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Department of Technology Systems

Using Computer Vision Technology to Create Smart Work Zones

Work Zone Crashes in NC

January 1, 2008 – July 31,2018

Number of Accidents	Severity	Average (per year)
2973	B (NON-INCAPACITATING INJURY)	281
325	A (INCAPACITATING INJURY)	31
200	K (FATAL)	19

K-Level : fatal (deaths that occur within twelve months of the crash)
A-Level: incapacitating injury (injuries serious enough to prevent normal activity for at least one day such as massive loss of blood, broken bones, etc.)
B-Level: non-incapacitating injury (non-K or A injuries that are evident at the scene such as bruises, swelling, limping, etc.)

Work Zone Crashes in NC

DESCRIPTION	%
REAR END, SLOW OR STOP	32.9
FIXED OBJECT	12.6
ANGLE	9.1
OVERTURN/ROLLOVER	5.5
PEDESTRIAN	5.2
SIDESWIPE, SAME DIRECTION	4.9
LEFT TURN, SAME ROADWAY	4
RAN OFF ROAD - RIGHT	4
HEAD ON	3.1
MOVABLE OBJECT	2.4
SIDESWIPE, OPPOSITE DIRECTION	2.4
RAN OFF ROAD - LEFT	2.4
OTHER NON-COLLISION	2
OTHER COLLISION WITH VEHICLE	1.1
PARKED MOTOR VEHICLE	1

Two focus areas emerge

- Queue detection and alerts
- Work zone intrusion detection and alerts

January 1, 2008 – July 31,2018

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Worker Safety

Year	Number of WZ Intrusion Fatalities in NC	Number of Fatal Accidents Involving Worker Fatality
2011	1	0
2012	2	1
2013	1	1
2014	4	1
2015	2	2
2016	2	1
2017	0	0
2018 (Jan - July)	1	0

Road construction is one of the most dangerous occupations in the United States.

Road Workers are 6 times more likely to be injured or killed on the job compared to other professions.

Work activity type involved in WZ crashes

Type of Work	%
Construction work area	79.5
Intermittent/moving Work	3.4
Maintenance work area	12.6
No	1.1

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Work Zone Intrusion Detection

- Commonly reported issues with existing products:
  - difficulties in deployment,
  - high false alert rates,
  - cost ($1,200 - $6,000),
- Computer vision based approaches may address some of the issues
  - Easier to setup
  - Promising AI based object detection technology
  - Becoming more cost effective
  - Flexible implementation
  - Suitable for both long-term construction and short-term maintenance project deployments or moving work

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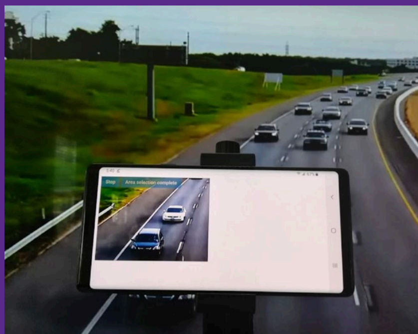
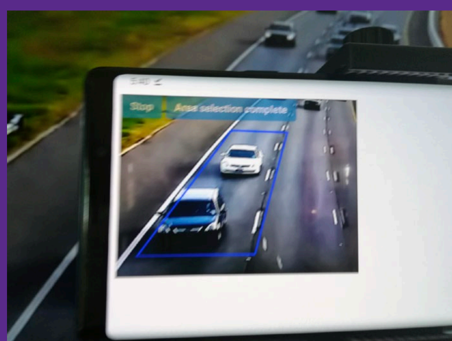
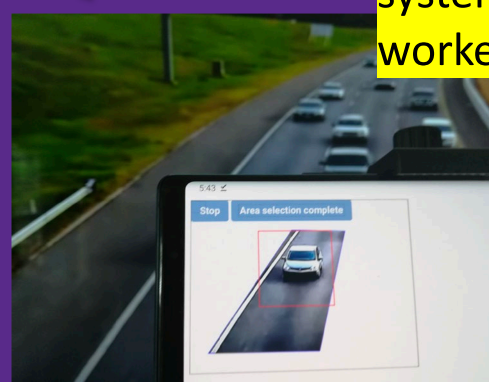
ECU Proof-of-concept WZ Intrusion System



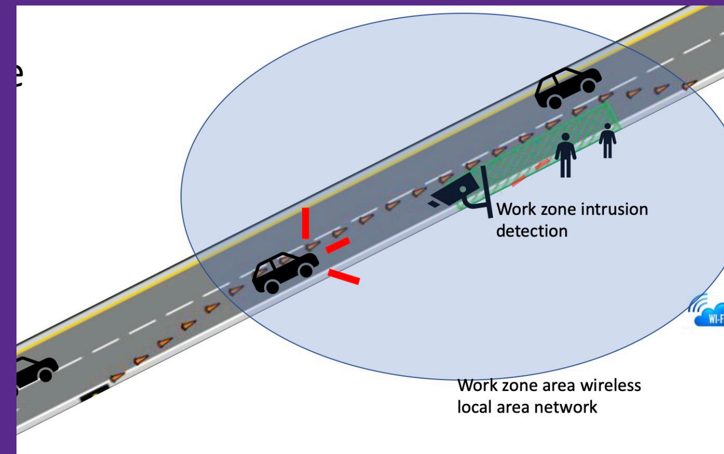
Position the camera



Select the polygon area to monitor



When intrusion detected, the system alerts workers



Alert systems embedded in safety vests

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Selection of Polygons

Google Vision Kit AIY
$89.99

Intel’s Movidius
With neural compute
engine

Lab setup at ECU

TensorFlow Lite: lightweight solution for mobile and embedded devices. Capability run on Android, iOS and various embedded systems (Raspberry Pi and Edge TPUs).
TensorFlow.js: Enables deploying models in JavaScript environments (e.g. in a web browser or server-side with Node.js). Supports defining models in JavaScript. Training directly in the web browser is possible.

goal: cost < $500 (sensor + 2 wearable alert devices)

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In-situ Transfer Learning to Boost Detection Accuracy

Data gathered in the field

Original Model

New Improved Model

Transfer Learning on location

AI Based Solutions Becoming More Cost-effective

- Low-cost hardware becoming available
- Model training time/required computing power can be reduced via transfer learning
- Open source object detection models
- AI development becoming easier (new TensorFlow release)

Conclusions/Thoughts

- Pragmatic short term solutions have potential to provide considerable safety improvements in WZ
- AI based computer vision solutions have potential for short term deployment
- Focusing on a pragmatic set of areas has potential to provide short/mid term benefits. Possible focus areas:
  - Queue detection
  - WZ intrusion detection
  - Methods to provide early warnings to large trucks
  - Push notification server to disseminate alerts

Questions? Comments?

ECU

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Quadrant Roadway Intersection Guidebook

an NCDOT Research & Innovation Summit Presentation

May 7, 2019

Project Background

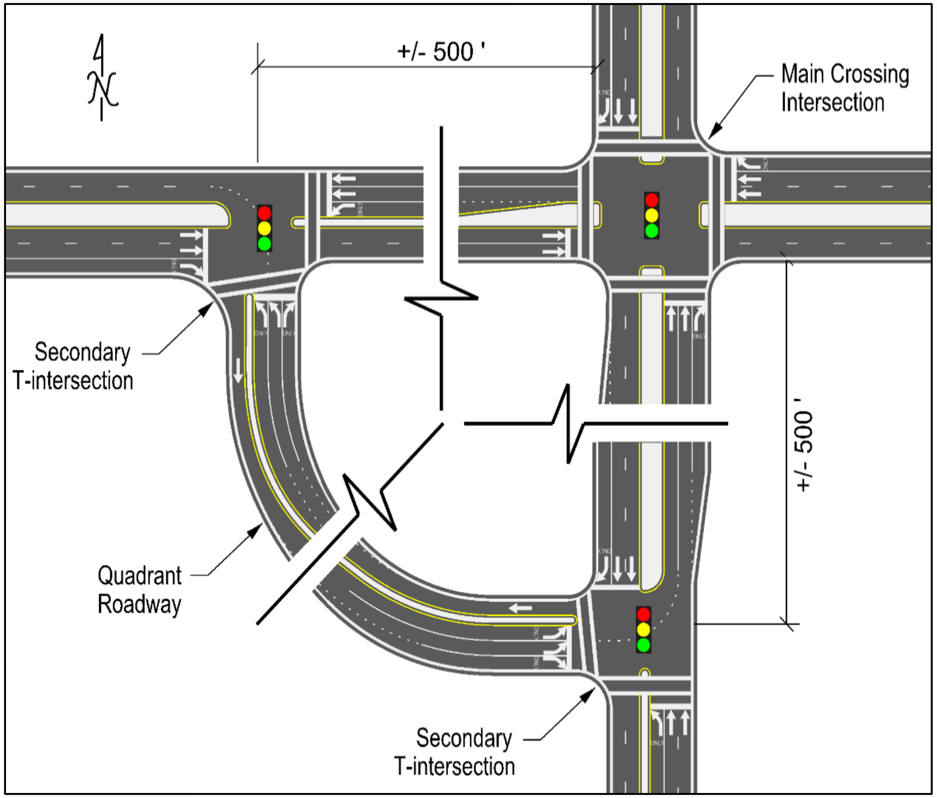
Quadrant Roadway Guide Outline

- Chapter 1 – Introduction
- Chapter 2 – Policy and Planning
- Chapter 3 – Multimodal Considerations
- Chapter 4 – Safety
- Chapter 5 – Operational Characteristics
- Chapter 6 – Operational Analysis
- Chapter 7 – Geometric Design
- Chapter 8 – Signals, Signing & Marking
- Chapter 9 – Construction and Maintenance

U.S. Department of Transportation Federal Highway Administration

QR Intersection Overview

- Requires roadway in one intersection quadrant
- Preferable intersection spacing +/-500 ft
- Signal control at main and secondary T-intersections
- Only thru/right movements at main intersection
- All left turns made using quadrant roadway (various turn patterns)



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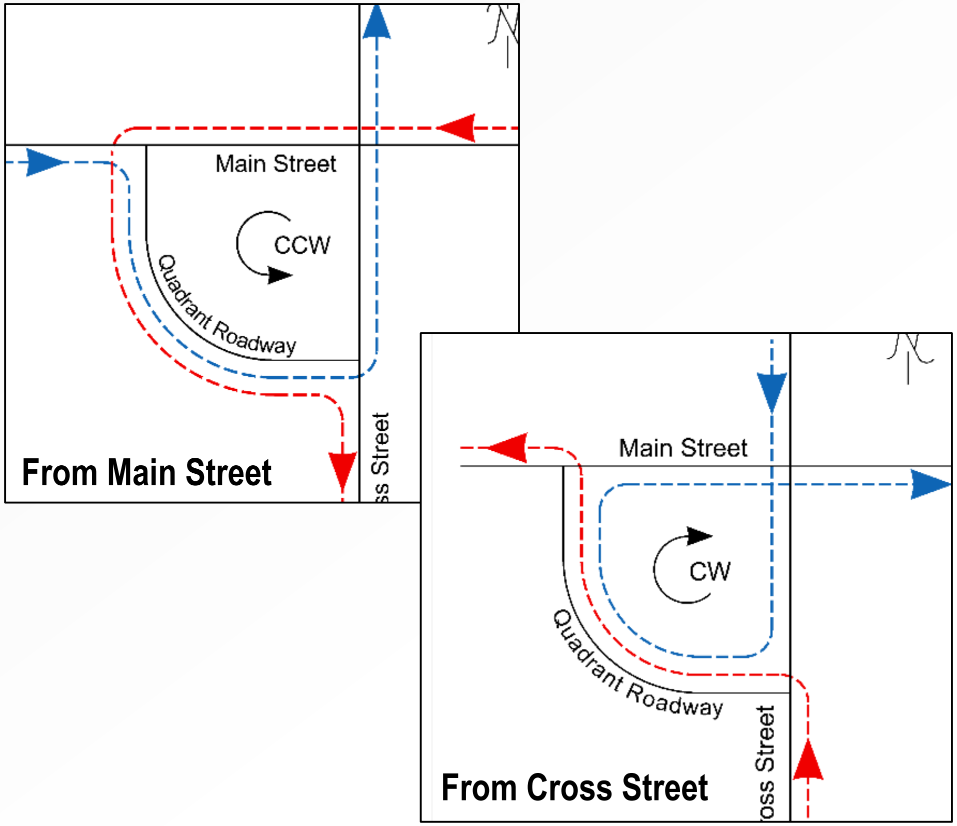
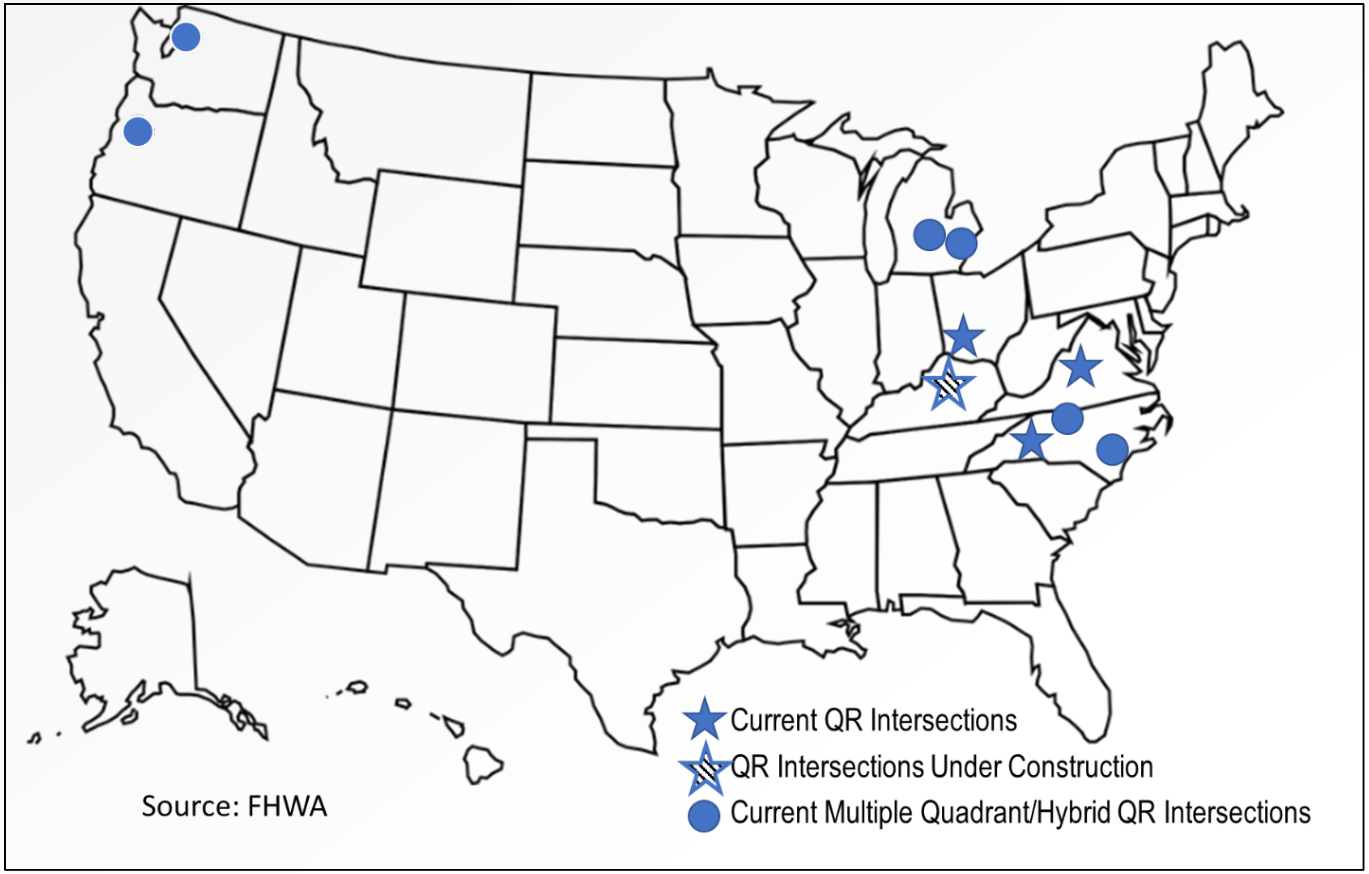


Applications: U.S. QR Intersections

Full, Partial and Hybrid QR's constructed (or under construction) in the U.S.



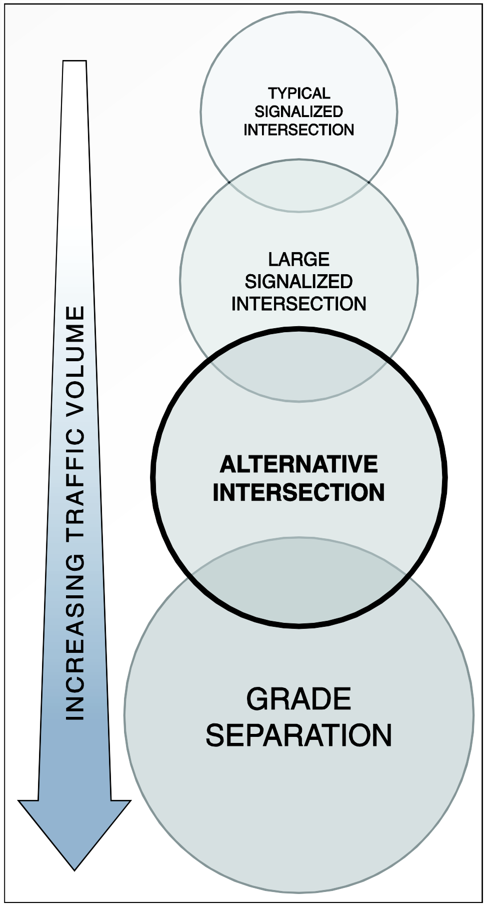
Applications: SR 4 / SR 4 Bypass, Fairfield OH

Applications: US-21 at NC-73, Huntersville NC

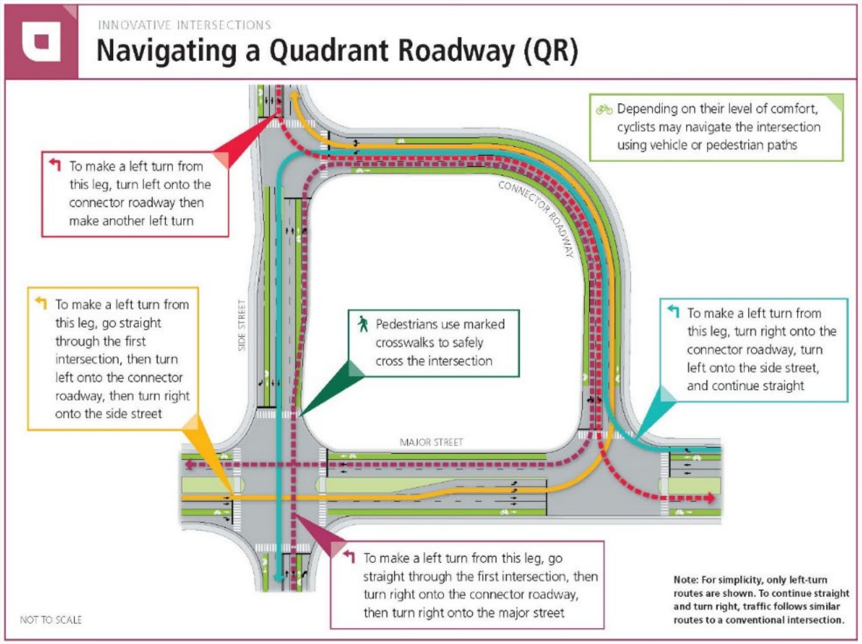
Applications: US-340/SR-522 at SR-55, Front Royal VA

Considerations for Alternative Intersections

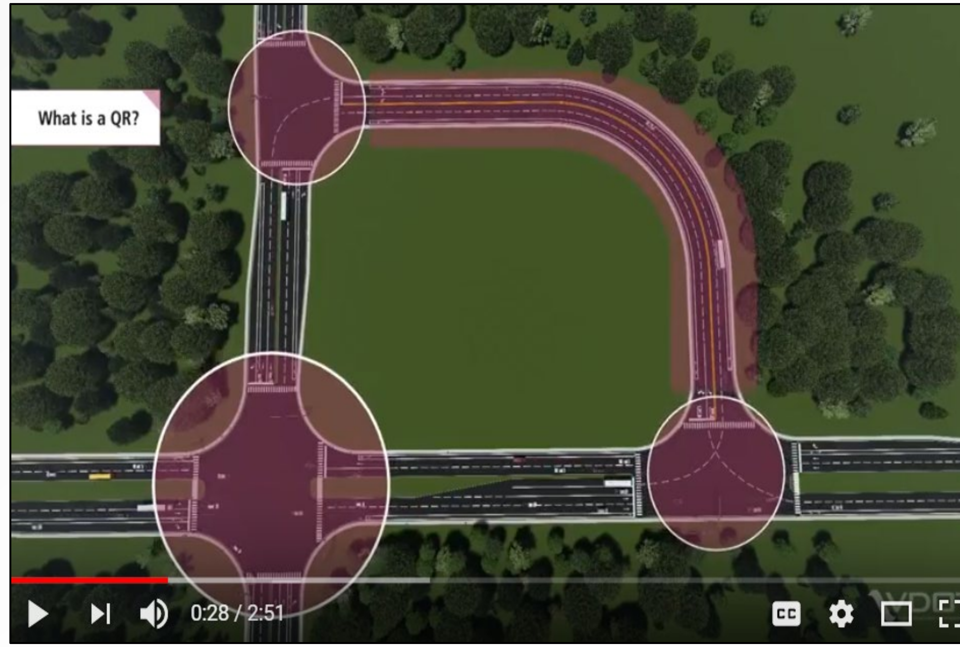
- Alternative Intersections and Interchanges
  - Potential to improve safety and reduce delay
  - Potential for lower cost than traditional solutions
  - Unfamiliar to practitioners and drivers due to limited existing applications
  - Require specific planning and policy considerations for all users
  - On-going need for public involvement and education



Stakeholder Outreach: Marketing Materials

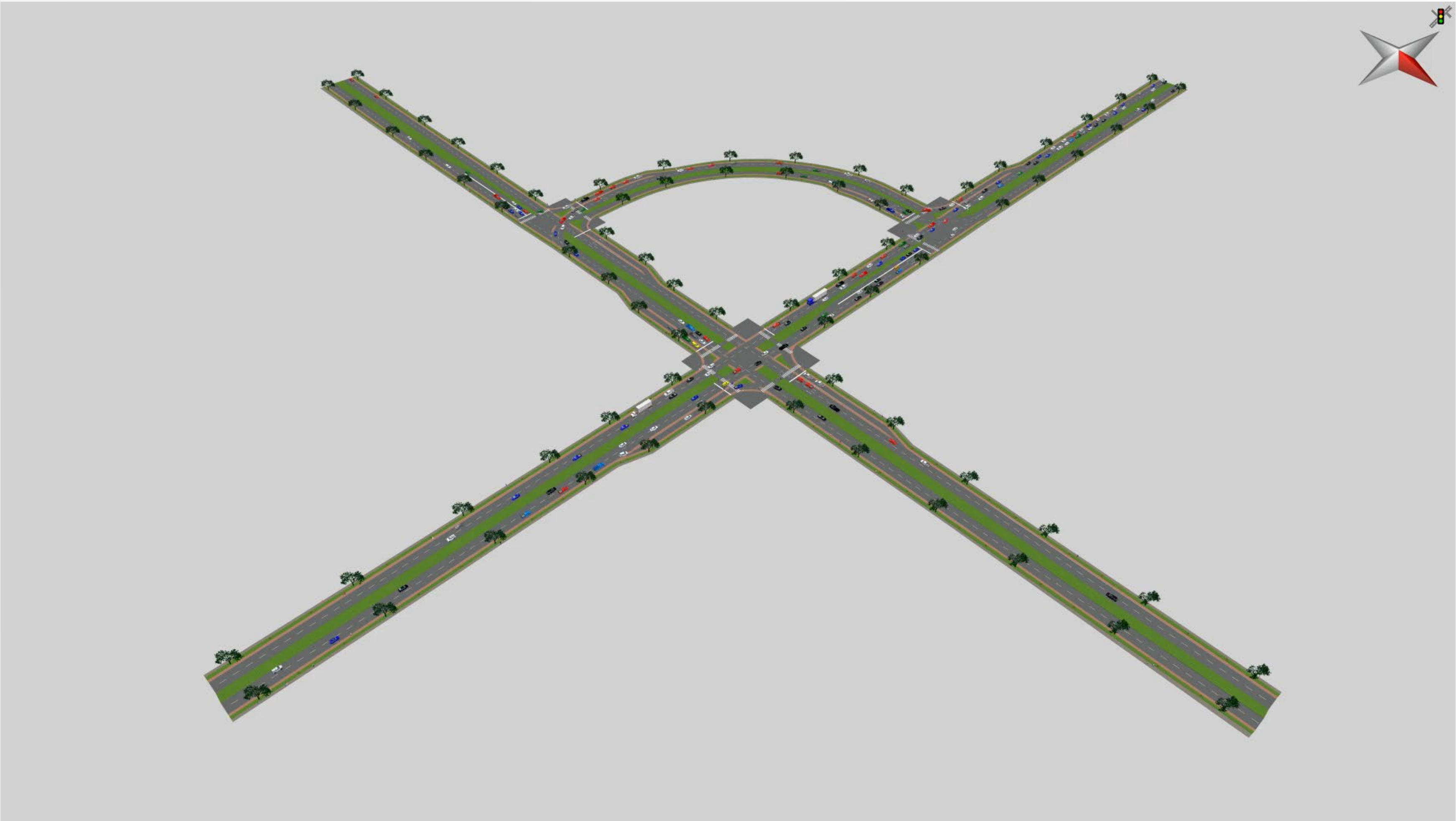


Graphic Explaining QR Operations



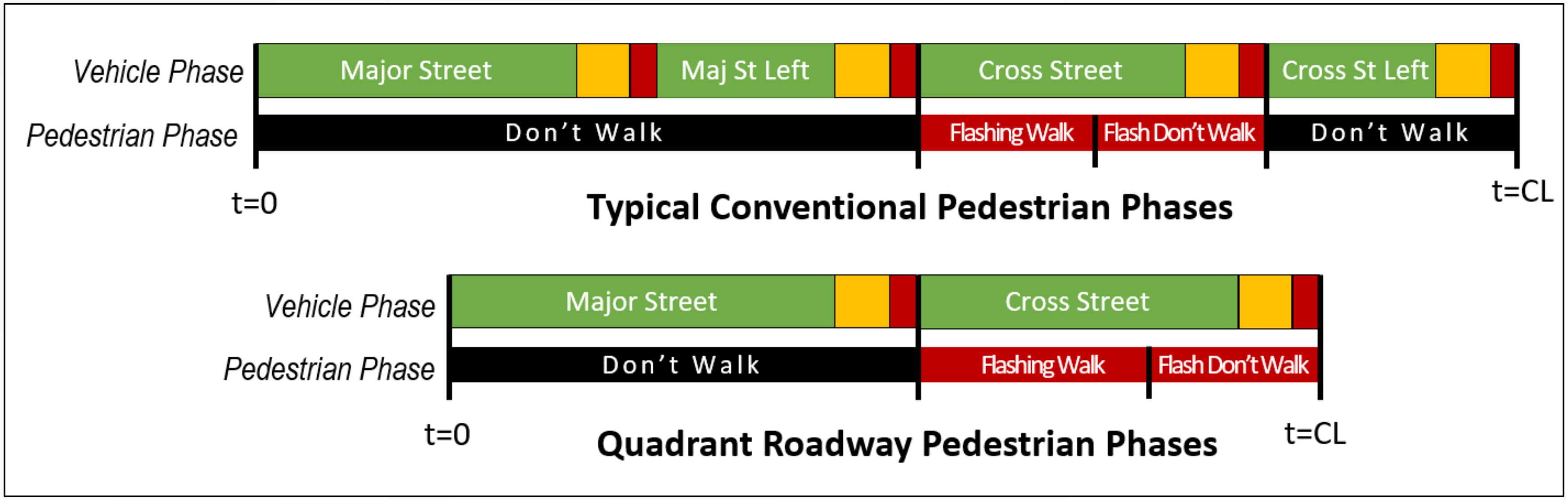
VDOT Video Explaining QR Operations and Benefits

QR Intersection Video



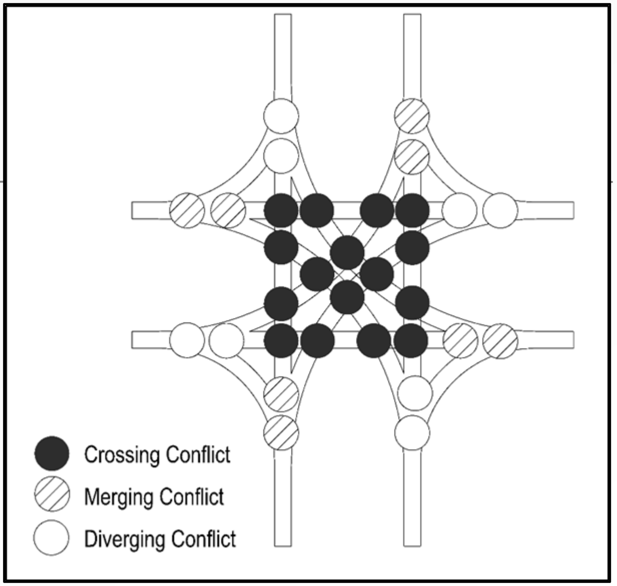
User Accommodations: Pedestrians

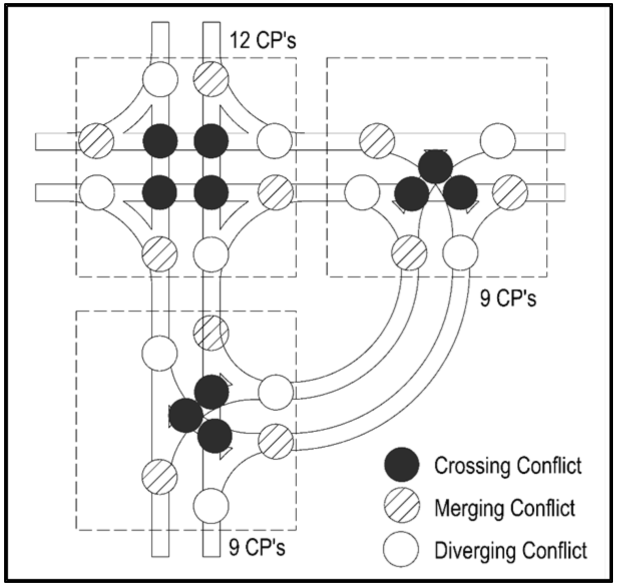
- Reduced pedestrian-vehicle conflict points
- Shorter pedestrian crossing distances (less exposure)
- Longer, more frequent pedestrian crossings



Safety Principles

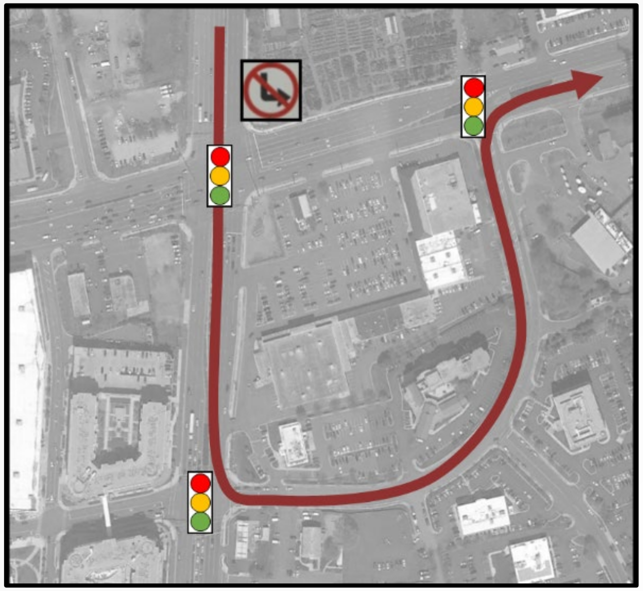
- Conflict type correlated with severity
  - Crossing conflict most severe
- Conventional intersection
  - 32 conflict points
  - 16 crossing, 16 merge/diverge
- QR Intersection
  - 30 conflict points (3 intersections)
  - 10 crossing, 20 merge/diverge



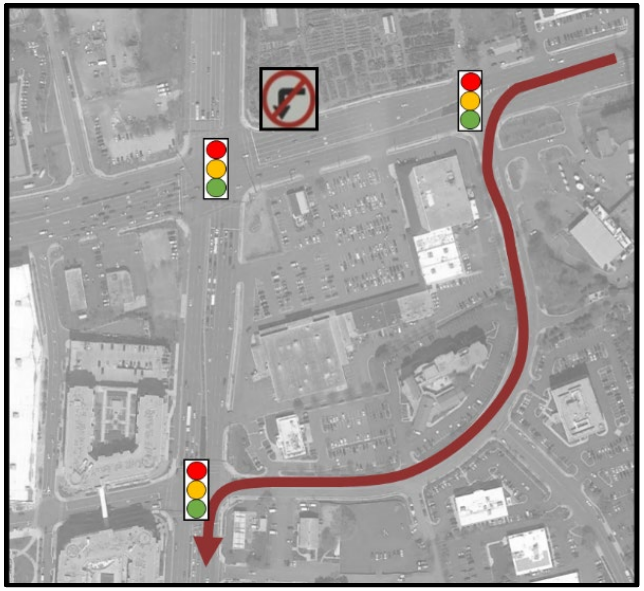


Safety Considerations

- Each of four QR intersection left turns are unique and have significantly different geometric and operational impacts



MT-QL-QR



QL-QL

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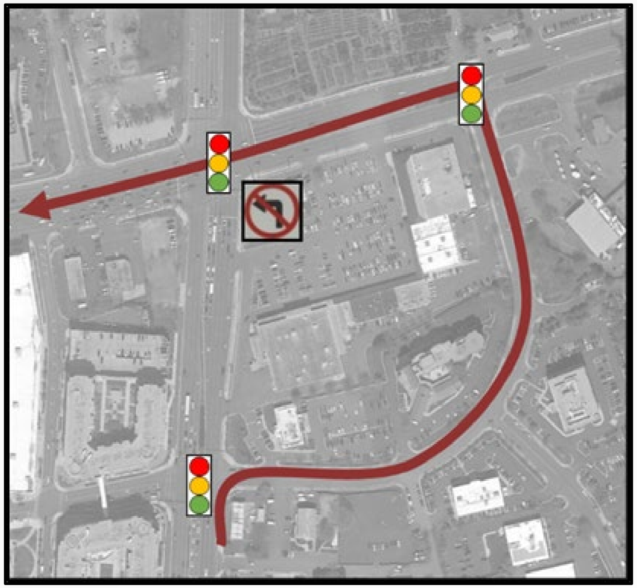
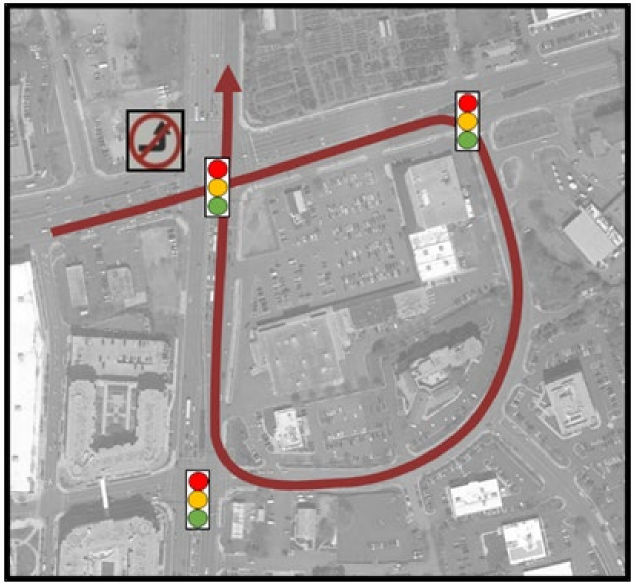


QR-QL-MT



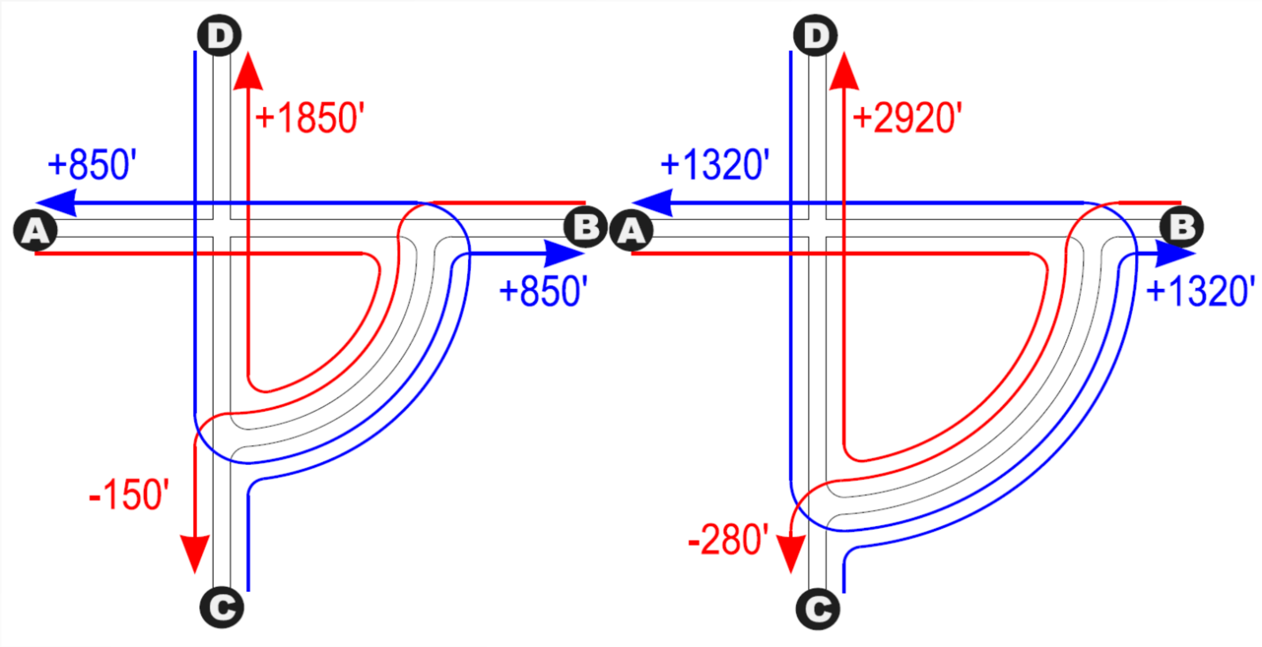
MT-QR-QR-MT

Operational Considerations

- Access Management Principles
  - Median along quadrant roadway
  - RIRO or directional access to quadrant (if any)
  - Consolidate internal access
  - Preserve T-intersection
  - Impacts “perceived” greater than actual

Operational Characteristics

- No hard maximum spacing rule, but further the secondary T-intersection is from the main, the greater the travel distance; could become untenable to motorists

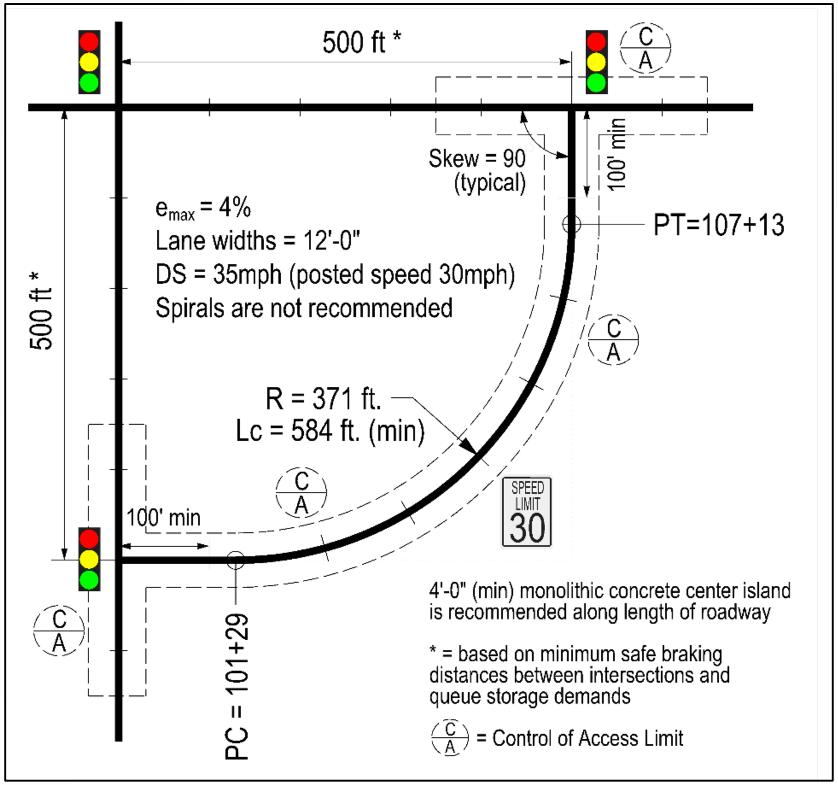


Equal 500-foot spacing

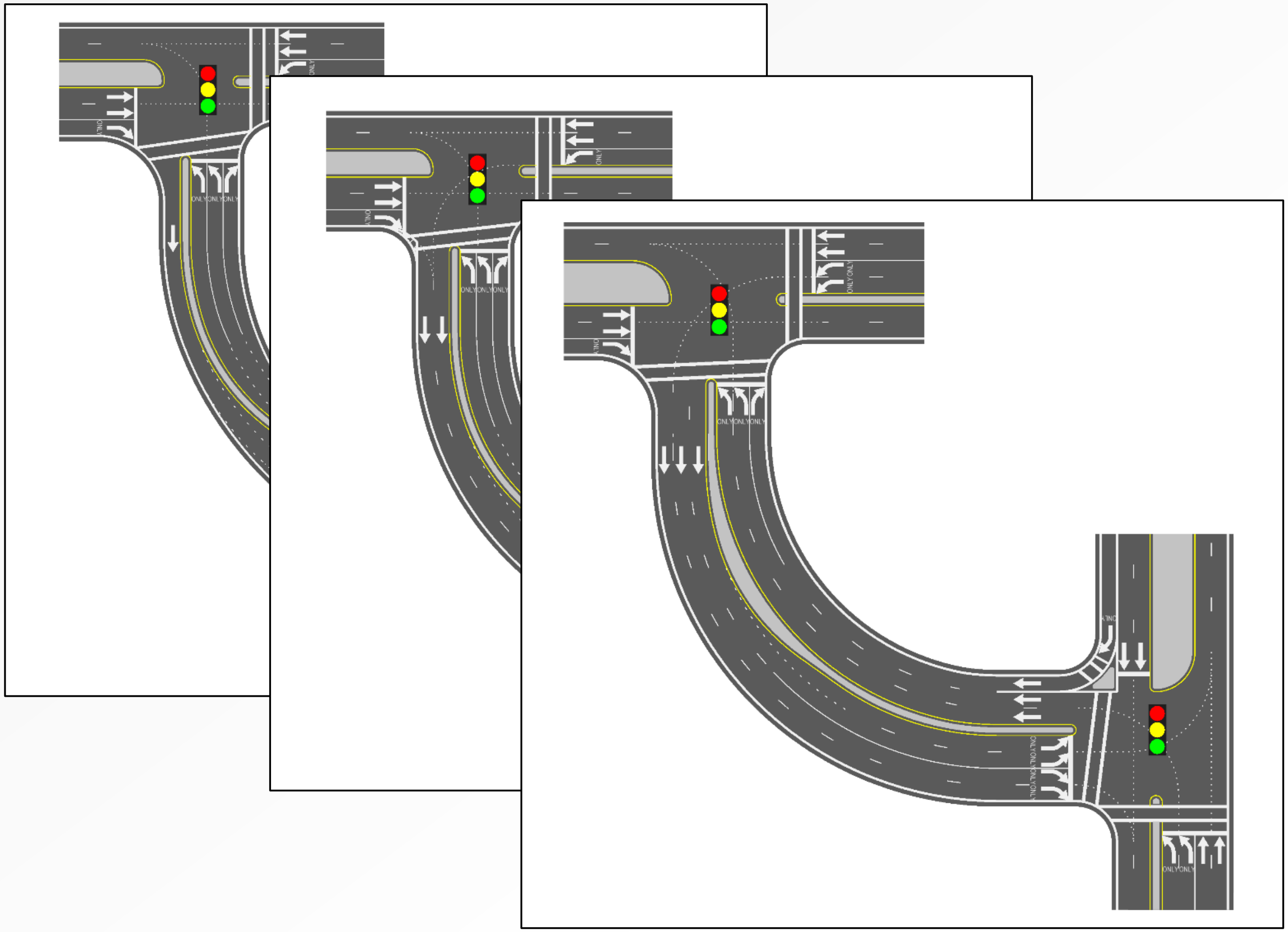
Equal 800-foot spacing

Geometric Design: QR Design Speed

- QR is low-speed urban roadway
- Minimum horizontal curve: DS=30 mph; max DS=35 mph
  - Larger radii encourages higher speeds than desired
- AASHTO minimum curve
  - DS=30: 250 ft
  - DS=35: 371 ft
- 100-ft tangent approaching main/cross street desired



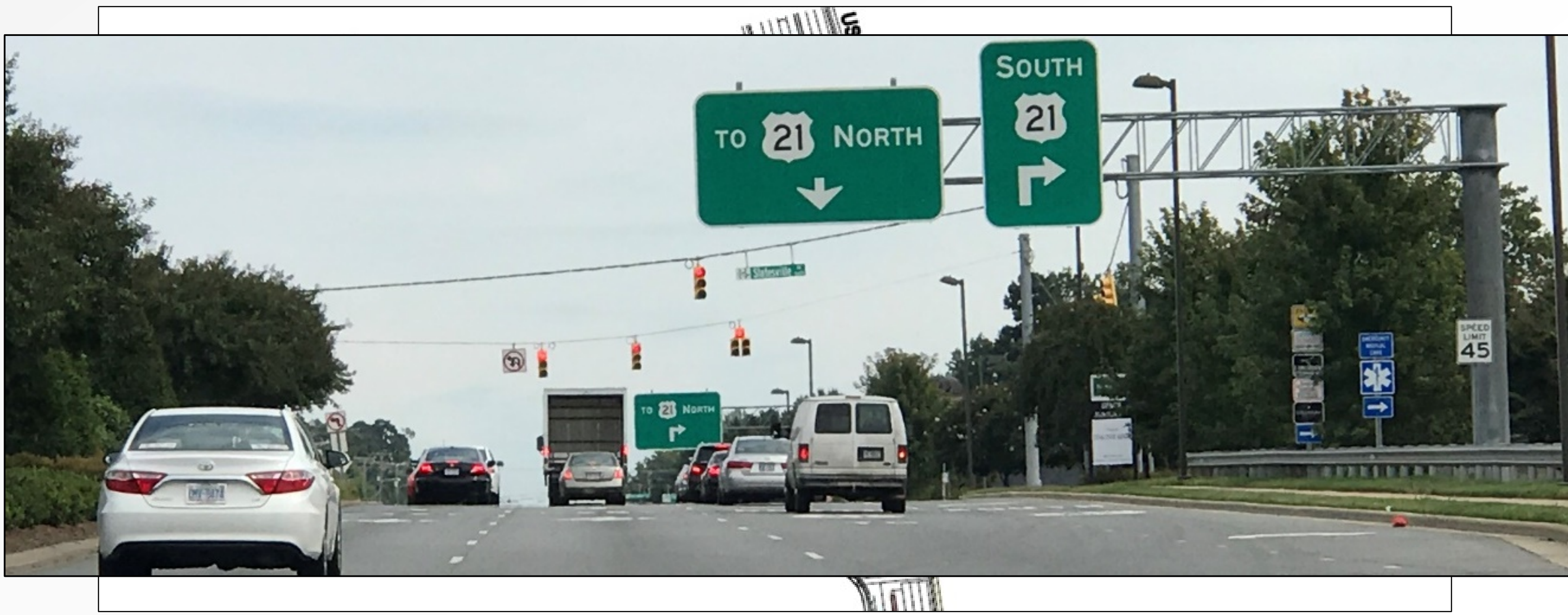
Geometric Design: Lanes on QR



Signing: Regulatory Signs

Signing: Overhead Signs

- Overhead signs recommended for:
  - Left turn movements where motorists may have to move from left lane (expected) to the right lane



Pavement Marking

- In-pavement lane guidance shields are used at all QR intersections built to date to help w/ route guidance

Appendices

- Appendix A: Catalogue/Profiles of Known QR Intersections
- Appendix B: Marketing/Outreach Materials
- Appendix C: Publications
  - ITE Paper
  - FHWA Tech Brief
  - ACEC Paper on Ohio QR Intersection

Next Steps

✓ Guide is written and reviewed by FHWA technical staff

- 508c Compliance Reviews and edits underway
- Guide published by late summer
- Full webinar presentation by FHWA (fall 2019)
- 6th International Urban Street Symposium (May 2020)

Questions?

Systemic, Risk-Based Pedestrian Safety Process

Libby Thomas

NCDOT Research and Innovation Summit
NC A & T State University
Greensboro, NC

THE UNIVERSITY OF NORTH CAROLINA
HIGHWAY SAFETY RESEARCH CENTER

www.hsrc.unc.edu

May 7, 2019

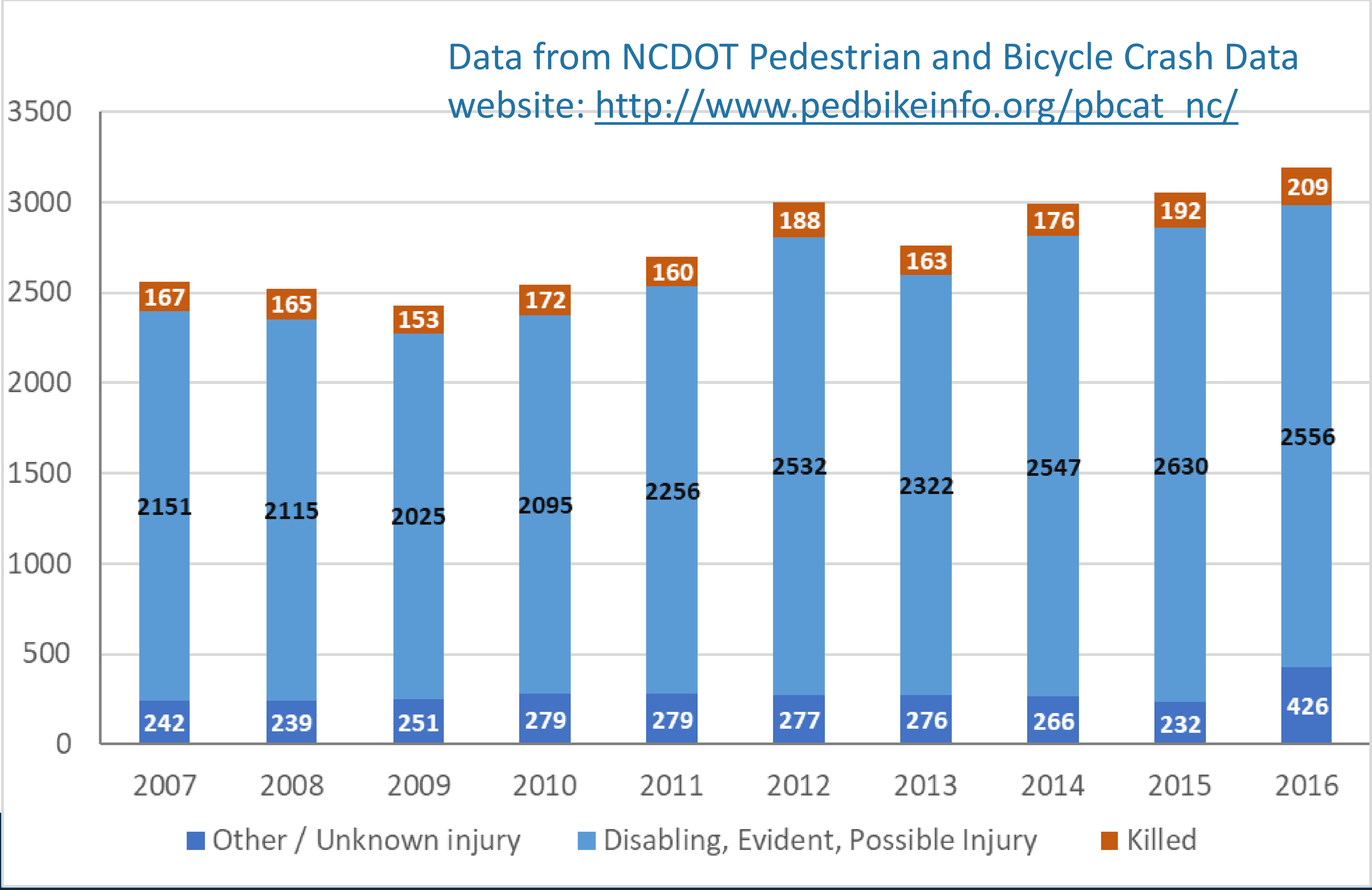
Overview of presentation

- What is the problem to be solved?
- How can the systemic safety analysis and prioritization approach help?
- What is the process?
- What are the steps?
- Who is using it?
- What is needed for NC to apply it?

Problem - NC Pedestrian Crash and Injuries

2012 – 2016 vs. 2007 – 2011

- 18% average increase in ped. crashes
- 13% average increase in ped. fatalities
- 14% of total fatalities
- Lack of mobility and options



Why do we need a systemic, risk-based safety process for pedestrians?

- Pedestrian crashes, although too high and climbing, are often rare, widely dispersed across a network, and mobile in time (especially severe ones) making cost-effective treatment targeting a challenge
- Crash risk factors for pedestrians may be different than for motor vehicle-only crashes (but some of the treatments improve safety for all modes)
- The process needs to be tailored to data related to pedestrians, and to provide guidance on how to gather, analyze needed data and apply context-appropriate treatments (and avoid building future problems)

Systemic Approach Definition

"A systemic approach is a data-driven, network-wide (or system-level) approach to identifying and treating high-risk roadway features correlated with specific or severe crash types. Systemic approaches seek not only to address locations with prior crash occurrence, but also those locations with similar roadway or environmental crash risk characteristics."

Tenets of a systemic approach*

- Identifies a safety concern based on an evaluation of data at the system (or network) level
- Establishes common characteristics (risk factors) of locations where severe crashes occur
- Emphasizes low-cost safety countermeasures to address the risk factors for high severity types of crashes
- Prioritizes locations across the entire roadway network *where treatable risk factors are present*, with or without a prior crash history

*Preston, H., R. Strom, J. D. Bennett, and B. Wemple. *Systemic Safety Project Selection Tool*. Publication FHWA-SA-12-019. FHWA, U.S. Department of Transportation, 2013.

Benefits of a Systemic Approach

- Improved safety at more locations with more proactive approach
- Informed decision-making utilizes data on key risk factors, reliable prioritization metrics
  - Don’t simply “chase the hot spots”
- Optimized investment
  - Cost-effective use of resources
  - Consistency in application

Spot Safety Approach

Makes improvements at individual sites or road segments with relatively high numbers of crashes, without regard to other sites with similar risk factors.

Corridor Retrofit Approach

Makes improvements at several adjacent locations (with possibly similar risk factors), not all of which may have experienced a high number of crashes.

Systemic Approach

Makes improvements at locations with a high predicted crash risk or presence of key risk factors, regardless of actual crash history.

Systematic Approach

Makes improvements at all sites in an area, regardless of predicted crash risk or crash history.

Figure 2, Systemic Pedestrian Safety Analysis, NCHRP Report 893
https://www.nap.edu/catalog/25255/systemic-pedestrian-safety-analysis

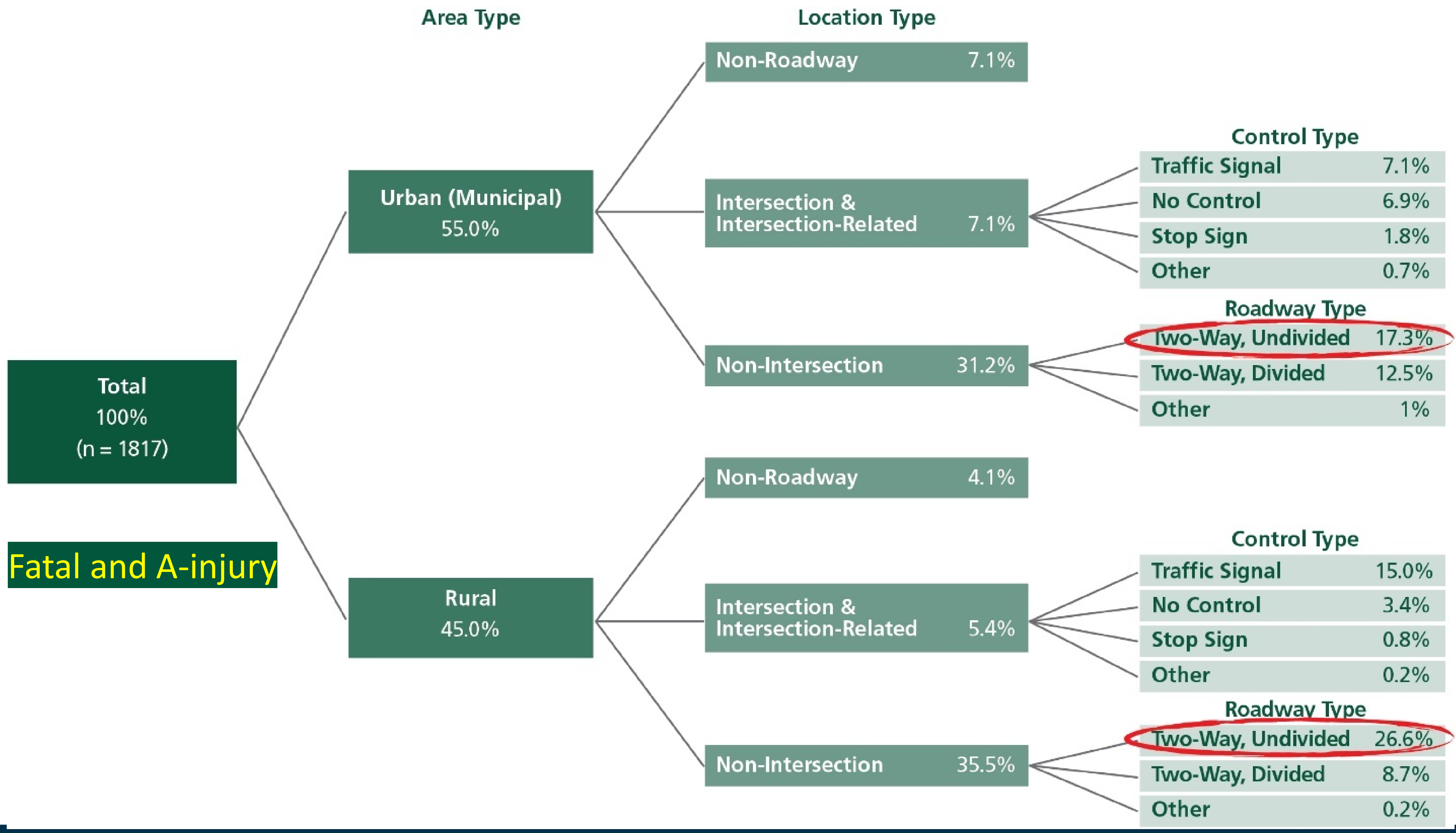
Steps in the process

1. Define scope and crash type target
2. Compile data
3. Determine risk factors
4. Identify potential treatment sites
5. Select potential countermeasures tl address identified risks
6. Refine/prioritize projects, fund and implement
7. Evaluate / improve data and proces evaluate projects

Figure 3, Systemic Pedestrian Safety Analysis, NCHRP Report 893
https://www.nap.edu/catalog/25255/systemic-pedestrian-safety-analysis

Step 1 – Define Study Scope & Focus

- Define boundaries
- Identify a 'problem' type that accounts for a large % of the problem
- Typically, only crash data is used
- May employ descriptive means such as crash tree diagrams (see NC example at right)



Step 2 – Compile Data for Analysis, Screening, Prioritization

- Guidebook provides information and examples on how and why to make data:
  - Current and complete
  - Easily accessible (digital)
  - Centralized
  - Linkable across databases, and spatially-referenced
- Recommended data for systemic analysis include:
  - Pedestrian crash records, including injury severity, crash type, and spatial references
  - Detailed roadway data with key characteristics such as # of lanes
  - Vehicle traffic and pedestrian volumes or secondary data to estimate volumes (e.g., transit ridership, population/employment density, etc.)
  - Other measures of the built and social environment

Step 3 – Determine Risk Factors

- Recommended approach:
  - Identify risk factors from regression modeling of jurisdiction-wide data (i.e., develop Safety Performance Functions or SPFs) (City of Seattle, Washington)

- Alternative approaches:
  - Identify risk factors from prior research plus local judgment (Arizona, & Oregon, 1st iteration)
  - Infer risk factors from roadway and crash data frequency analyses (California, 1st iteration)

Systemic Pedestrian Safety Analysis, NCHRP Report 893
https://www.nap.edu/catalog/25255/systemic-pedestrian-safety-analysis

Identify *treatable* risk factors Arizona example – State highways

Risk Factor Category	Risk Factor	Data Source
Existing conditions	Posted Speed Limit	ADOT GIS
	Operating Environment/Number of Lanes/ Roadway Width	
	Missing Sidewalk Link	
	Paved Shoulder Width	
	Prior Crashes	
	Traffic Volume	
	Signalized Intersection Spacing	
Pedestrian Demand	Population Density	U.S. Census Bureau
	Attractors (e.g., convenience stores, schools, parks)	Land Use Maps and Visual Inspection (Corridor-level only)
	Land Use (commercial and high-density housing)	
At-Risk Groups	% Households in Poverty	U.S. Census Bureau
	% Households with No Vehicle	Land Use Maps and Visual Inspection (Corridor-level only)
	At-Risk Groups (Children, Elderly, and Handicapped)	

Kimley-Horn and Associates, Inc. *Arizona Department of Transportation Pedestrian Safety Action Plan Update*. Publication MPD0053-16. Arizona Department of Transportation, 2017.

Step 4 – Identify Treatment Sites

- Identify sites with risk factor characteristics from analysis results, or from prior knowledge
  - Sites with risk factors could be identified through combinations of existing roadway/land use/other data, internet tools (Google maps, etc.)
- Ideally – data types needed to understand exposure potential and prioritize sites would be available from data and analysis steps
  - Predictive modeling *versus*
  - Expert weighting process and additional ranking considerations

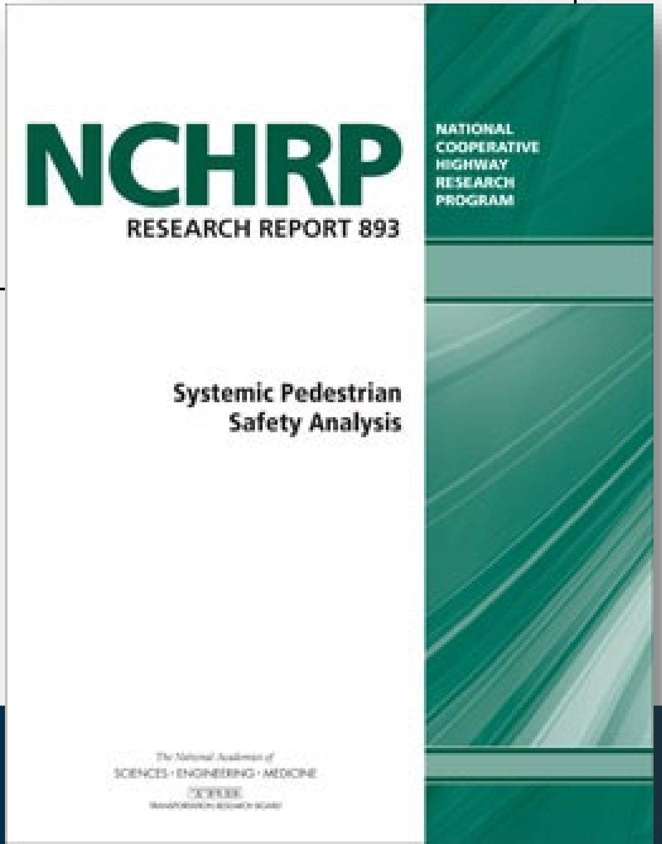
Step 5 – Select Potential Countermeasures

- Criteria:
  - Relation to systemic target crash types and locations
  - Safety effectiveness
  - Cost (initial + maintenance)
  - Feasibility of systemic implementation
- Selection process:
  - Iterative process to match treatment sites (i.e., exhibiting focus risk factors or crash types) with potential countermeasures that address risks
  - Perform diagnosis at proposed treatment sites to confirm

Step 5 – Select Countermeasures

12 recommended countermeasures provided in NCHRP Report 893:

Signalized or Unsignalized crossing locations (including midblock)	Unsignalized locations only (midblock or intersection)	Signalized Intersections only (or signal is added)
High visibility crosswalks	In-Roadway Yield-to-Pedestrian (R1-6) sign	Leading pedestrian interval
Traffic calming (raised devices)	Advance Stop/Yield Bars and R1-5/5a Sign	Longer pedestrian phase
Median crossing island	Pedestrian Hybrid Beacon	Restricted left turn
Reduce number of lanes / road diet		
Curb extension and parking restriction		
Location-specific lighting improvement		



Next Steps

- Step 6 - Refine/implement treatment plan
  - Validate diagnosis, identify other issues
  - Bundle like sites for potential treatment
  - Identify funding sources
  - Perform economic analysis – package sites with similar risks and treatment plans
  - Consider other local priorities
  - Allocate funding and construct treatments
- Step 7 - Evaluate – combine sites for safety evaluation; evaluate process

Oregon uses Cost Effectiveness Index and splits funding 50:50 among crash-based and systemic risk-based projects.

Definition: Cost Effectiveness Index

The Cost Effectiveness Index (CEI) estimates the cost to reduce one vehicle-pedestrian crash. It is calculated using the equation below:

$$CEI = \frac{Project\ cost}{Expected\ reduction\ in\ pedestrian\ crashes}$$

Application – Identify Effective Potential Countermeasures

- Projects developed based on bundling sites with common risk factors, traffic/land use contexts, and matching with relevant treatments; prioritized based on model predictions (as needed)

Risk Characteristics	Number of Segments (of top 500 SPF-pred.)	SPF-Prediction (average per site per year)	Prior Observed Crashes (average per site per year)	Potential Countermeasures
4+ thru lanes (29.4 mi)	357	0.061	0.064	Road diets and/or median islands
TWLTL (15.3 mi)	152	0.053	0.067	Median island (with/without road diet)
4+ thru lanes & TWLTL (12.7 mi)	129	0.054	0.067	Road diets and/or median islands
4+ lanes & Parking (9.5 mi)	102	0.074	0.060	Road diets and/or median islands AND Curb extension + parking restriction
4+ lanes, TWLTL & Parking subset (3.1 mi)	25	0.055	0.085	Road diets and median islands; AND Curb extension + parking restriction

Jurisdictions using systemic / partially systemic pedestrian safety process

Jurisdiction	Risk factor determination	Prioritization
Seattle	Modeling – SPF development	Risk factors presence + predictions (SPF or EB) from the models
Oregon	Expert/prior risk factor research	Risk factor weighting, spatial screening to identify risk segments + account for nearby up/downstream segment scores (+SPF models); 50:50 funding with spot safety
Arizona	Expert / prior risk factor research	Risk factor weighting; Bundling of similar high crash + high risk sites for economic analysis, implementation
California	Matrix of crash types by location types developed by expert team to generate high	Projects developed locally, apply for systemic funding allocated by State

Can NC apply the Systemic approach to pedestrian safety?

NC status & Data needs

Crash data

√+ NC already has multiple years high quality, crash typed, geo-located data

Roadway data – geometrics, operations, pedestrian/bicycle facilities, transit

√ - Room for improvement, completion, GIS-linkable

"Exposure" data

√ **Motor vehicle volume** – very limited on some road types

√ - **Pedestrian volume** – in progress, commitment to develop good short, long-term statewide sample and procedures for use in estimating volumes for specific locations

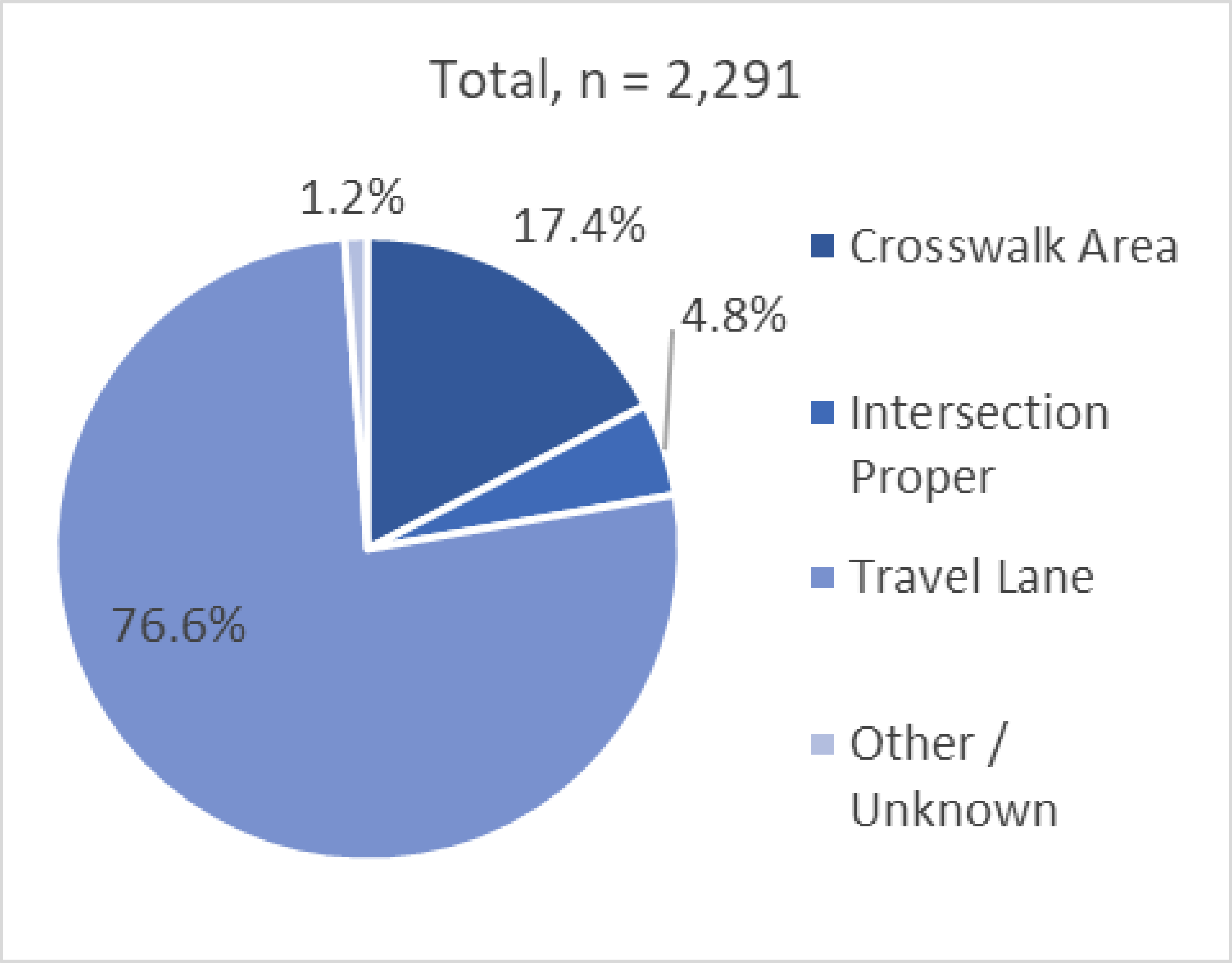
√ **Land use data** – Available*

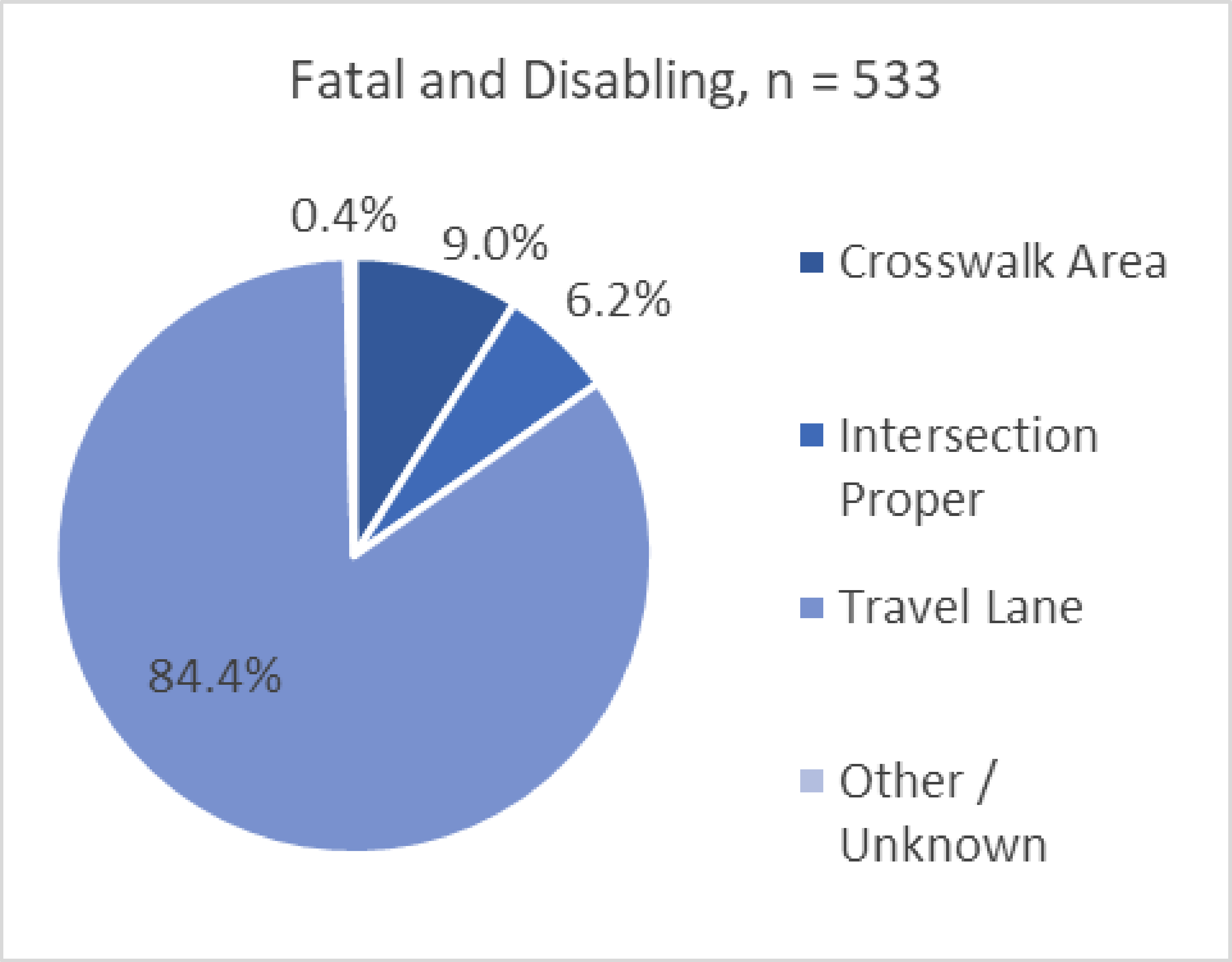
√ **Census data** – Available*

* Just requires scaling, linking in GIS

Step 1 – NC example: Top NC Pedestrian Crash Type (15% of all) and Most Injurious Type (31% of fatal and disabling)

Pedestrian is crossing the roadway, motorist is going straight





Thomas, L., M. Vann, & D. Levitt. (2018) North Carolina Pedestrian Crash Types, 2012-2016. Available at: http://www.pedbikeinfo.org/pbcat_nc/pdf/summary_ped_types12-16.pdf

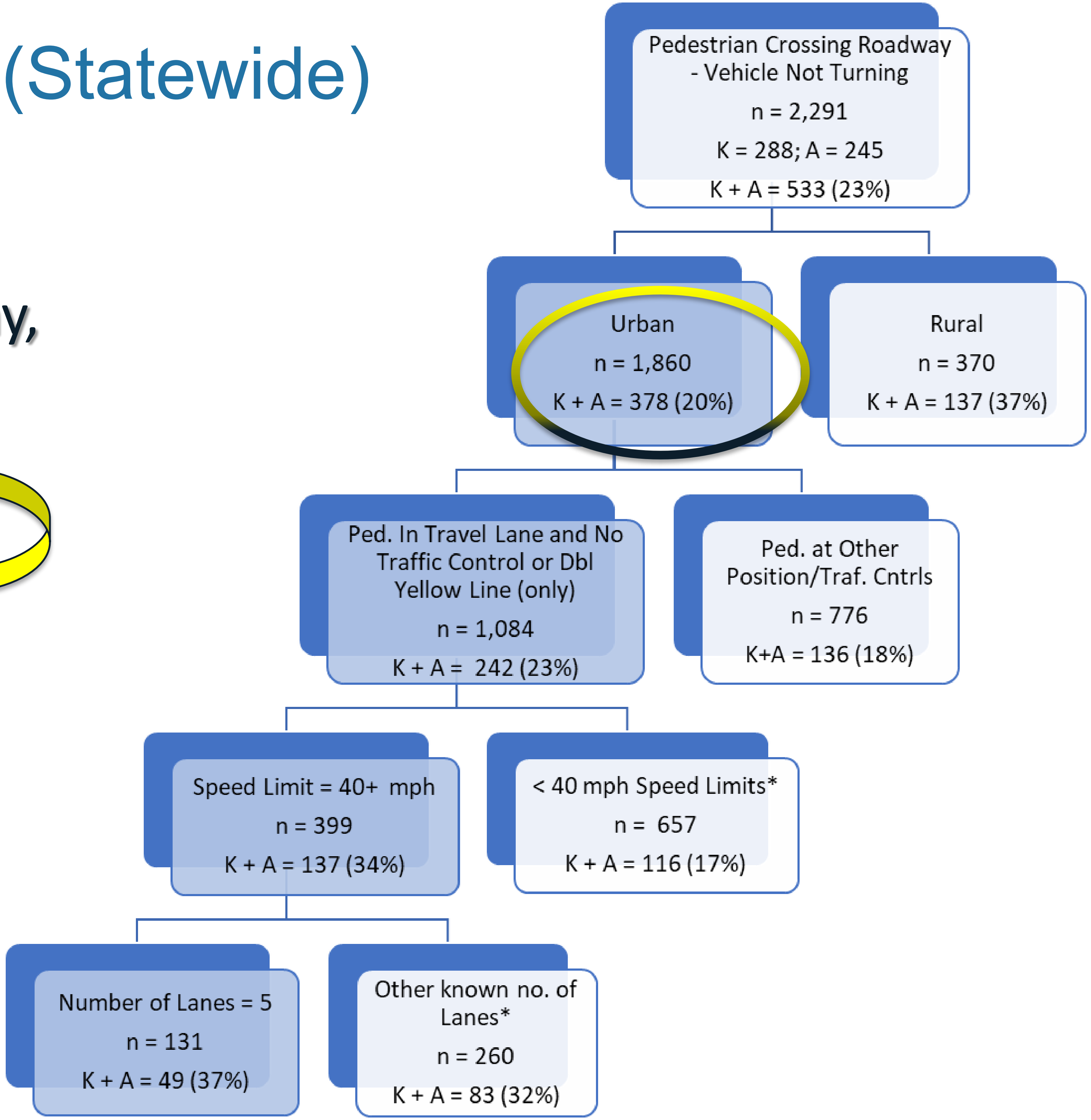
Example: Focus Crash Type (Statewide)

Pedestrian is crossing the roadway, motorist going straight

Urban area

No traffic control/markings for motorist

High speed limits



Thomas, L., M. Vann, & D. Levitt. (2018) North Carolina Pedestrian Crash Types, 2012-2016. Available at: http://www.pedbikeinfo.org/pbcat_nc/pdf/summary_ped_types12-16.pdf

Can NC apply the Systemic approach to pedestrian safety?

- Already crash type and geo-code pedestrian crashes; summary trends/ focus types
- What are your ideas?
- Provide assistance to regional/local agencies in developing or compiling the needed data for analysis
  - Roadway and facilities variables, transit variables
  - Pedestrian and motor vehicle counts/volume estimates
  - Land use (typically available)
  - Census data
- Provide resources or support for analysis
- Incorporate risk-based prioritization metrics
- Provide funding for systemic projects

Step 3: Determine Risk Factors

What jurisdictional/analysis level:

- State level – NC example done on a frequency/severity proportions basis
  - Ideally need to control for traffic volume and pedestrian activity
- Local/regional level – needed for project development focus
  - Focus crash types may not be same statewide
  - Risk factors may also vary
  - Land use, demographic, transit data likely more readily available

Acknowledgments

- Funded under NCHRP Project 17-73
  - Libby Thomas, Laura Sandt, Charlie Zegeer, Wesley Kumfer, Katy Lang, and Bo Lan

  University of North Carolina Highway Safety Research Center, Chapel Hill

  - Zachary Horowitz, Andrew Butsick, and Joseph Toole

  Kittelson & Associates, Inc., Portland, OR

  - Robert J. Schneider, Consultant, *University of Wisconsin-Milwaukee*
- NCHRP Project 17-73 panel members and Lori Sundstrom and Ann Hartell, project managers

Questions?

Thank you for your attention!

More information and case examples:

Thomas, L., L. Sandt, C. Zegeer, W. Kumfer, K. Lang, B. Lan, Z. Horowitz, A. Butsick, J. Toole, and R. J. Schneider. *NCHRP Research Report 893: Systemic Pedestrian Safety Analysis*. National Cooperative Highway Research Program Project No. 17-73. Transportation Research Board, 2018. Available at: http://www.trb.org/NCHRP/Blurbs/178087.aspx

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May 15, 2019

Type III Microprismatic Sign Service Life

Dr. William Rasdorf
Patricia Machado
North Carolina State University

NCDOT Research & Innovation Summit

May 7, 2019

Greensboro, NC

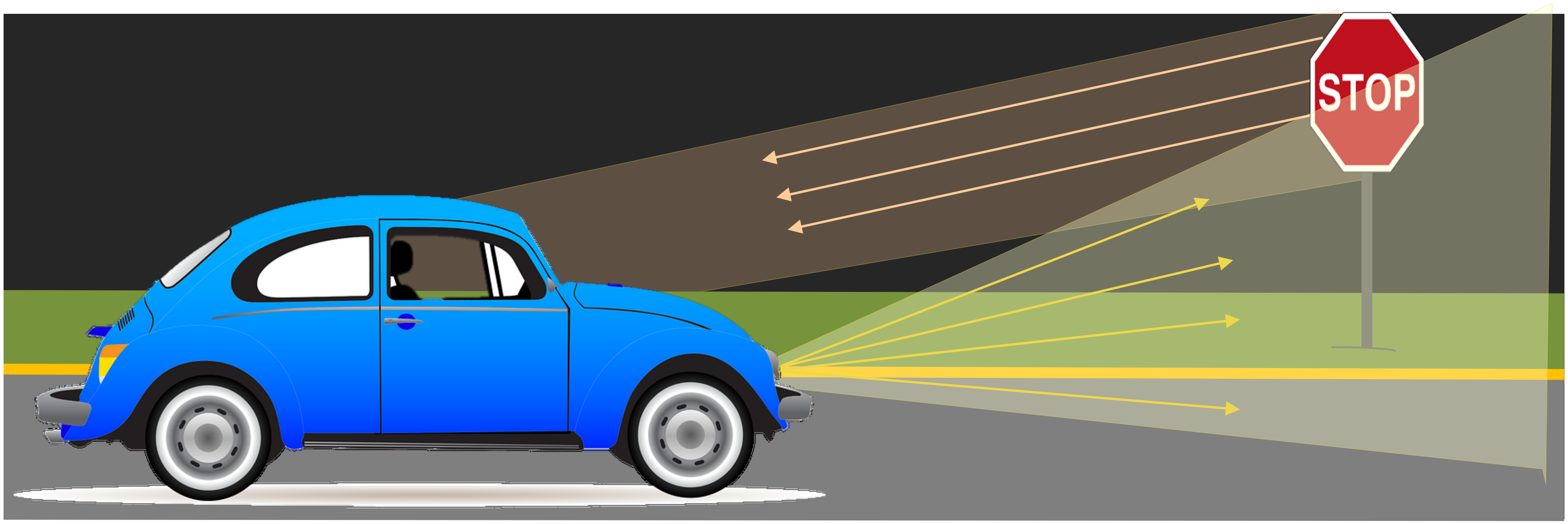
Objective

Assess **Sign Service Life** for Microprismatic Type III Sheeting

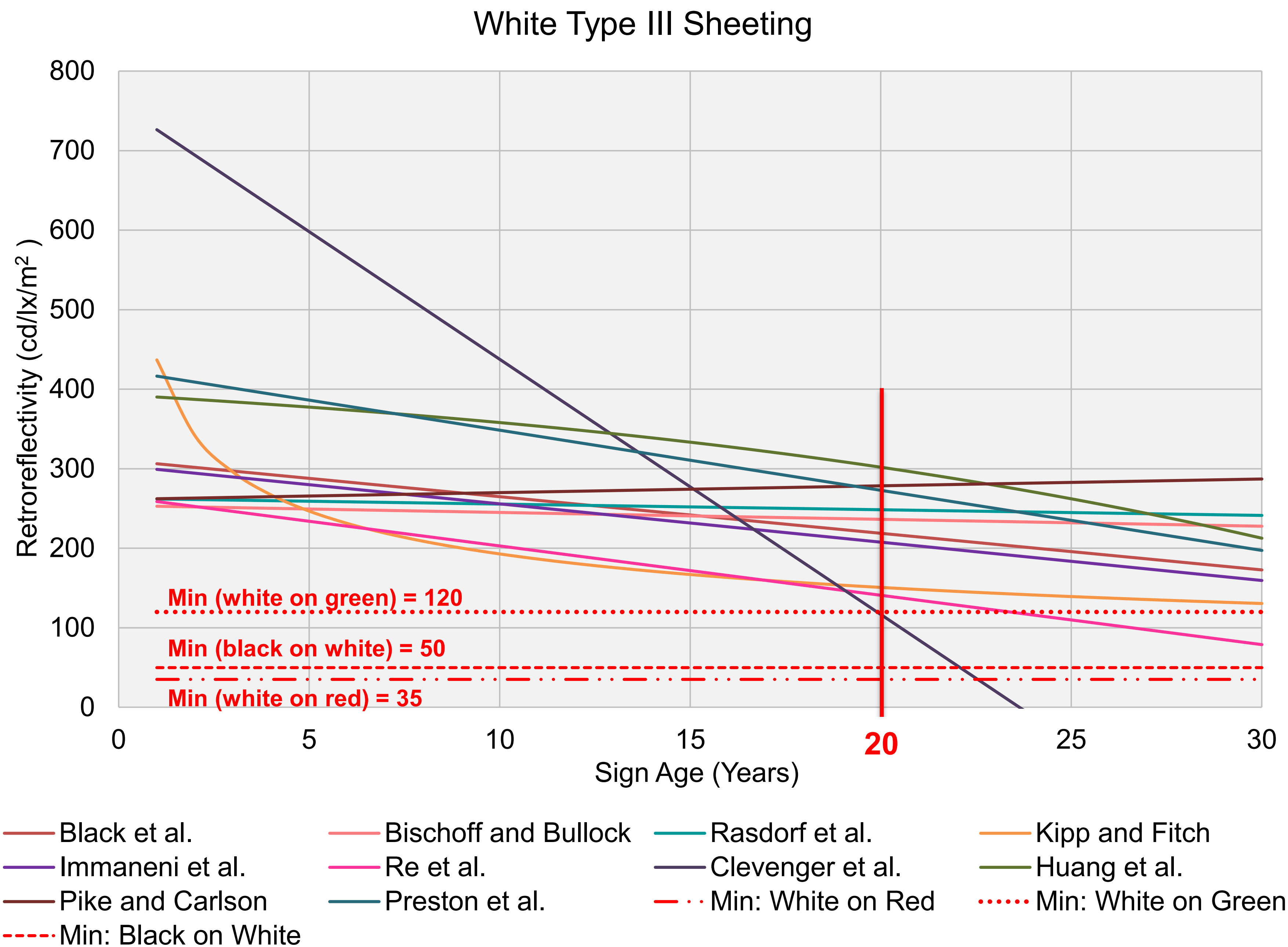
Methodology

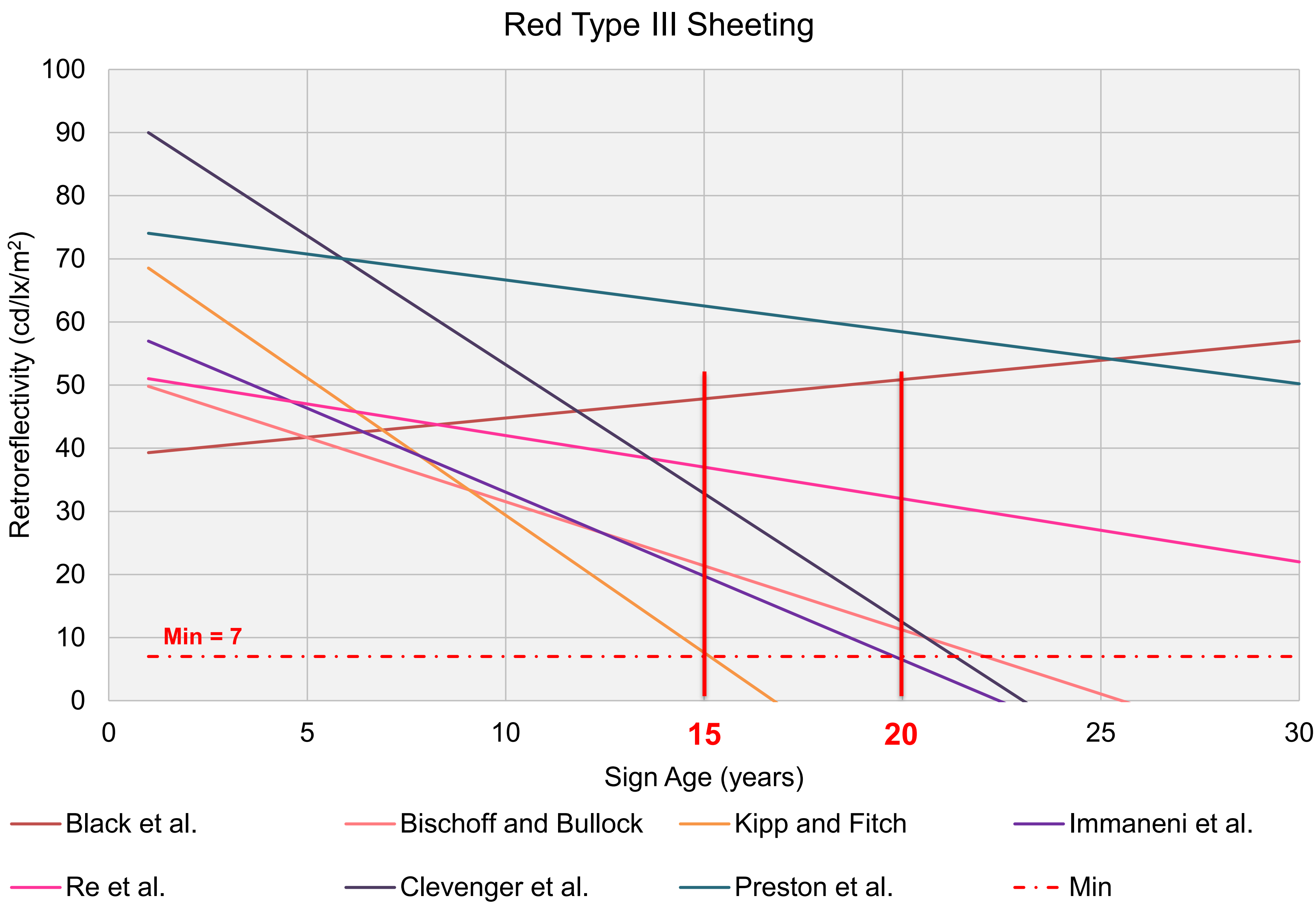
- **Conducted an Extensive Literature Review**
- **Met with Three State DOTs and Two Sign Shops**
- **Simulated Sign Condition Over Time**
- **Analyzed Sign Service Life from Five Different Perspectives**
    1. Retroreflectivity Deterioration Models
    2. Findings of Other Studies
    3. Comparison of Glass Beaded and Microprismatic Sheeting
    4. Microprismatic Sheeting Warranty
    5. Simulation Model

1. Retroreflectivity Deterioration Models



- **Analysis of 10 retroreflectivity studies**
- **Sheeting was primarily glass beaded**
- **Retroreflectivity versus sign age**
  - White sheeting: 20 years and above
  - Yellow sheeting: 21 years and above
  - Red sheeting: 15 years and above
  - Green sheeting: 22 years and above
- **All previous deterioration models predict a sign life ≥ 20 years (red ≥ 15 years)**


White Type III Sheeting
800
700
600
500
400
300
200
100
0
Retroreflectivity (cd/lx/m^2)
Min (white on green) = 120
Min (black on white) = 50
Min (white on red) = 35
0
5
10
15
20
25
30
Sign Age (Years)
Black et al.
Bischoff and Bullock
Rasdorf et al.
Kipp and Fitch
Immaneni et al.
Re et al.
Clevenger et al.
Huang et al.
Pike and Carlson
Preston et al.
Min: White on Red
Min: White on Green
Min: Black on White


Red Type III Sheeting
Retroreflectivity (cd/lx/m²)
100
90
80
70
60
50
40
30
20
10
0
Min = 7
0
5
10
15
20
25
30
Sign Age (years)
Black et al.
Bischoff and Bullock
Kipp and Fitch
Immaneni et al.
Re et al.
Clevenger et al.
Preston et al.
Min

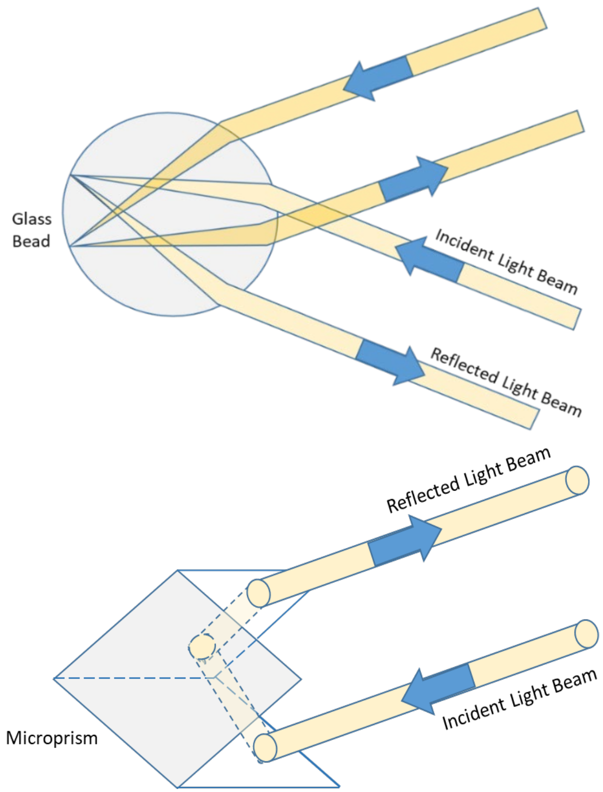
2. Findings of Other Studies

Authors	Location	Sign Service Life-
Dumont et al. (2013)	Minnesota	Minimum: 15 years
Immaneni et al. (2009)	North Carolina	20 to 30 years for white 24 years for yellow and red 37 years for green
Clevenger et al. (2012)	Pennsylvania	Minimum: 15 years
Pulver et al. (2018)	South Carolina	10 years
Kipp and Fitch (2009)	Vermont	15 years for red 15 to 20 years for white, yellow, and green
Pike and Carlson (2014)	Wyoming	Recommendation: 15 years

- **Most literature studies recommend a sign life ≥ 15 years**

3. Comparison of Glass Beaded and Microprismatic Sheeting

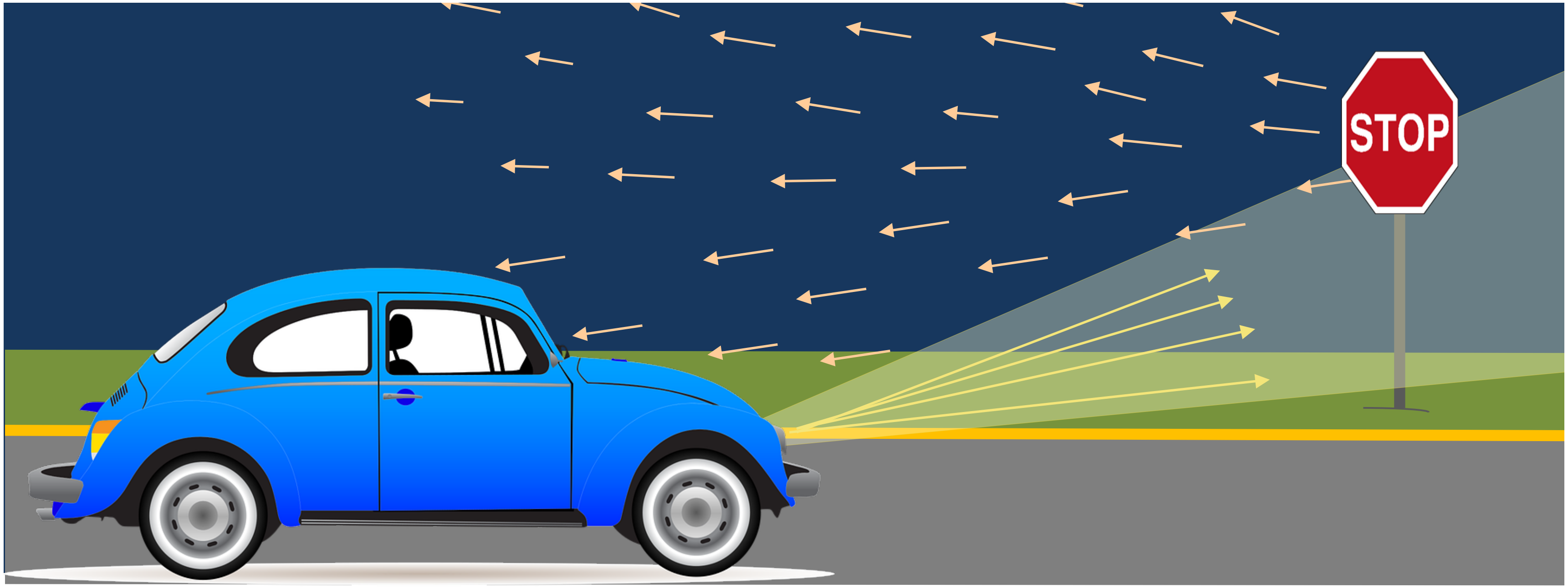
- Microprismatic sheeting is more retroreflective than glass beaded sheeting



Source: 3M (2011), "High Intensity Prismatic vs High Intensity Beaded Reflective Sign Vinyl"

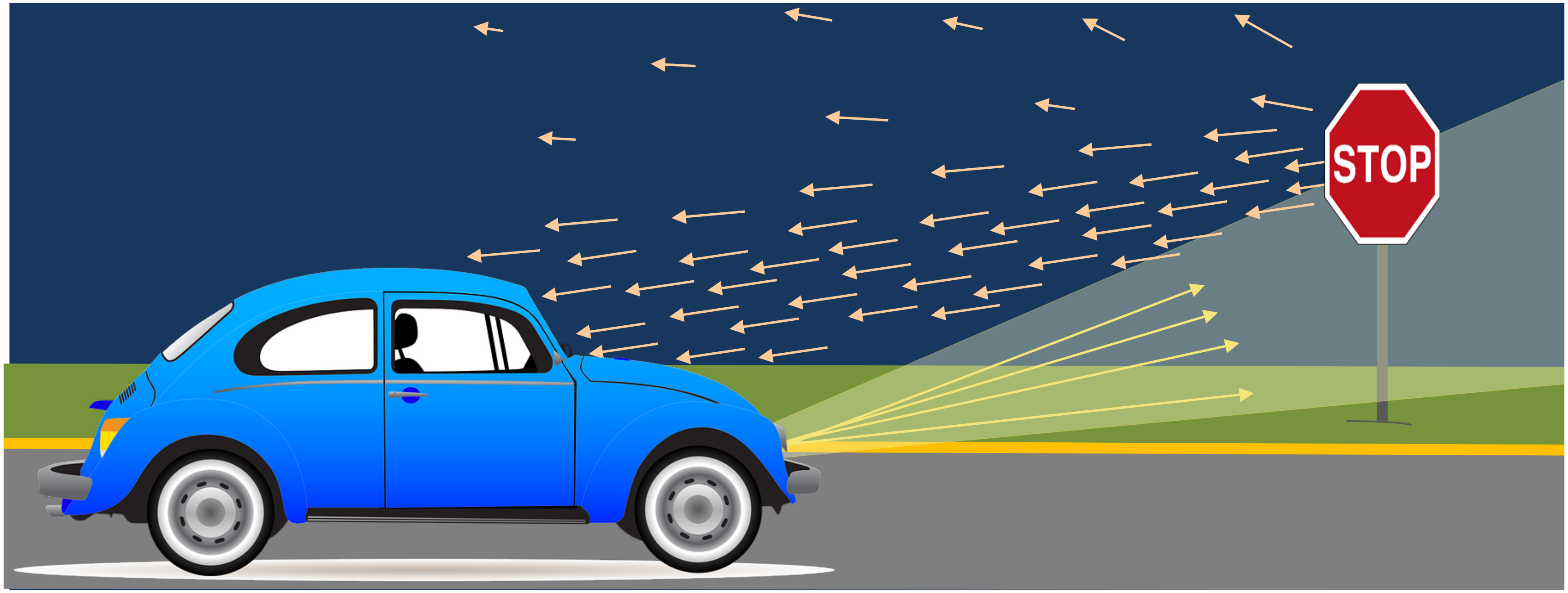
Glass Beaded Sheeting

- Glass beaded has a greater diffuse reflection (<u>less</u> light is reflected back to driver)



Microprismatic Sheeting

- Microprismatic has a lower diffuse reflection (more light is reflected back to the driver)



Initial R_A Comparison

Color	Initial R_A		Improvement From Glass-Beaded to Microprismatic
	Glass Beaded Type III	Microprismatic Type III (High Intensity Prismatic)	
White	250	560	124%
Yellow	170	420	147%
Red	45	84	87%
Green	45	56	24%

- **Most, if not all, previous studies were done on glass beaded signs**
- **Microprismatic sheeting is superior to previous results**

4. Microprismatic Sheeting Warranty

Color	Initial R_A	Warranted R_A at 12 Years (80% initial R_A)	Minimum R_A (MUTCD)	Performance Above Minimum R_A
White	560	448	120[a] 50[b] 35[c]	328 398 413
Yellow	420	336	75[d] 50[e]	261 286
Red	84	67	7	60
Green	56	45	15	30

a white on green
b black on white
c white on red
d signs smaller than 48 inches
e signs greater or equal 48 inches

- **Warranty levels far exceed minimums for all colors**

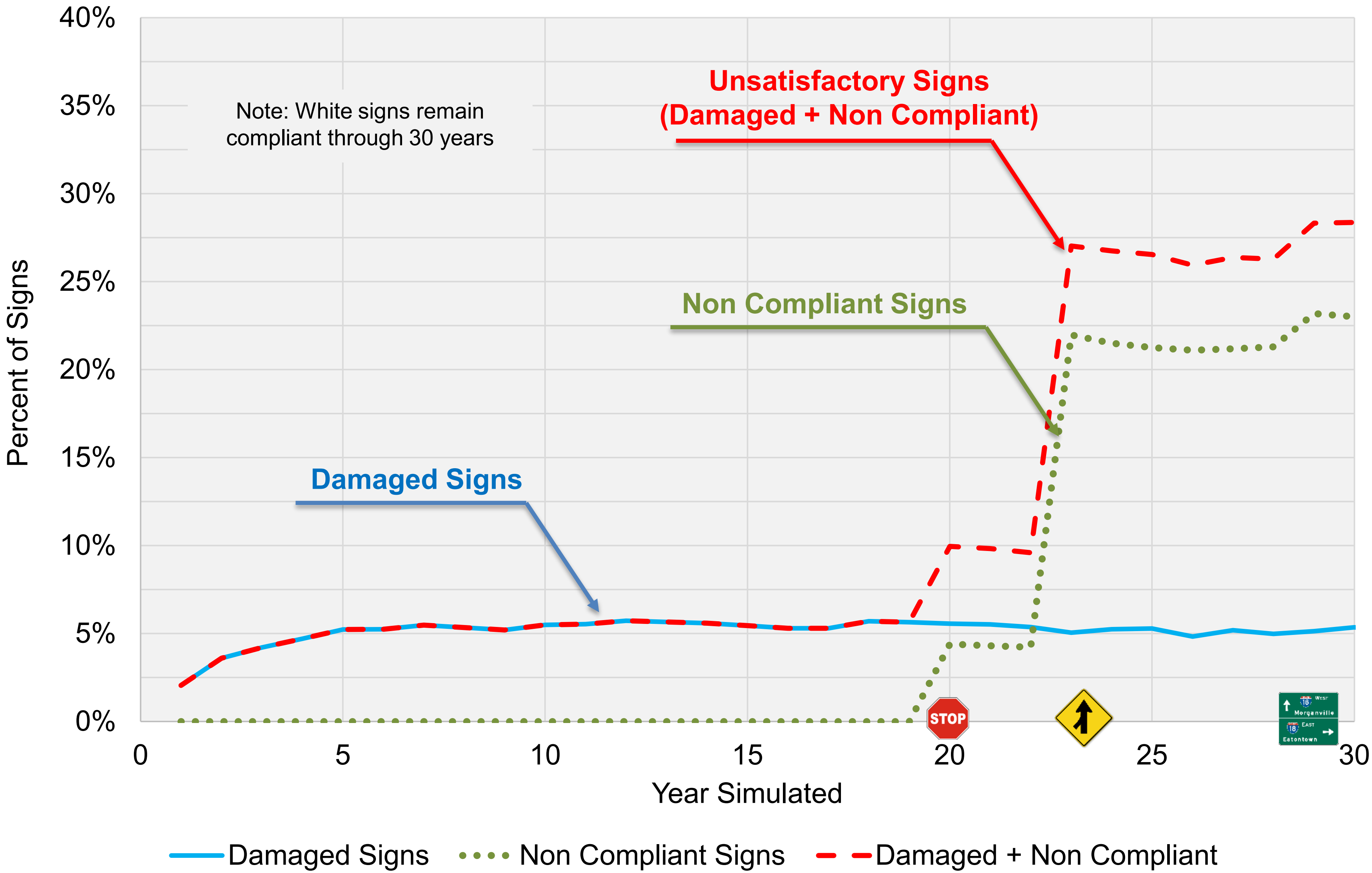
5. Simulation

Input Parameters	Values and Equations	Data Source
Number of Signs Simulated	10,000	-
Period Simulated	30 years	-
Annual Damage Rate	4.04%	Rasdorf et al. (2006)
Annual Spot Replacement Rate	41.09% (of damaged signs)	Modified from Rasdorf et al. (2006)
White Sign R_A Deterioration Model	304.089 – 4.815 Age	Immaneni et al. (2009)
Yellow Sign R_A Deterioration Model	193.01 + 5.644 Age – 0.552 Age^2	Immaneni et al. (2009)
Red Sign R_A Deterioration Model	59.632 – 2.658 Age	Immaneni et al. (2009)
Green Sign R_A Deterioration Model	53.386 – 1.345 Age	Immaneni et al. (2009)

R_A: Coefficient of Retroreflectivity

Simulation Results (10.000 signs)

Damage rate 4.04% of signs. Spot replacement rate 41.09% of damaged signs.



Simulation Results

- No Blanket Replacement or Nighttime Inspections

Years	Non Compliant Signs*	Damaged Signs	Unsatisfactory Signs **
1 to 19	0%	2% to 5%	2% to 5%
20 to 22	4% 	5%	10%
23 to 28	21% 	5%	26%
29 and 30	23% 	5%	28%

* Below the Minimum Required Retroreflectivity Levels

** Unsatisfactory Signs = Non Compliant + Damaged

Conclusions

- All sources decisively show that a **sign service life of 20 years** is acceptable for Type III microprismatic sheeting

Implementation

- NCDOT adopted a statewide blanket replacement cycle of 20 years
- After fully implemented, estimated **annual cost savings of $3.8 million** related to sign replacement

Thank you!

Questions?

Crash Based Evaluation of the Watch for Me (WFM) NC Program

Raghavan Srinivasan

THE UNIVERSITY OF NORTH CAROLINA HIGHWAY SAFETY RESEARCH CENTER

www.hsrc.unc.edu

Research Team and Sponsor

- Research Team
  - Taha Saleem (Principal Investigator)
  - Bo Lan
  - Raghavan Srinivasan
  - Laura Sandt
  - Kristin Blank
  - Sam Alden Blank
- Sponsor
  - North Carolina Department of Transportation (Project 2018-38)
    - Edward Johnson (Division of Bicycle and Pedestrian Transportation)

Watch for Me (WFM) NC Program

- Paid media
  - Distribute pedestrian and bicycle safety messages to the general public
  - Sidewalk stencils, traditional and digital billboards, and external/internal bus ads
- Local outreach and earned media
- Law enforcement operations
  - Targeted enforcement of pedestrian and/or bicycle-related laws
- Implementation was different depending on the community

WFM Participation

- 4 communities participated in the program when it was piloted in 2012
- Between 2012 – 2017, a total of 41 communities (from 29 counties) participated in the program
  - Varying participation duration
- The original 4 pilot communities are the only ones to have been involved in the program throughout
  - Carrboro
  - Chapel Hill
  - Durham
  - Raleigh

Study Objective

- Prior studies have focused on behavioral outcomes
- Examine the safety effectiveness of the Watch for Me program taking a crash-based approach
  - Pedestrian and bicycle crashes
- Help NCDOT assess the value of the program

Methodology

- Empirical-Bayes (EB) before-after evaluation
  - Many applications of EB method to evaluate the safety effect of engineering improvements
  - Not very common method for evaluation of non-engineering improvements
  - Included a reference/comparison group of agencies that did not participate in Watch for Me
  - Accounted for change in “exposure” and trends
- Level of Analysis
  - Site level
  - Corridor level
  - City level
  - County level (selected due to data limitations)

Data

- Crash Data
  - Pedestrian and Bicycle Crash Analysis Tool (**PBCAT**) data
  - Traffic Engineering Accident Analysis System (**TEAAS**) data
- Exposure Data
  - NCDOT VMT data
  - Vehicle distribution by size
  - Journey to work by mode
  - Average household income
  - Total population (urban/rural)
  - Population distribution by age group

Focus Crash Types

- Pedestrian Crashes
  - Total pedestrian crashes
  - Failing to yield crashes
  - Permissive left turn crashes
  - Walking along roadway crashes
  - Nighttime pedestrian crashes

- Bicycle Crashes
  - Total bicycle crashes
  - Over-taking crashes
  - Right-hook crashes
  - Nighttime crashes

Estimated Pedestrian Crash Safety Effects

- Statistically significant effects
  - Total pedestrian crashes
    - 12.8% reduction
  - Nighttime pedestrian crashes
    - 21.7% reduction
  - Failed to yield
    - 9.5% reduction
- Effects on *walking along roadway* and *permissive left turn crashes* were <u>not significant</u>
- Results were consistent based on sensitivity analysis

Estimate Bicycle Crash Safety Effects

- Prediction models unable to reliably predict bicycle crashes
- Inconsistent results based on sensitivity analysis
- Unable to conclude on the effectiveness of WFM on bicycle crashes

Overall Conclusions

- Application of EB before-after in a non-engineering setting
- Watch for Me NC seems to have been effective in reducing total, nighttime, and failed to yield pedestrian crashes
- The effect of Watch for Me on bicycle crashes could not be determined
- Limitations
  - Did not have specific exposure data on pedestrian and bicycle travel
  - Effects were estimated at county level rather than at city/corridor level

Questions?

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UNC CHARLOTTE

Optimal Variable Speed Limit Control in Connected Autonomous Vehicle Environment for Relieving Freeway Congestion

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NCDOT Innovation Summit

North Carolina A&T University, Greensboro, NC

Tuesday, May 7, 2019

Presentation Outline

- Introduction
- Design of Control Model
- Solution Algorithm
- Case Study
- Numerical Results
- Conclusion

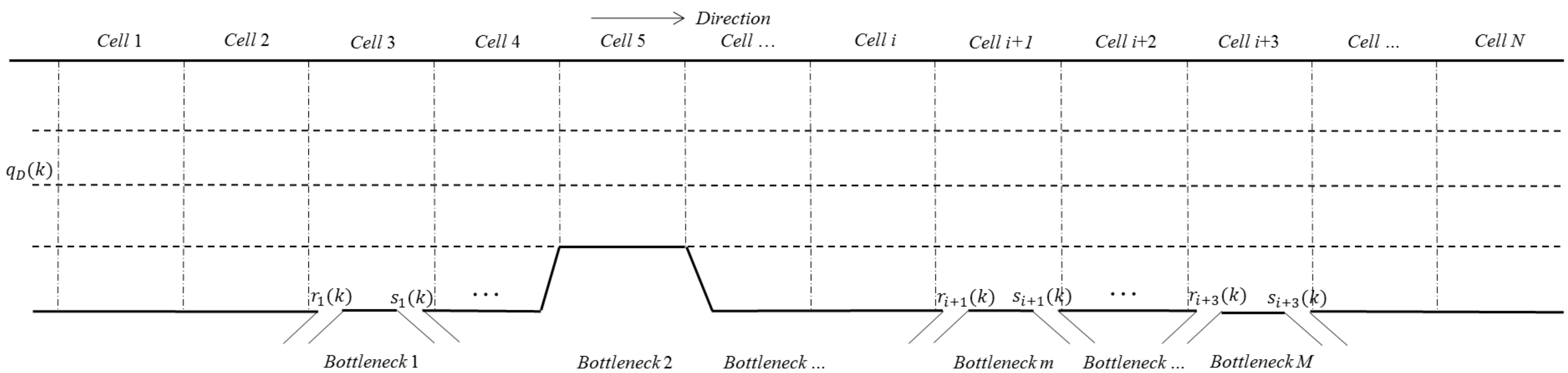
Introduction

- Traffic congestion has become a major problem around the world
- Active traffic management (ATM) is a scheme which can be used to relieve congestion and improve safety on freeways
- Variable speed limit (VSL) belongs to the ATM strategy, which enables one to change the posted speed limits dynamically on the basis of the real-time traffic and/or weather conditions
- VSL has been widely implemented around the world
  - Germany, England, Sweden, and the United States

Introduction – Cont.

- Emerging technologies have been developing during recent years
  - e.g., connected and autonomous vehicles (AVs)
- Enhanced outcomes can be achieved through integrating VSL control with CAVs
  - e.g., reduced total travel time and fuel consumption
- In this study, an integrated VSL control strategy with CAVs on the basis of cell transmission model (CTM) that explicitly considers mixed traffic flows including both trucks and cars

Design of Control Model



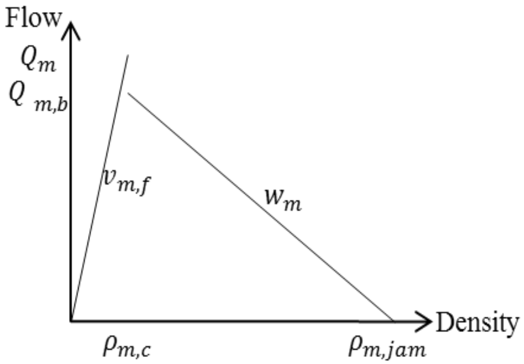
An Illustration of a Freeway Stretch with Multiple Bottlenecks

- The fundamental diagram (FD) is simplified as having a triangular relationship between flow and density
- When modeling mixed traffic flows, other classes of vehicles are converted to the passenger car equivalents (pce)
- A dynamic pce value that involves physical characteristics of vehicles and prevailing speeds on freeways is used (van Lint et al. 2008)

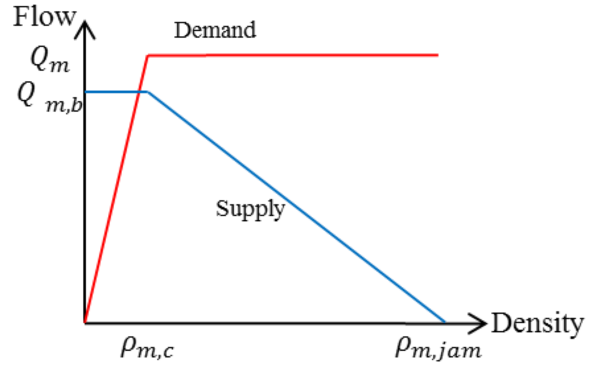
$$\eta_{i,j}(k) = \eta\left(sd_j, HW_j, v_{i,j}(k)\right) = \frac{sd_j + HW_j v_{i,j}(k)}{sd_{car} + HW_{car} v_{i,car}(k)}$$

Design of Control Model – Cont.

- To model the capacity drop phenomenon at bottlenecks, a discontinuous FD is used

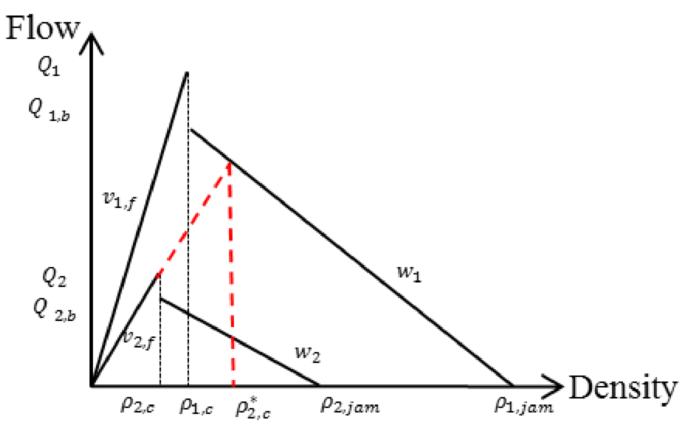


FD with a Capacity Drop



Demand and Supply Lines

- To model mixed traffic flows, a combined FD is used



$$\rho_{2,c}^{*} = \frac{w_1 \rho_{1,jam}}{w_1 - v_{2,f}}$$

FD with Capacity Drops for Two Vehicle Classes

Design of Control Model – Cont.

- The intelligent driver model (IDM) developed by Treiber et al. (2000) is adopted to model the car-following characteristics
- In the IDM, the acceleration $a(k)$ during time interval *k* can be computed

$$a(k) = a\left[1 - \left(\frac{v(k)}{v_0}\right)^4 - \left(\frac{s^*(k)}{s(k)}\right)^2\right] \qquad s^*(k) = max\left(0, s_0 + v * HW + \frac{v(k)\Delta v(k)}{2\sqrt{ab}}\right)$$

- An AV is formulated by adopting the IDM with its headway being smaller than the human-driven vehicle's
- If an AV is following another AV, a smaller headway will be used (0.6s)
- If an AV is following a human-driven vehicle, the vehicle will be acting as a regular AV (1.1s)

Design of Control Model – Cont.

- Minimize total travel time (TTT) and total speed variation (TSV)

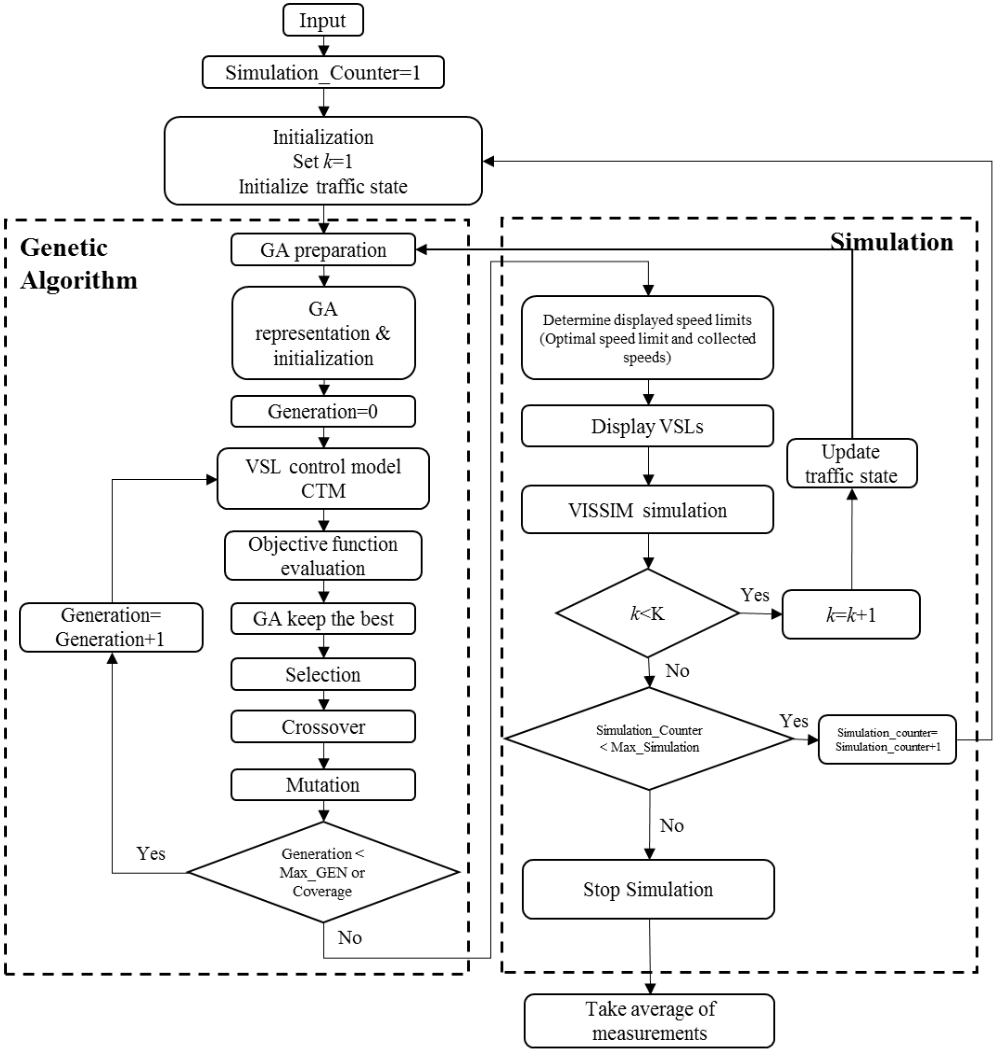
$$TTT = T\sum_{k=1}^{T_p}\sum_{i=1}^{N}\sum_{j=1}^{J}\rho_{i,j}(k)l_i$$

$$TSV = \sum_{j=1}^{J}\sum_{k=1}^{T_p}\sum_{s=1}^{S}\sum_{i=vsl_{s-1}+1}^{vsl_s}\left[u_i(k)-\left(\frac{vsl_s-i}{N_s}v_{vsl_{s-1},j}(k)+\frac{i-vsl_{s-1}}{N_s}v_{vsl_s,j}(k)\right)\right]$$

- ***min*** $J = w_1 TTT + w_2 TSV + \boxed{\sum_{s=1}^{S-1}\left(u_{vsl_s}(k)-u_{vsl_s+1}(k)\right)^2}$ penalty function
- ***s.t.***
  - $v_{min} \le u_i(k) \le v_{max}$
  - $u_i(k) \in V$ $\mathbf{V}= \{15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70 \text{ mph}\}$
  - $|u_i(k+1) - u_i(k)| \le 10$
  - $|u_i(k) - u_{i-1}(k)| \le 10$

Solution Algorithm

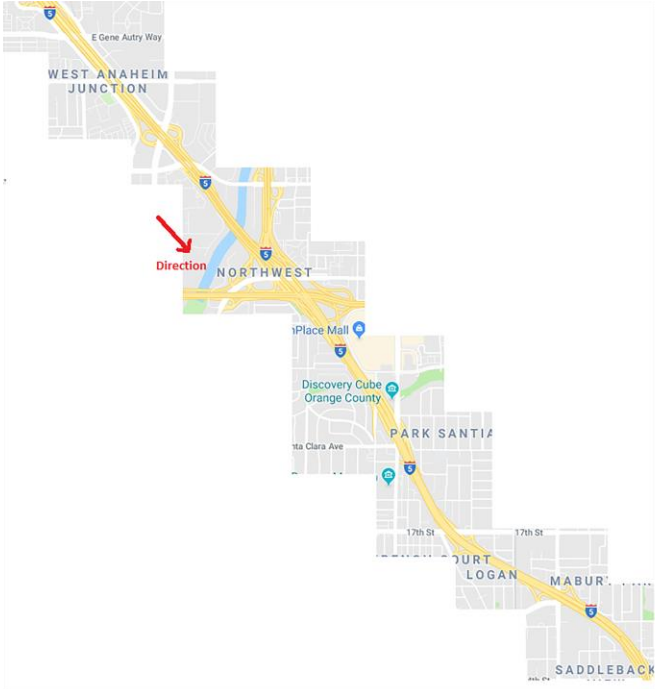
- Genetic algorithm (GA), is selected to optimize the variable speed limits
- Two modules are included
  - GA and VISSIM simulation
- The modified CTM is used to predict the traffic states



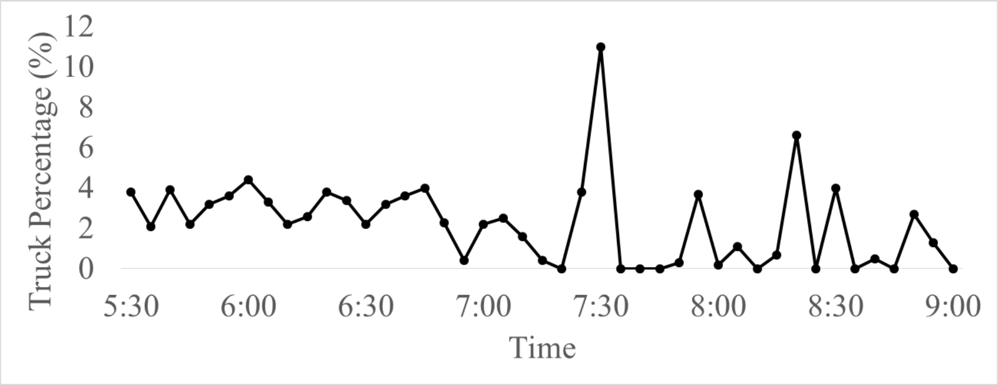
GA Flow Chart for Determining Optimal Speed Limit Set

Case Study

- A real-world freeway corridor is selected
- The studying period is from 5:30 am to 9:00 am on weekdays
- The field data is aggregated into 5-min counts
- The length of the selected freeway corridor is about 5 miles



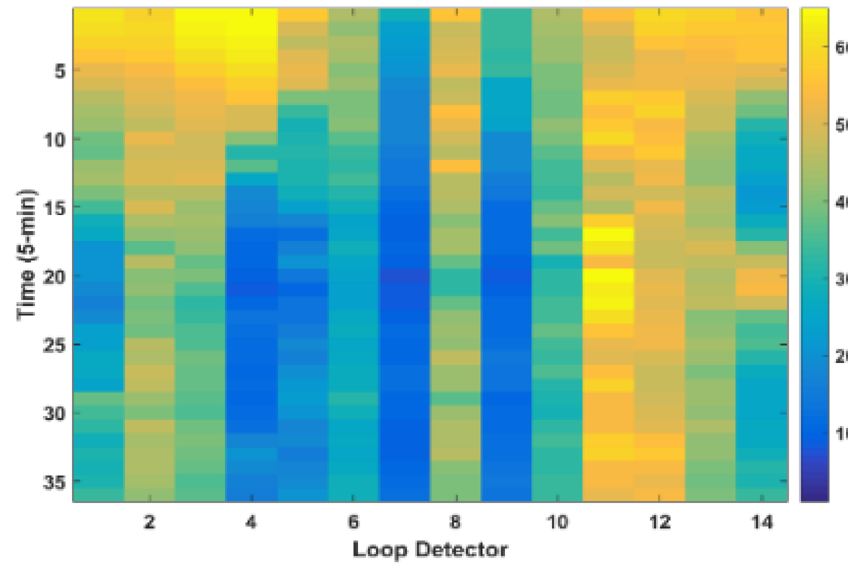
Map of the Case Study



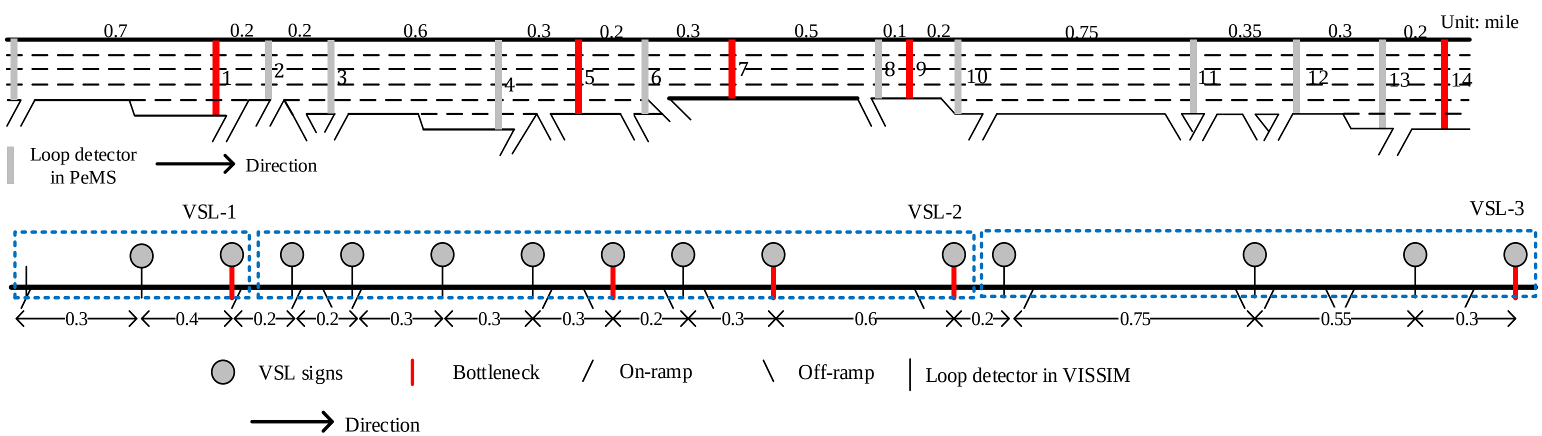
Truck Percentage vs. Study Period

Case Study – Cont.

- A preliminary analysis is performed to identify the positions of bottlenecks (Fan and Gong 2017; Gong and Fan 2017; Gong and Fan 2018)
- Five bottlenecks
  - Detectors 1, 5, 7, 9, and 14
- Three VSL control subsystems are deployed in this study



Speed Profiles at each Loop Detector



Numerical Results

- Three types of vehicles (i.e., human-driven cars, trucks, and autonomous cars) are included
- Traffic parameters need to be computed (Dervisoglu et al. 2008)
  - E.g., capacity, jam density, and shock wave speed

Computation Results of the CTM at each Bottleneck

Parameters		Bottleneck 1	Bottleneck 2	Bottleneck 3	Bottleneck 4	Bottleneck 5
Capacity (pce/h/lane)		2232	1749	1797	1733	1702
Drop Capacity (pce/h/lane)		2023	1517	1669	1528	1630
Magnitude of Capacity Drop (%)		10.35	15.28	7.66	13.45	4.41
Shock Wave Speed (mph)		10.99	7.26	8.67	8.62	9.24
Critical Density (pce/mile/lane)		34.34	26.33	27.33	26.6	25.66
Jam density (pce/mile/lane)		214.39	235.3	219.86	203.81	202.08
Car (human-driven and AVs)	Free Flow Speed (mph)	64.99	66.42	65.74	65.16	66.32
	Critical Density (veh/mile/lane)	34.34	26.33	27.33	26.6	25.66
Truck	Free Flow Speed (mph)	59.99	61.42	60.74	60.16	61.32
	Critical Density (veh/mile/lane)	20.52	15.12	15.45	15.20	14.45

Numerical Results – Cont.

- To obtain a close match between the collected and simulated traffic data, driver behavior parameters of VISSM are calibrated (Yu and Fan 2017)
  - e.g., standstill distance (CC0) and headway time (CC1)
- Parameters that are used to model the car-following characteristics of the AVs are selected on the basis of existing studies

The IDM's Parameter Value

Vehicle Types	HW_j	a	b	s_0
Human-driven vehicle	1.6 s	3.28 ft/s^2	-6.56 ft/s^2	4.13 ft
AV follows a human-driven vehicle	1.1 s	3.28 ft/s^2	-6.56 ft/s^2	0
AV follows an AV	0.6 s	3.28 ft/s^2	-6.56 ft/s^2	0
References	Treiber et al. 2000; Shladover et al. 2012; Milanés and Shladover 2014; Khondaker and Kattan 2015; Grumert et al. 2015; Li et al. 2017			

Numerical Results – Cont.

- A 3.5-hour simulation with a 30-minute (from 5:30 am – 6:00 am) warm up period is conducted
- The speed limit set that minimizes the objective function over a given prediction horizon (i.e., T_p=5 min)
- The speed limit changes every minute (i.e., T_c=1min)
- The discrete time step used in the control model is T=10s
- w_1=0.9 and w_2=0.1 are selected for the simulation
- Various scenarios are designed in this study

Simulation Scenarios and Descriptions

Scenarios	Description
Scenario 1	With 100% human-driven vehicles and without VSL control
Scenario 2	With 10% AVs and without VSL control
Scenario 3	With 100% human-driven vehicles, VSL control, and the CTM without considering mixed traffic flows
Scenario 4	With 100% human-driven vehicles, VSL control, and the extended CTM
Scenario 5	With 10% AVs and VSL control, and the extended CTM

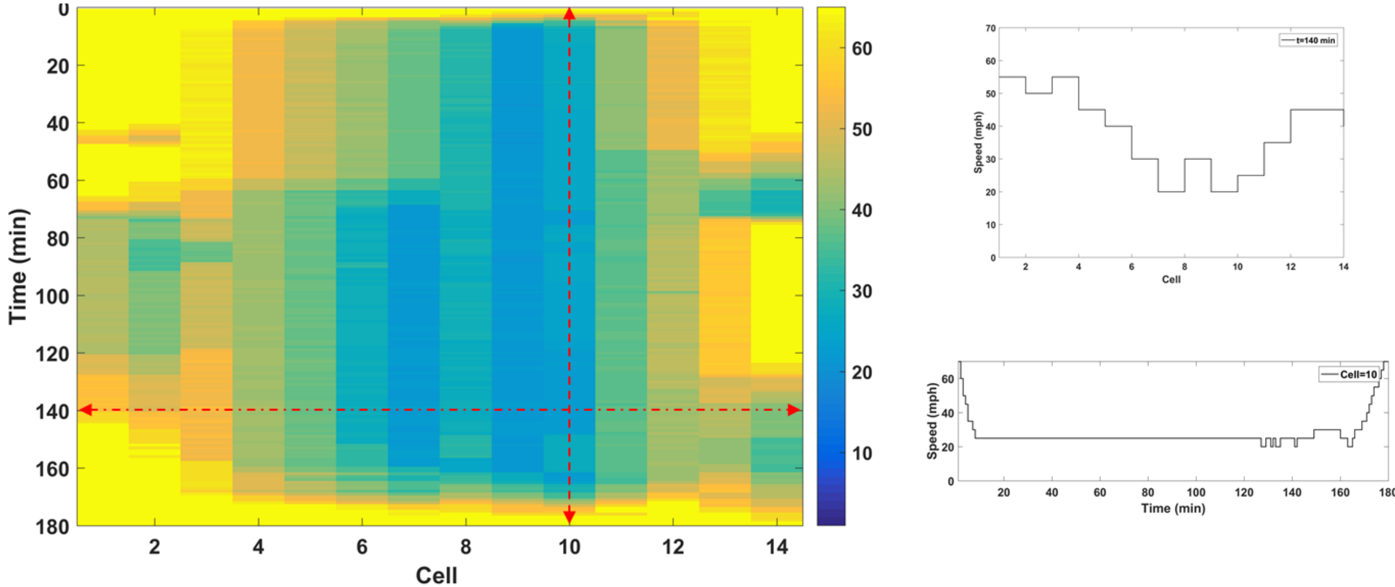
Numerical Results – Cont.

Performance Comparison under Different Scenarios

Scenario	TTT (veh-h)	Average delays (s)	Average number of stops	Emission (g)			Improvement (%)					
				CO_2	NOx	Particulate	TTT	Delays	Number of stops	CO_2	NOx	Particulate
Scenario 1	8140.51	400.76	67.58	650.33	1734.2	1951	-	-	-	-	-	-
Scenario 2	7988.12	385.75	61.77	641.59	1730.57	1950.45	1.87	3.75	8.59	1.34	0.21	0.03
Scenario 3	5469.65	170.59	26.99	608.91	1585.7	1851.3	32.81	57.43	60.06	6.37	8.56	5.11
Scenario 4	5337.68	158.71	25.74	605	1583.5	1846.12	34.43	60.4	61.91	6.97	8.69	5.38
Scenario 5	5328.65	139.81	25.33	600.32	1578.54	1838.54	34.54	65.11	62.52	7.69	8.98	5.76

- Simulation results under the five designed scenarios
  - TTT, average delays, average number of stops, and emission
- Scenario 1: without control
- Scenarios 3 and 4
  - Examining whether the extended CTM outperforms the CTM without considering mixed traffic flows
- Scenario 4 – VSL control
- Scenario 5 – VSL control in an AV environment

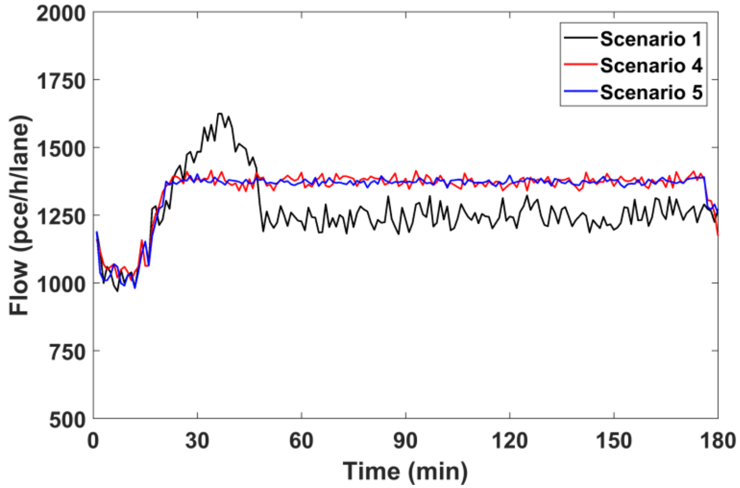
Numerical Results – Cont.



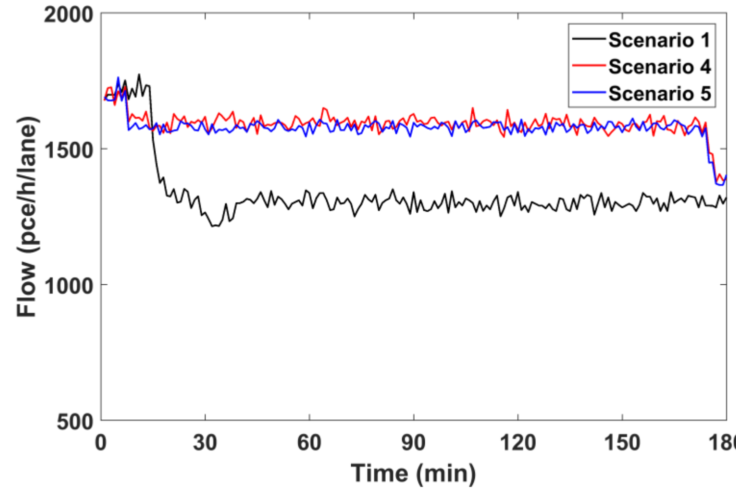
Contour of Speed Limit under Scenario 4

- Speed harmonization impact of VSL control
  - Speed differences among the adjacent cells are noticeably reduced
  - The vehicle speeds at the most congested bottlenecks begin to recover at the end of the simulation
  - The gradual change of color indicates that a smoother transition of speeds among cells has been achieved

Numerical Results – Cont.



Flow Profiles at Bottleneck 2



Flow Profiles at Bottleneck 3

- Equilibrium flow (pce/h/lane) profiles during the entire simulation period at bottlenecks 2 and 3 under scenario 1, scenario 4, and scenario 5
  - When traffic demands are greater than the bottleneck capacity, under scenario 1, a drop in flow at the bottleneck can be observed
  - Under scenarios 4 and 5, the equilibrium flow with VSL control remains steady and a higher discharge value is achieved compared to that without VSL control

Conclusion

- A proof-of-concept study on developing a VSL control strategy with CACC in an AV environment for a freeway corridor is performed
- The VSL control is developed on the basis of the extended CTM which considers the capacity drop phenomenon at the bottleneck
- The proposed VSL control model takes the mixed traffic flow (including human-driven cars, trucks and AVs) into consideration
- A real-world freeway corridor is selected to examine the developed control strategy
- The simulation results demonstrate that the developed VSL control can be used to greatly enhance the operational efficiency, improve safety, and reduce the emissions of greenhouse gases
- The VSL control in an AV environment outperforms the VSL control without CACC

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QUESTIONS AND COMMENTS?

THANK YOU!

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