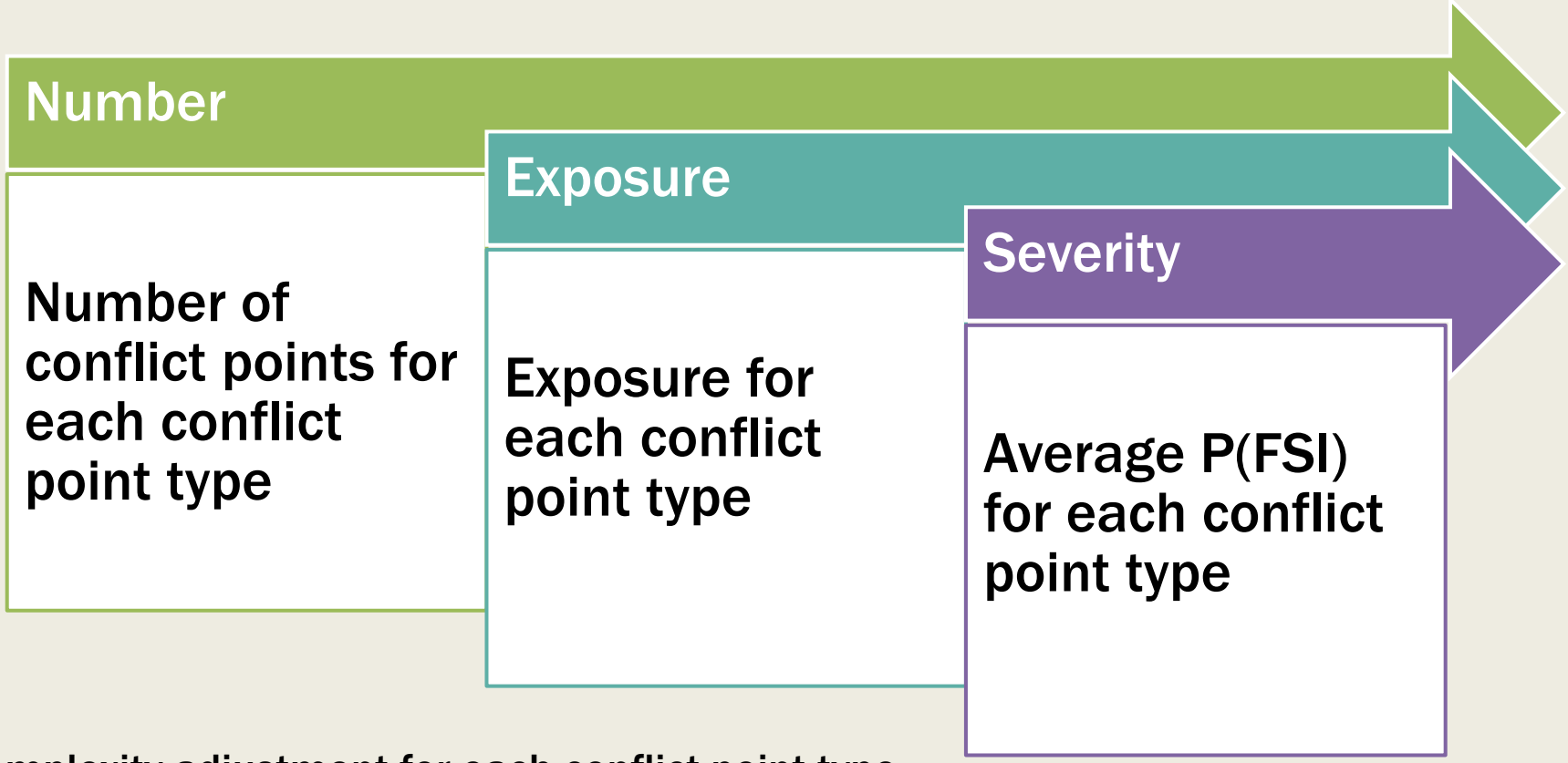


SSI DATA NEEDS

Required Operational and Geometric Inputs	Other Operational and Geometric Inputs
• Posted speed limit • AADT volumes • Number of through lanes in one direction on each approach	• Through, right-turning, left-turning, and U-turning movement speeds • Roundabout entering, circulating, and exiting movement speeds • Nonmotorized AADT volumes • Directional split • Turning movement proportions (or turning movement AADT volumes) • Left-turn traffic signal phasing (protected, protected/permitted, or permitted) • Collision angles between conflicting movements (may vary from default due to intersection skew)

SSI MEASURES OF EFFECTIVENESS (MOE)

For each conflict point type (crossing, merging, diverging & non-motorized):



Complexity adjustment for each conflict point type

SSI MEASURES

- Number of conflict points for each conflict point type
- Exposure for each conflict point type
- Average P(FSI) for each conflict point type
- Average complexity adjustment for each conflict point type

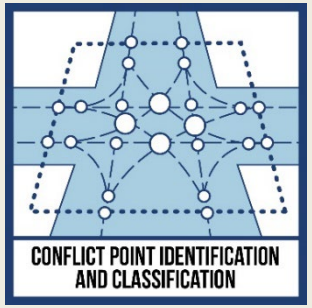
SSI Score

- The SSI measures are combined through an SSI score
- Range from 0 to 100
  - 100 = near Safe System (low probability of FSI)
- Conflict point type SSI scores + Intersection SSI score

SSI METHOD OVERVIEW

1. Conflict point identification and classification

Crossing, merging, diverging, nonmotorized



2. Conflict point exposure

Volumes (vehicular and nonmotorized)

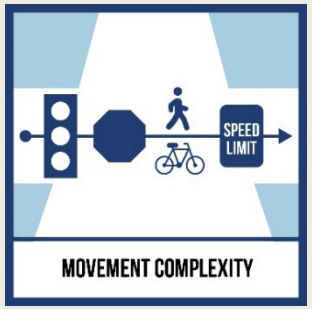
3. Conflict point severity (probability of FSI)

Vehicle-vehicle: speeds and conflict angles

Nonmotorized: speeds

4. Movement Complexity

- Conflicting traffic
- Traffic control devices
- Additional complexity for nonmotorized users



Intersection conflicts have different speeds and collision angles

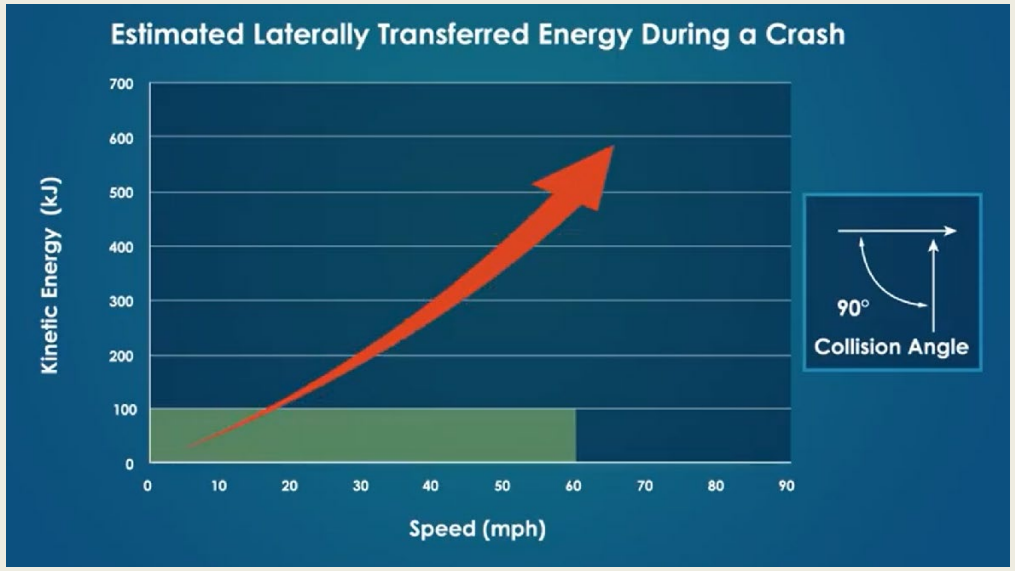
INTERSECTION CONFLICT POINT CATEGORIZATION

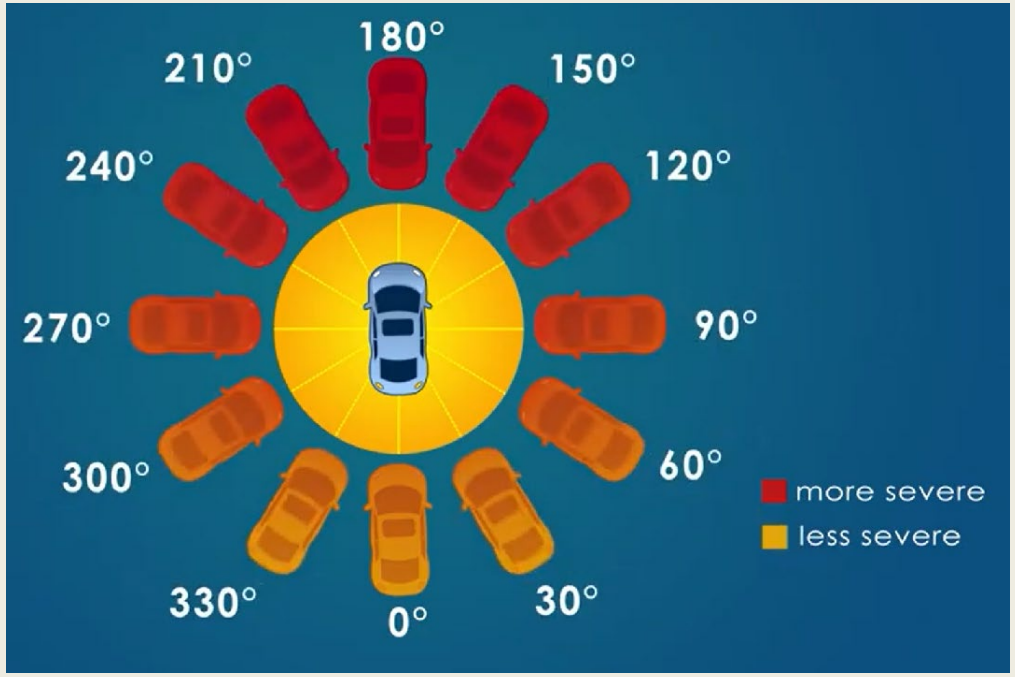
Crossing conflict point—vehicle paths come from different traffic streams, intersect, and then proceed as two separate traffic streams

Merging conflict point—vehicle paths come from different traffic streams and converge into the same traffic stream

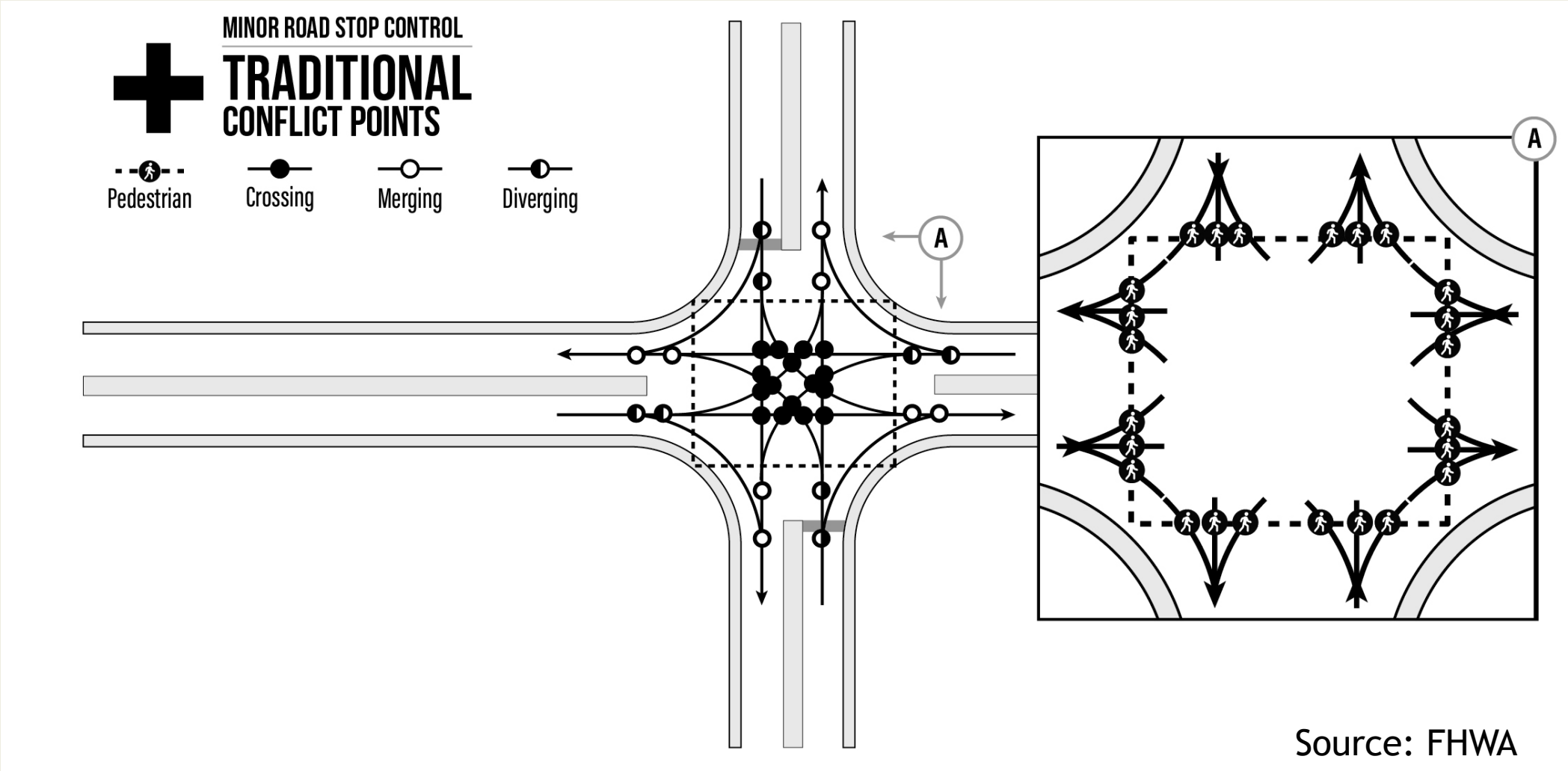
Diverging conflict point—vehicle paths diverge from a single traffic stream into two separate traffic streams

Nonmotorized conflict point—a vehicle path crosses a pedestrian/cyclist path





CONFLICT POINTS: MOVEMENT BASIS



Source: FHWA

CONFLICT POINT IDENTIFICATION & CLASSIFICATION

- SSI version 1.0 assumptions and limitations:

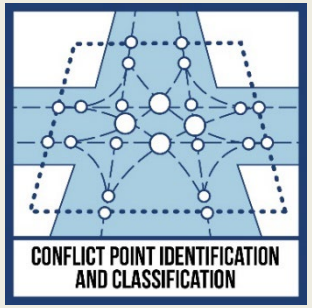
  - Does not consider rear-end conflicts that result from speed differentials that arise from traffic congestion or deceleration and stopping due to traffic control devices.

  - Assumes that bicyclists follow the same paths as pedestrians through intersections.

SSI METHOD OVERVIEW

1. Conflict point identification and classification

Crossing, merging, diverging, nonmotorized



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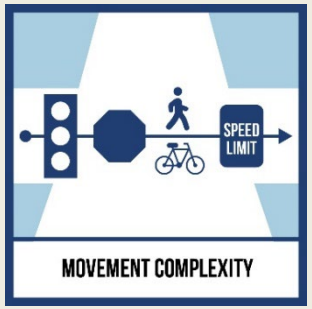
3. Conflict point severity (probability of FSI)

Vehicle-vehicle: speeds and conflict angles

Nonmotorized: speeds

4. Movement Complexity

- Conflicting traffic
- Traffic control devices
- Additional complexity for nonmotorized users



EXPOSURE INDEX AT EACH CONFLICT POINT, I_c

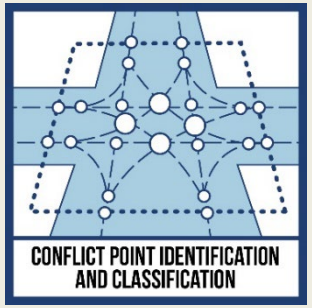
$$I_c = Q_{1,c} * Q_{2,c}$$

- I_c = Exposure Index at conflict point c
- $Q_{1,c}$ and $Q_{2,c}$ are determined using the daily volumes, turning movements, and intersection geometry

SSI METHOD OVERVIEW

1. Conflict point identification and classification

Crossing, merging, diverging, nonmotorized



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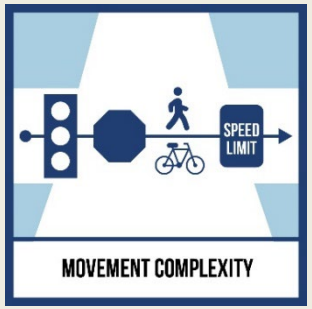
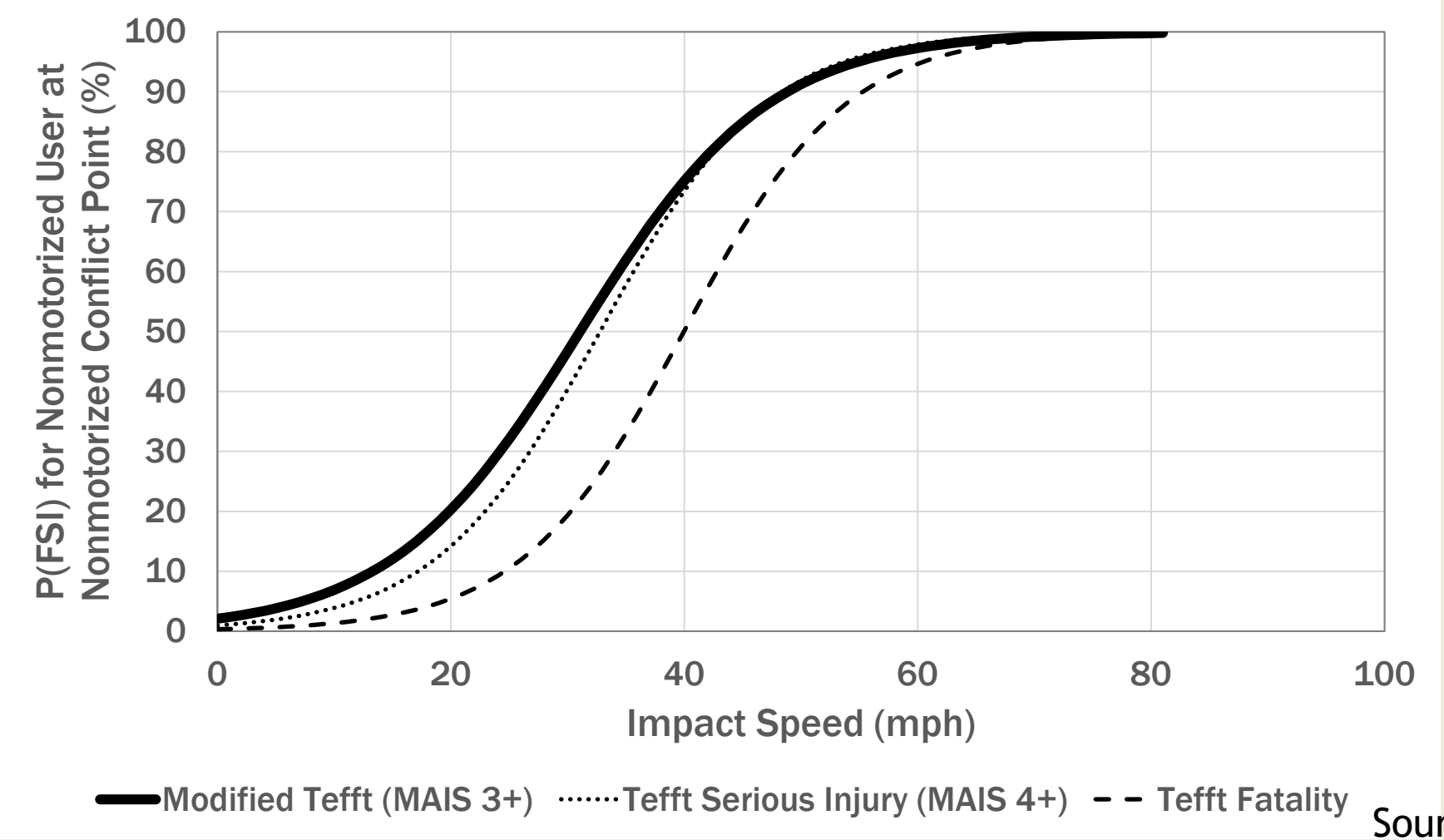


CONFLICT POINT SEVERITY: NONMOTORIZED CONFLICT POINTS



The SSI method defines fatal and serious injuries as injuries with abbreviated injury scale (AIS) scores of 3 or above.

Source: FHWA

CONFLICT POINT SEVERITY: INJURY SCALE

AIS Code	Injury	Example Injury	Probability of Death (%)
0	None	No injury	0
1	Minor	Superficial laceration	0
2	Moderate	Fractured sternum	1 – 2
3	Serious	Open humerus fracture	8 – 10
4	Severe	Perforated trachea	5 – 50
5	Critical	Ruptured liver with tissue loss	5 – 50
6	Maximum	Total severance of aorta	100

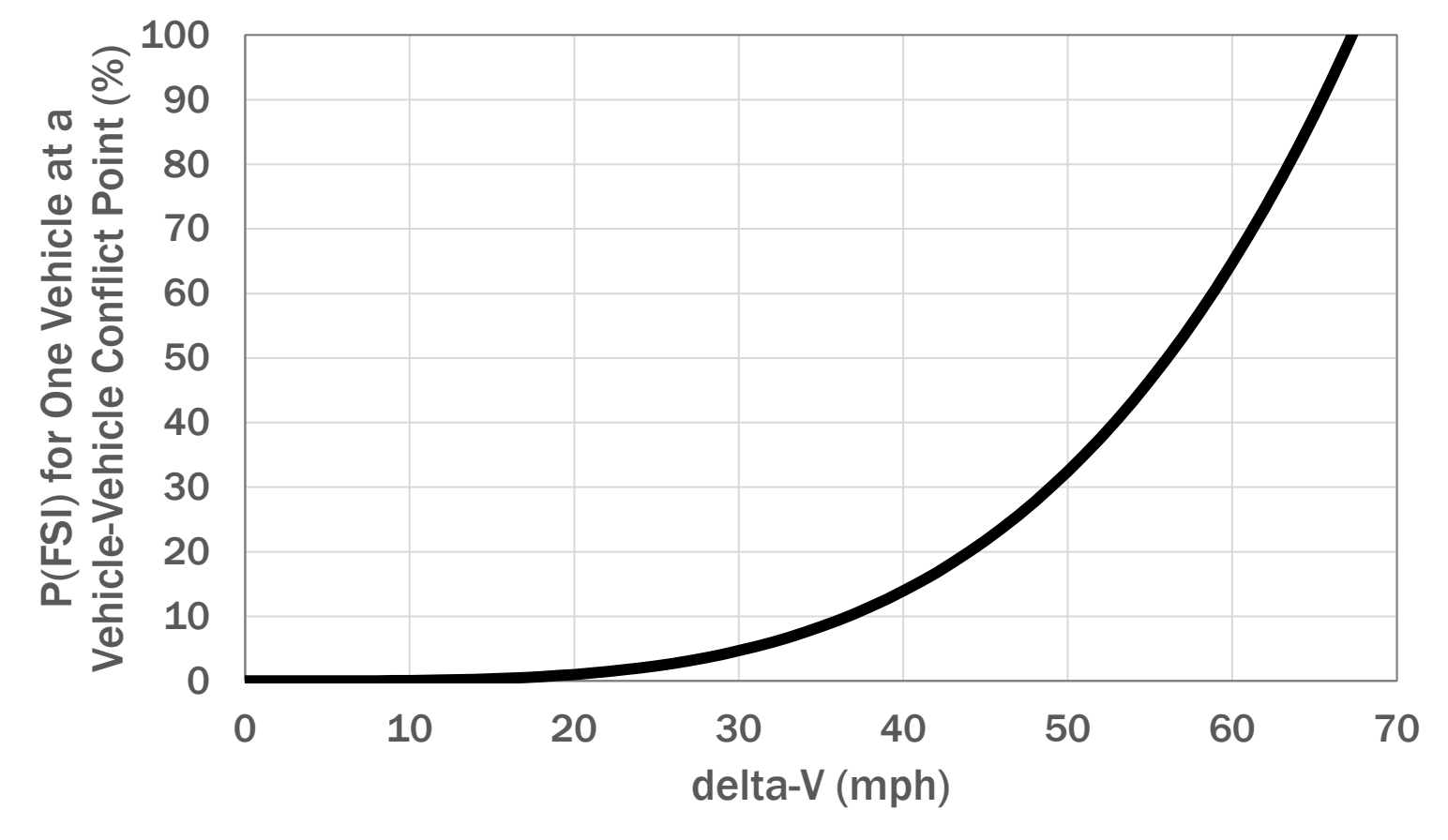
Note: AIS = abbreviated injury score.

Source: FHWA

The SSI method defines fatal and serious injuries as injuries with abbreviated injury scale (AIS) scores of 3 or above.

CONFLICT POINT SEVERITY: VEHICLE-TO-VEHICLE CONFLICT POINTS

- P(FSI) – probability of at least one fatality or serious injury as a result of a crash between conflicting road users making the typical movements that define the conflict point.



Source: FHWA

SPEED AND ANGLE ASSUMPTIONS

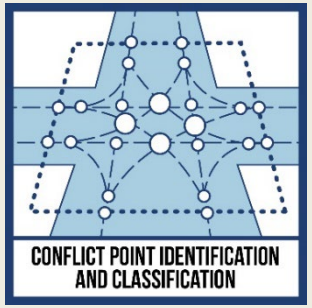
Speed Category	Speed (mph)	
	Low End	High End
Major through	0.9 * Major PSL	1.1 * Major PSL
Major left	10	30
Major right	10	20
Minor through	0.7 * Minor PSL	Minor PSL
Minor left	10	30
Minor right	10	20
Stop control near-side	10	20
Stop control far-side	20	30
Signal control near-side	10	20
Signal control far-side	20	30
Roundabout entering	10	20
Roundabout circulating	15	25
Roundabout exiting	20	30

Collision Type	Typical Collision Angle Range (deg)
Crossing – Broadside	80 – 100 (or 260 – 280)
Crossing – Left Turn	220 – 240
Crossing – Roundabout	45 – 75
Merging	30 – 60 (or 300 – 330)
Diverging	0 – 20 (or 340 – 360)

SSI METHOD OVERVIEW

1. Conflict point identification and classification

Crossing, merging, diverging, nonmotorized



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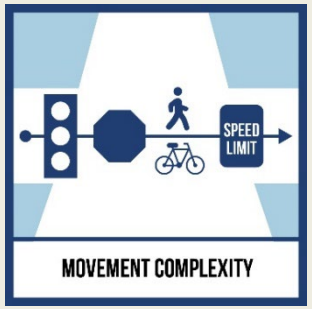


MOVEMENT COMPLEXITY (USER WORKLOAD)

- SSI method quantifies complexity (based on user workload) of different movements, while accounting for traffic control
- Conflicting Traffic Complexity Factor (L_1):
  - Traffic Control Parameter
  - Conflicting Lanes Parameter
  - Conflicting Speed Parameter
- Pedestrian Movement Complexity Factor (L_2)

CONFLICTING TRAFFIC COMPLEXITY FACTOR

Traffic Control Parameter

- Accounts for complexity reduction when certain movements are separated in time by the type of traffic control

Conflicting Lanes Parameter

- Accounts for added complexity of larger intersections (more lanes)
- Additional "Scores" for Cross, Merge, & Total Turn
- Motorized and nonmotorized

Conflicting Speed Parameter

- Accounts for the added complexity of judging for gaps under higher speeds

CONFLICTING TRAFFIC COMPLEXITY FACTOR (L_1)

SSI version 1.0

$$L_1 = a_{traffic\ control} * a_{conflicting\ lanes} * a_{conflicting\ speed}$$

$a_{traffic\ control}$ = traffic control parameter

$a_{conflicting\ lanes}$ = conflicting lanes parameter

$a_{conflicting\ speed}$ = conflicting speed parameter

TRAFFIC CONTROL PARAMETER

Accounts for the reduction in complexity when certain movements are separated in time by the type of traffic control

$$a_{traffic\ control} = BTCAV + (1 - f) * (1 - BTCAV)$$

- Base traffic control adjustment value (BTCAV):
  - Permitted: 1.0.
  - Protected/Permitted: 0.6 – 0.9 (based on CMF Clearinghouse ID 4270).
  - Protected: 0.005 – 0.015 (based on CMF ID 333).
  - Stop-Control: 0.4 – 0.5 (based on CMF ID 309, inverse).

- *f*: a weight given to the use of traffic control devices, and user compliance to those traffic control devices, to separate conflicts. (Adjust based on local experiences.)

CONFLICTING TRAFFIC COMPLEXITY FACTOR

Traffic Control Parameter

- Accounts for complexity reduction when certain movements are separated in time by the type of traffic control

Conflicting Lanes Parameter

- Accounts for added complexity of larger intersections (more lanes)
- Additional "Scores" for Cross, Merge, & Total Turn
- Motorized and nonmotorized

Conflicting Speed Parameter

- Accounts for the added complexity of judging for gaps under higher speeds

CONFLICTING LANES PARAMETER

Accounts for the overall intersection size and complexity of user workload when making specific movements through the intersection

$$a_{conflicting\ lanes,\ veh} = \text{Cross Score}_{veh} + \text{Merge Score}_{veh}$$

$$a_{conflicting\ lanes,\ nonmotorized} = \text{Cross Score}_{nonmotorized} + \text{Total Turn Score}_{nonmotorized}$$

1. Major through and right turn
2. Major left turn
3. Minor through and right turn
4. Minor left turn
5. Nonmotorized

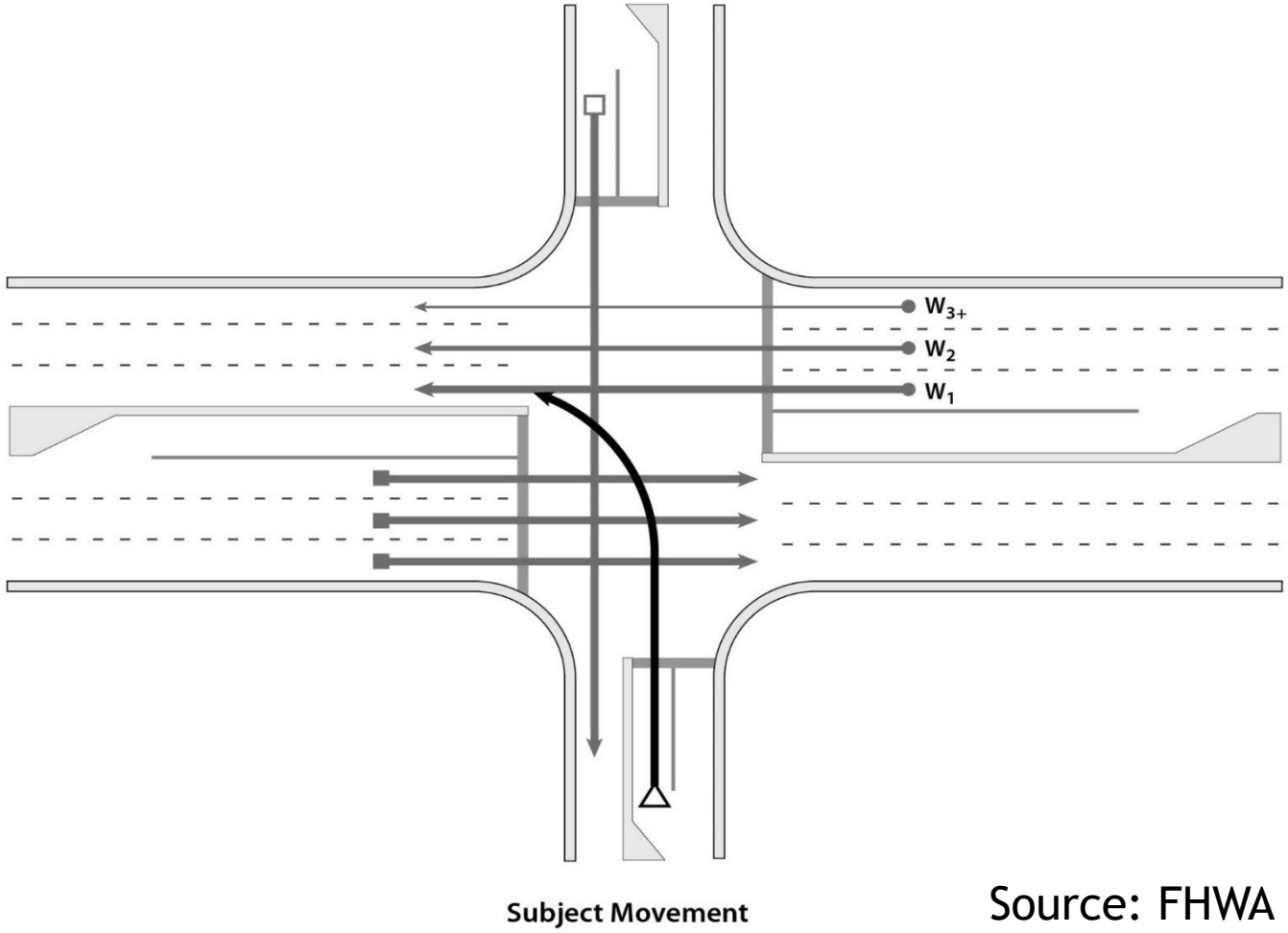
The parameter is based on the number of lanes that carry conflicting traffic movements for the selected movement of interest

CROSS SCORE$_{VEH}$

Example:

For the left-turn movement shown in this example, the movement crosses 3-lanes of the major road (eastbound lanes) and one oncoming southbound lane

Crossing Score = 4



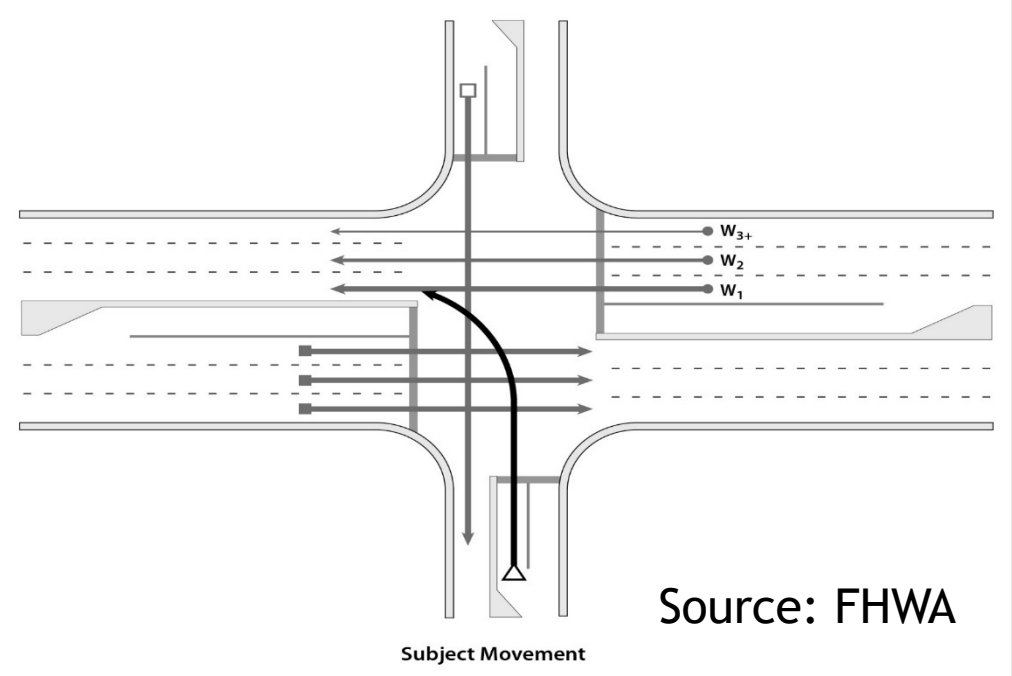
Source: FHWA

MERGE SCORE$_{VEH}$

- Considers the number of lanes on the intersection approach that the subject movement is merging with, N_M.

Number of Through Lanes on Merge Approach (N_M)	Merge Score
1	M
2	$M(1 + W_2)$
3+	$M[1 + W_2 + W_{3+}(N_M - 2)]$

Merge score$_{veh}$ (subject movement) = $1[1 + 0.75 + 0.5(3 - 2)] = 2.25$



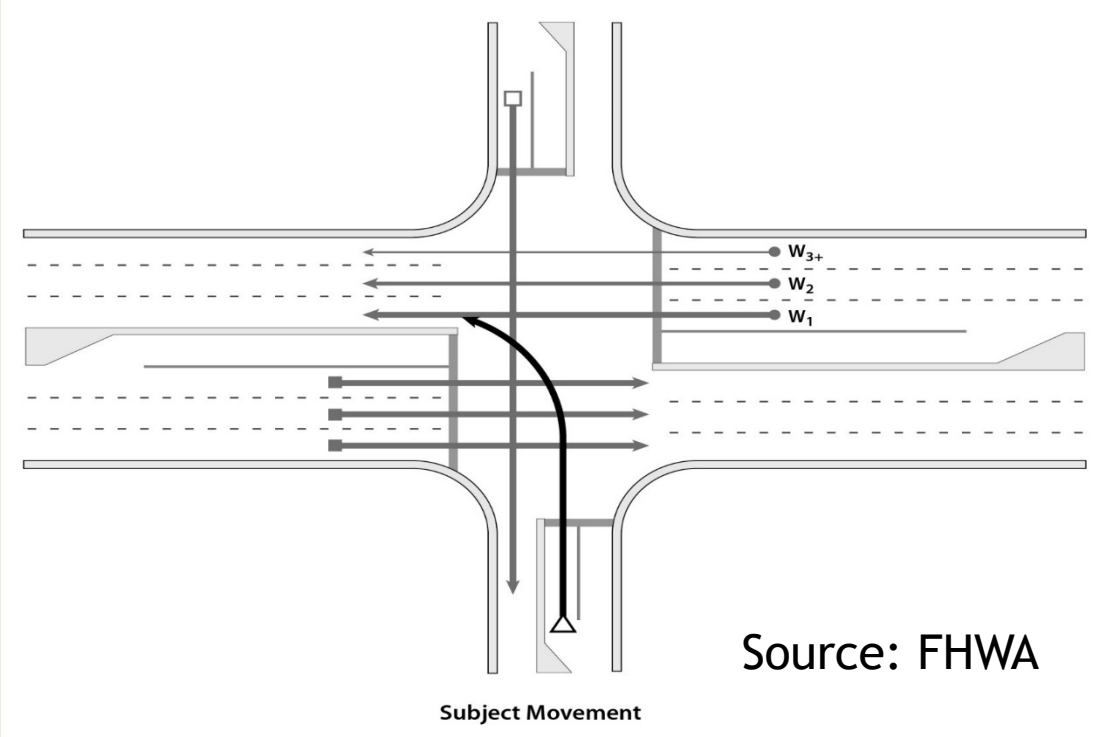
W2 and W3+ represent the merging weights for Lane 2 (the lane adjacent to the lane the driver is merging into) and Lane 3+ (any lanes beyond Lane 2) accounting for the relative level of attention needed from the driver for selecting a gap.

CONFLICTING LANES PARAMETER

The merge score is added to the cross score to determine the overall conflicting lanes parameter

- Cross Score$_{veh}$ (subject movement) = 4
- Merge Score$_{veh}$ (subject movement) = 2.25

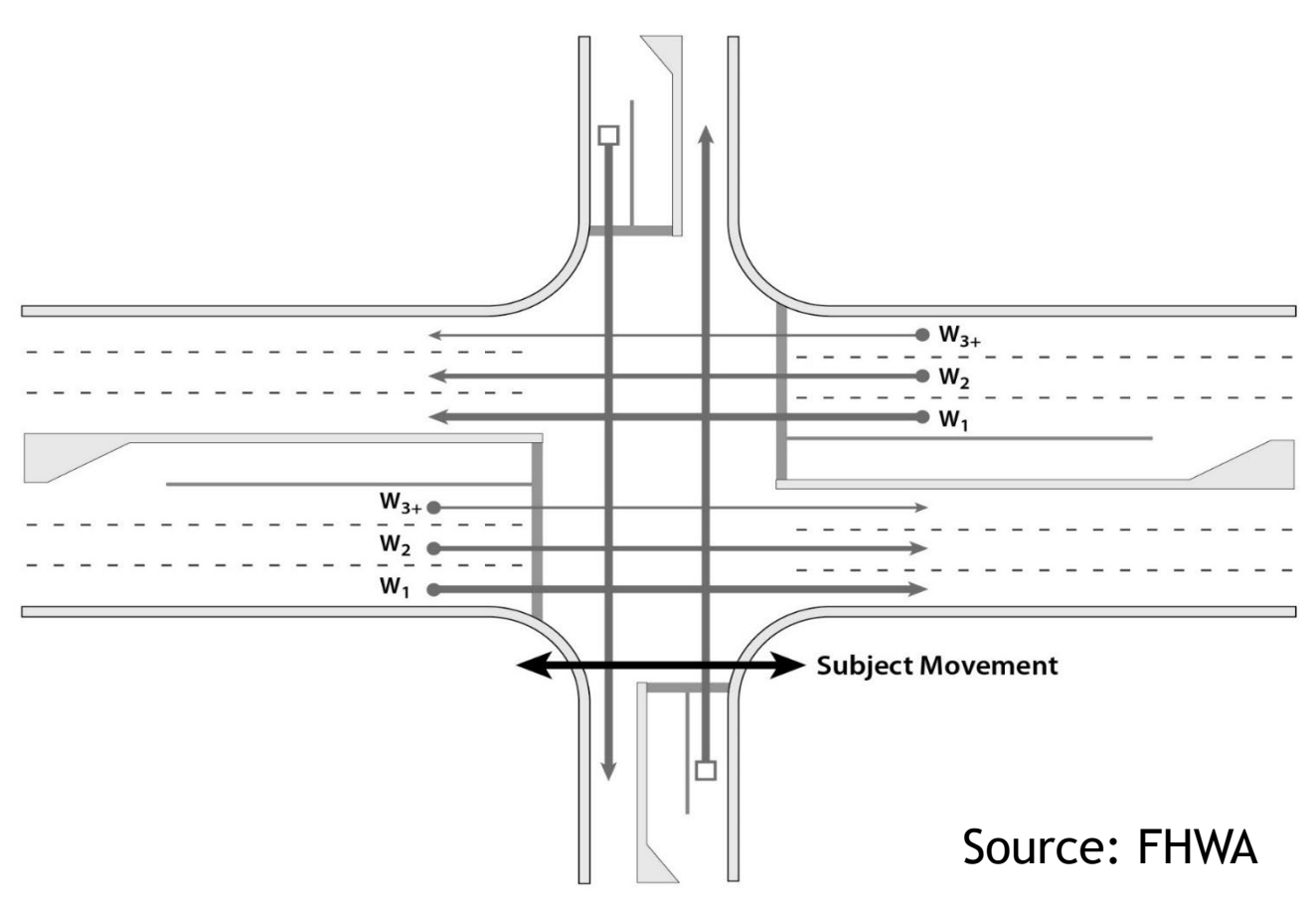
- $a_{conflicting\ lanes,veh}$ (subject movement) = 6.25



Source: FHWA

CROSS SCORE$_{NONMOTORIZED}$

- The maximum number of through lanes that the nonmotorized movement must cross without refuge (turn lanes are not considered in the current SSI method)

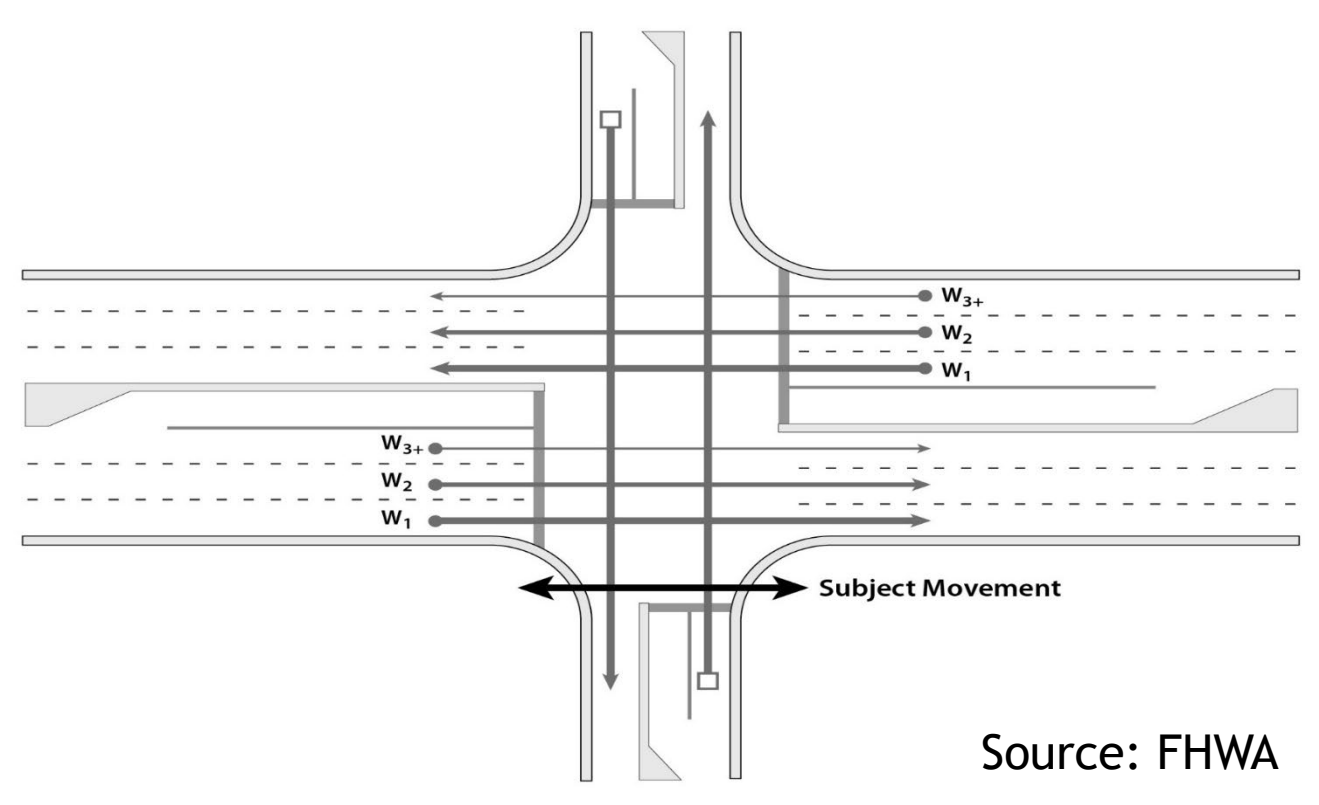


Source: FHWA

TOTAL TURN SCORE$_{NONMOTORIZED}$

Considers complexity added by pedestrians or cyclists checking for oncoming vehicles from approaches parallel to their movement.

Number of Through Lanes on Parallel Approach (N_P)	Approach Nonmotorized Turn Score
1	1
2	$1 + W_2$
3+	$1 + W_2 + W_{3+}(N_P - 2)$



Source: FHWA

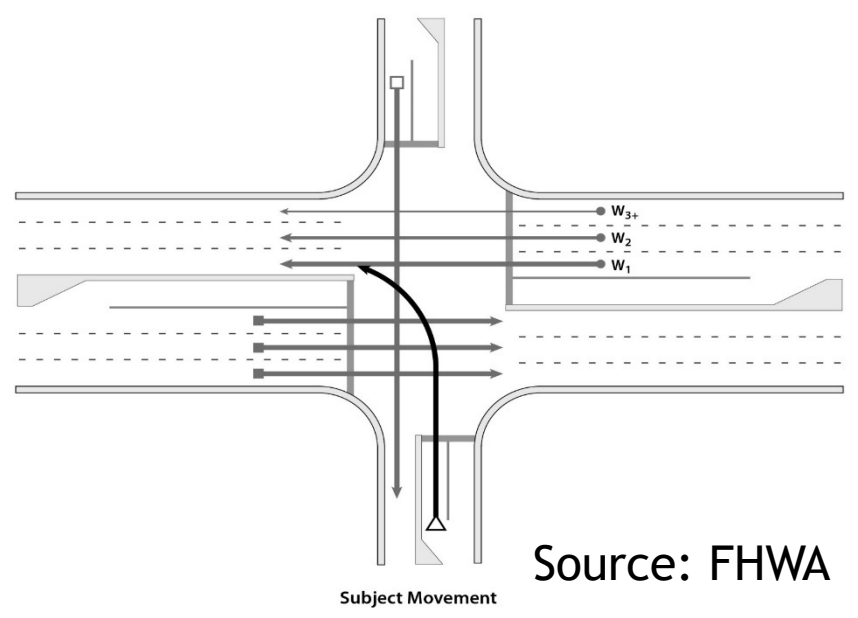
Total turn score$_{nonmotorized}$ (subject movement) = 1[1 + 0.75 + 0.5(3 – 2)] + 1[1 + 0.75 + 0.5(3 – 2)] = 2.25 + 2.25 = 4.5

CONFLICTING LANES PARAMETER, NONMOTORIZED

The cross score is added to the total turn score to determine the overall conflicting lanes parameter for a nonmotorized movement

- Cross Score$_{nonmotorized}$(subject movement) = 2
- Total Turn Score$_{nonmotorized}$ (subject movement) = 4.5

- $a_{conflicting\ lanes,nonmotorized}$ (subject movement) = 6.5



Source: FHWA

CONFLICTING TRAFFIC COMPLEXITY FACTOR

Traffic Control Parameter

- Accounts for complexity reduction when certain movements are separated in time by the type of traffic control

Conflicting Lanes Parameter

- Accounts for added complexity of larger intersections (more lanes)
- Additional "Scores" for Cross, Merge, & Total Turn
- Motorized and nonmotorized

Conflicting Speed Parameter

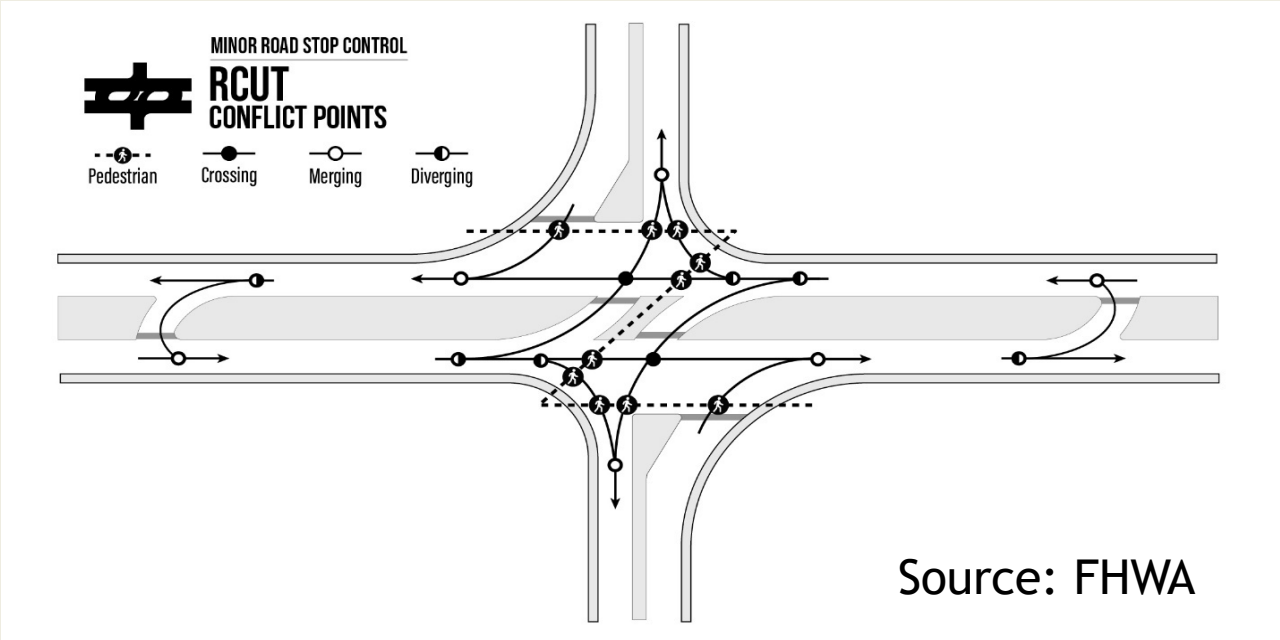
- Accounts for the added complexity of judging for gaps under higher speeds

CONFLICTING SPEED PARAMETER, $A_{CONFLCTING\ SPEED}$

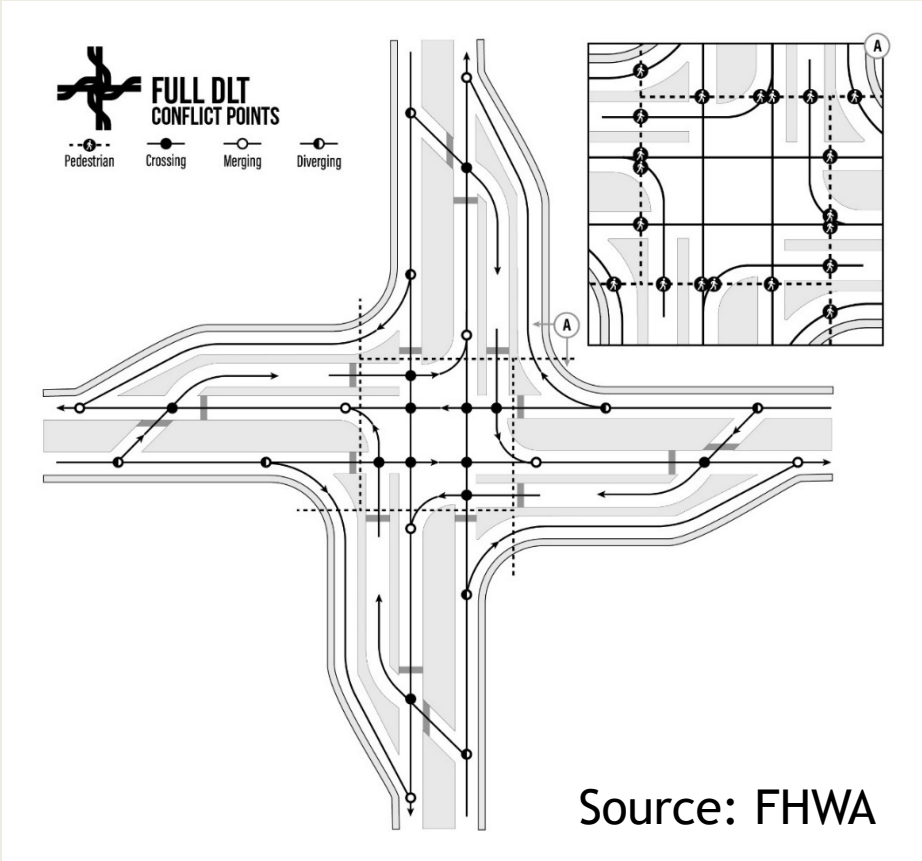
- Accounts for road user need to judge the speeds of conflicting traffic at the intersection when searching for a gap
- Higher speeds of conflicting traffic increases the complexity
- The SSI method defines the conflicting vehicle speed, V_c, as the highest speed of all the conflicting traffic streams
- Conflicting Speed parameter is computed based on a 60 mph top threshold (arbitrary) and research supporting that a 10% reduction in speed is associated with a 15% reduction in crash likelihood (Campbell et al., 2012):

$$a_{conflicting\ speed} = 1 - \left(\frac{60 - V_C}{60} * \frac{0.10}{0.15}\right)$$

NONMOTORIZED MOVEMENT COMPLEXITY FACTOR, L_2



Source: FHWA



Source: FHWA

$$L_2 = 1 + i_{indirect} + i_{non-intuitive}$$

$i_{indirect}$ = indirect paths indicator

$I_{non\text{-}intuitive}$ = nonintuitive motor vehicle movements indicator

DERIVING AN SSI SCORE

- Each conflict point has an exposure index, severity, and either one (for vehicle-vehicle conflict points) or two (for nonmotorized conflict points) complexity factors
- The individual concepts are combined through an SSI score
- The method produces an SSI score for each conflict point type (i.e., crossing, merging, diverging, nonmotorized) as well as for the overall intersection

The SSI score ranges from 0 to 100, with 100 representing a near Safe System (i.e., very low probability of a fatality or serious injury) for the users considered by this method.

SUM OF EXPOSURE-SEVERITY-COMPLEXITY PRODUCTS

Number of conflict points of type t

Exposure index

Severity

Nonmotorized Movement Complexity Factor

$$E_t = \sum_{i=1}^{n_t} \left[I_{i,t} * \mathrm{P(FSI)}_{i,t} * L_{1,i,t} * L_{2,i,t} \right]$$

Conflict Point Type
t = crossing, merging, diverging, or nonmotorized

Conflicting Traffic Complexity Factor

SSI SCORES FOR CONFLICT POINT TYPES

$$SSI_t = 100 \times \exp\left(-\frac{1}{z} \times E_t\right)$$

SSI score for conflict point type *t*.
t = crossing, merging, diverging, or nonmotorized.

Factor to normalize scores between 0 and 100 (equals 1.37×10^7).

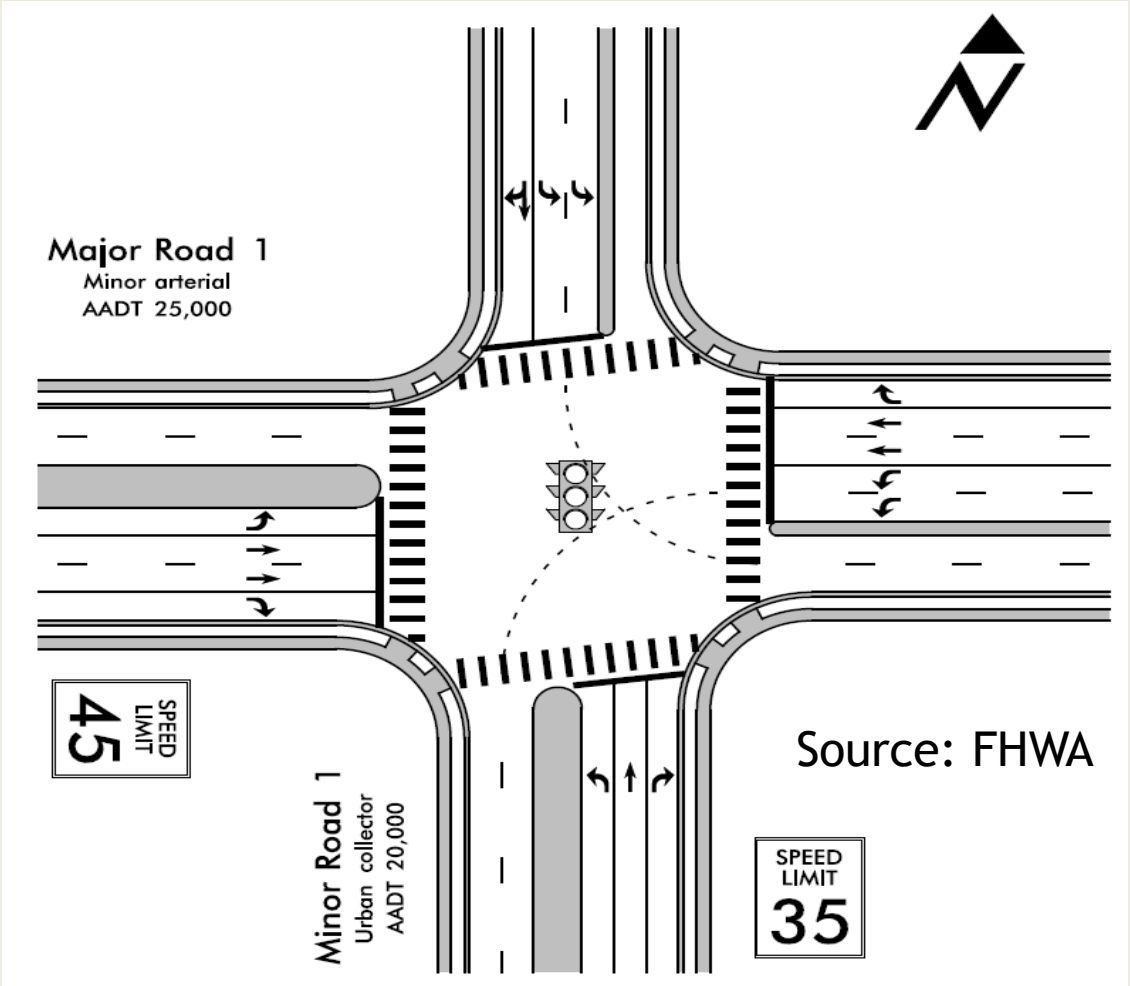
SSI SCORES FOR INTERSECTION

$$SSI_{int} = 100 \times \exp\left[-\frac{1}{z} \times \left(E_{crossing} + E_{merging} + E_{diverging} + E_{pedestrian}\right)/4\right]$$

SSI score for the intersection

EXAMPLE 1

Item	Input Value
Area type	Suburban
Functional classification – major	Minor arterial
Functional classification – minor	Collector
Design year AADT – major	25,000
Design year AADT – minor	20,000
Number of thru lanes – major	4
Number of thru lanes – minor	2
Traffic control type	Signalized
Posted speed limit – major	45
Posted speed limit – minor	35
Nonmotorized average daily traffic	2,400



Source: FHWA

CAPACITY ANALYSIS FOR PLANNING OF JUNCTIONS (CAP-X) RESULTS FOR EXAMPLE 1

Type of Intersection	Overall V/C Ratio	V/C Ranking
Quadrant Roadway	0.25	1
FDLT	0.27	2
MUT	0.31	T3
2x2 Roundabout	0.31	T3
PDLT	0.32	5
Bowtie	0.40	6
Signalized Traditional (existing)	0.44	7
Signalized RCUT	0.48	8
2x1 Roundabout	0.53	9
1x1 Roundabout	0.63	10
Unsignalized RCUT	0.85	11
AWSC Traditional	1.36	12
MRSC Traditional	1.38	13
Jughandle*	–	–

* The Jughandle intersection is not included in CAP-X, but it has the capacity to handle high intersection volumes.

SPICE RESULTS FOR EXAMPLE 1

Control Strategy	Predicted Crashes in Design Year (crashes/year)	
	Fatal & Injury	Total
Unsignalized RCUT	0.53	1.69
MUT	1.24	4.08
Jughandle	1.31	3.55
Signalized RCUT	1.38	4.08
FDLT	1.55	4.22
Signalized Traditional (existing)	1.77	4.80
2x2 Roundabout	No SPF	2.29
2x1 Roundabout*	–	–
Quadrant Roadway*	–	–
PDLT*	–	–
Bowtie*	–	–

* These intersection types are not included in SPICE but are included in the SSI library of intersections.

SSI SCORE RESULTS

Intersection Type	Intersection SSI Score	Conflict Type SSI Scores			
		Nonmotorized	Crossing	Merging	Diverging
2x1 Roundabout	52	8	93	98	100
MUT	44	10	52	83	88
2x2 Roundabout	42	4	90	98	100
Signalized RCUT	40	5	74	77	86
Bowtie	31	4	23	94	96
Quadrant Roadway	30	6	14	93	94
Jughandle	27	3	18	93	97
Signalized Traditional (existing)	24	2	19	93	100
Unsignalized RCUT	19	0	65	69	86
FDLT	10	0	32	91	97
PDLT	9	0	26	91	97

RELATIVE EXPOSURE, AVERAGE *P(FSI)*, AND AVERAGE COMPLEXITY ADJUSTMENT RESULTS FOR EXAMPLE 1

Intersection Type	Relative Exposure (Relative to Existing)				Average *P(FSI)*				Average Complexity Adjustment			
	NM	Cross	Merge	Diverge	NM	Cross	Merge	Diverge	NM	Cross	Merge	Diverge
2x1 Roundabout	1.00	1.00	1.51	1.49	0.33	0.00	0.00	0.00	1.83	0.92	0.99	1.00
MUT	1.25	0.84	2.58	2.88	0.33	0.04	0.01	0.00	1.04	0.84	0.77	1.00
2x2 Roundabout	1.00	1.00	1.51	1.49	0.33	0.00	0.00	0.00	2.44	1.22	1.15	1.00
Signalized RCUT	1.22	0.19	3.31	3.25	0.28	0.09	0.01	0.00	1.73	0.84	0.77	1.00
Bowtie	1.25	0.94	2.46	2.43	0.34	0.04	0.01	0.00	1.84	1.68	1.01	1.00
Quadrant Roadway	1.00	1.34	1.57	1.77	0.27	0.04	0.01	0.00	1.84	1.34	0.96	1.00
Jughandle	1.07	1.11	1.28	1.20	0.29	0.04	0.01	0.00	2.08	2.00	1.23	1.00
Signalized Traditional (existing)	**1.00**	**1.00**	**1.00**	**1.00**	**0.29**	**0.04**	**0.01**	**0.00**	**3.15**	**2.03**	**1.53**	**1.00**
Unsignalized RCUT	1.22	0.19	3.31	3.25	0.31	0.09	0.01	0.00	3.06	1.21	1.11	1.00
FDLT	1.00	0.89	1.00	1.00	0.32	0.04	0.01	0.00	4.37	1.30	2.01	1.00
PDLT	1.00	0.96	1.00	1.00	0.32	0.04	0.01	0.00	4.74	1.70	2.12	1.00

CONCLUSIONS AND FUTURE WORK

- Support application and improvement of the method.
- Adjusting or calibrating SSI scores for local conditions
  - Establish link between SSI scores and number of intersection crashes
  - Calibrate SSI parameters using observed crash data
- Based on fatal and serious injury crashes (AIS)
  - Requires link between crash data and hospital records
  - Surrogate analysis could use “KA” crashes

QUESTIONS