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National Solutions Worldwide Impact

Pedestrian and Bicycle Safety Performance Functions for the Highway Safety Manual (NCHRP 17-84)

Research Team

MRIGlobal Larson Institute SafeTREC Abley, NZ

Texas A&M Transportation Institute

Transportation Research Center

Defense Energy Health

Agenda

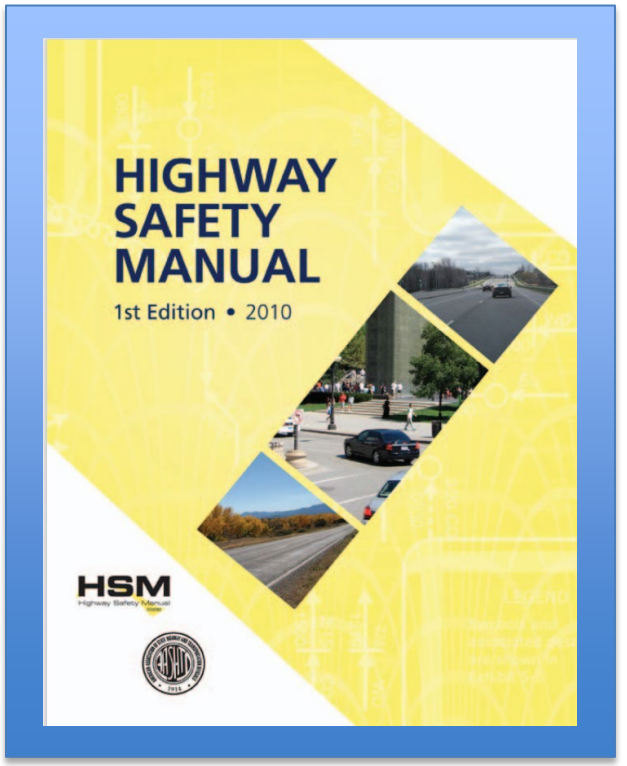
- Background
- Research objective and scope
- Review details and results of primary work plans
- Conclusions and recommendations
- Spreadsheet tools
- Future research

Background

- The Highway Safety Manual (HSM) is the premier guidance document for incorporating quantitative safety analysis in the highway transportation project development process

- HSM Part C models are most suited for estimating expected frequencies of motor-vehicle crashes, excluding pedestrian and bicycle crashes

- Explicit consideration of pedestrian and bicycle safety is critical for implementation of future editions of the HSM



Research Objective and Scope

- **Objective**
  - Develop pedestrian and bicycle SPFs for transportation practitioners at all levels to better inform planning, design, and operations decisions

- **Scope**
  - Develop pedestrian and bicycle SPFs for:
    - Roadway segments and intersections
    - Rural and urban areas

Primary Work Plans

- Develop Pedestrian and Bicycle SPFs Incorporating Available Pedestrian and Bicycle Exposure Data
- Develop Pedestrian and Bicycle Models Based on Road Assessment Program (RAP) Methodology
- Develop Pedestrian and Bicycle Models in the Absence of Pedestrian and Bicycle Exposure Data

Development of Pedestrian and Bicycle Models Incorporating Available Pedestrian and Bicycle Exposure Data

- Focused on developing pedestrian and bicycle SPFs for roadway segments and intersections in urban/suburban areas, for which exposure, crash, and inventory data were available

- Collected inventory, traffic volume, pedestrian and bicycle volume, and crash data in two urban/suburban areas:

  - Minneapolis (MN)
    - Database included up to 13 yrs of data (2006 – 2018)

  - Philadelphia (PA)
    - Database included up to 6 yrs of data (2013 – 2018)

Data Collection – Site Characteristics (Roadway Segments)

General Segment Elements

- Presence of lighting
- Posted speed limit
- Median type
- Median width
- Presence of traffic calming
- No. of driveways
- No. of bus/transit stops
- No. of schools
- No. of alcohol sales establishments

Directional Elements

- Number of travel lanes
- Width of travel lanes
- Shoulder width
- Parking lane width
- Bicycle facility types
  - Type of protection
  - Buffer width
  - Lane width
  - One-way vs two-way
  - Colored pavement
- Shared use path
  - Path width
  - Buffer width
- Sidewalks
  - Width
  - Buffer width
  - Type of protection
- Midblock Crossings
  - Control type
  - Advanced yield/stop lines
  - Crossing length

Data Collection – Site Characteristics (Intersections)

General Intersection Elements

- Number of legs
- Control type
- Lighting
- Overhead flashing beacon
- School zone
- No. of bus/transit stops
- No. of schools
- No. of alcohol sales establishments

Elements by Leg (Inbound and Outbound)

- Width of through lanes
- Width of left-turn lanes
- Width right-turn lanes
- Presence of right-turn channelizing islands
- Parking lane width
- Outside shoulder width
- Inside shoulder width
- Median type / width
- Bike lane width / buffer width
- Type of left-turn or right-turn operations
- Presence of colored pavement for bike lanes
- Presence of bike box
- Presence of crosswalk
- Crosswalk type
- Total crosswalk length
- Presence of median refuge island
- Presence of shared-use path crossing
- Presence of advance yield/stop lines
- Posted speed limit

Pedestrian and Bicycle Exposure Data

- Developed direct demand models to obtain pedestrian and bicycle exposure for study sites in database

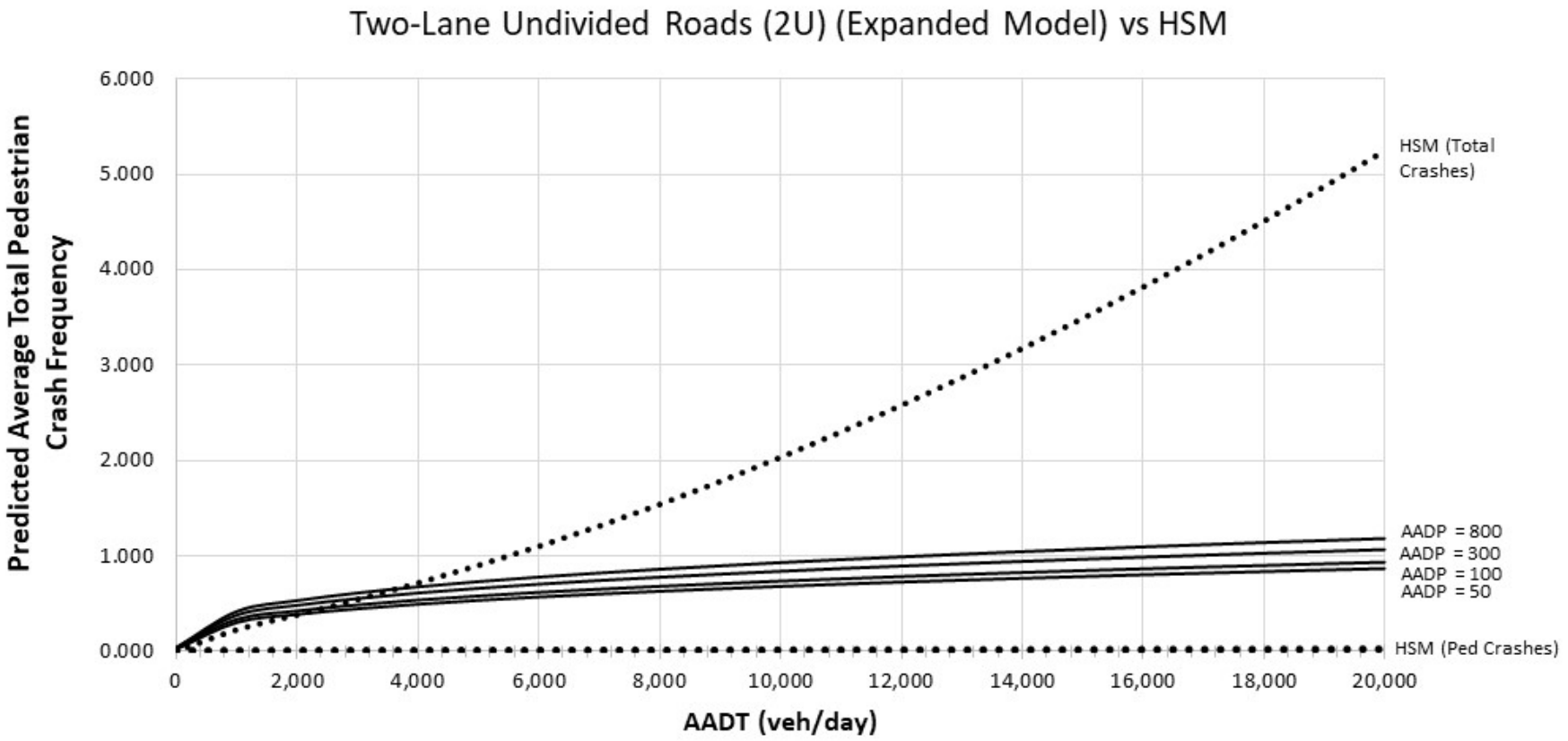
$$Ped\ or\ Bike\ Volume = f\begin{pmatrix} sociodemographics \\ land\ use \\ street\ network \\ transit\ access \\ etc. \end{pmatrix}$$

- Developed models at multiple scales
  - e.g. Population within 0.5, 0.25, and 0.1 miles

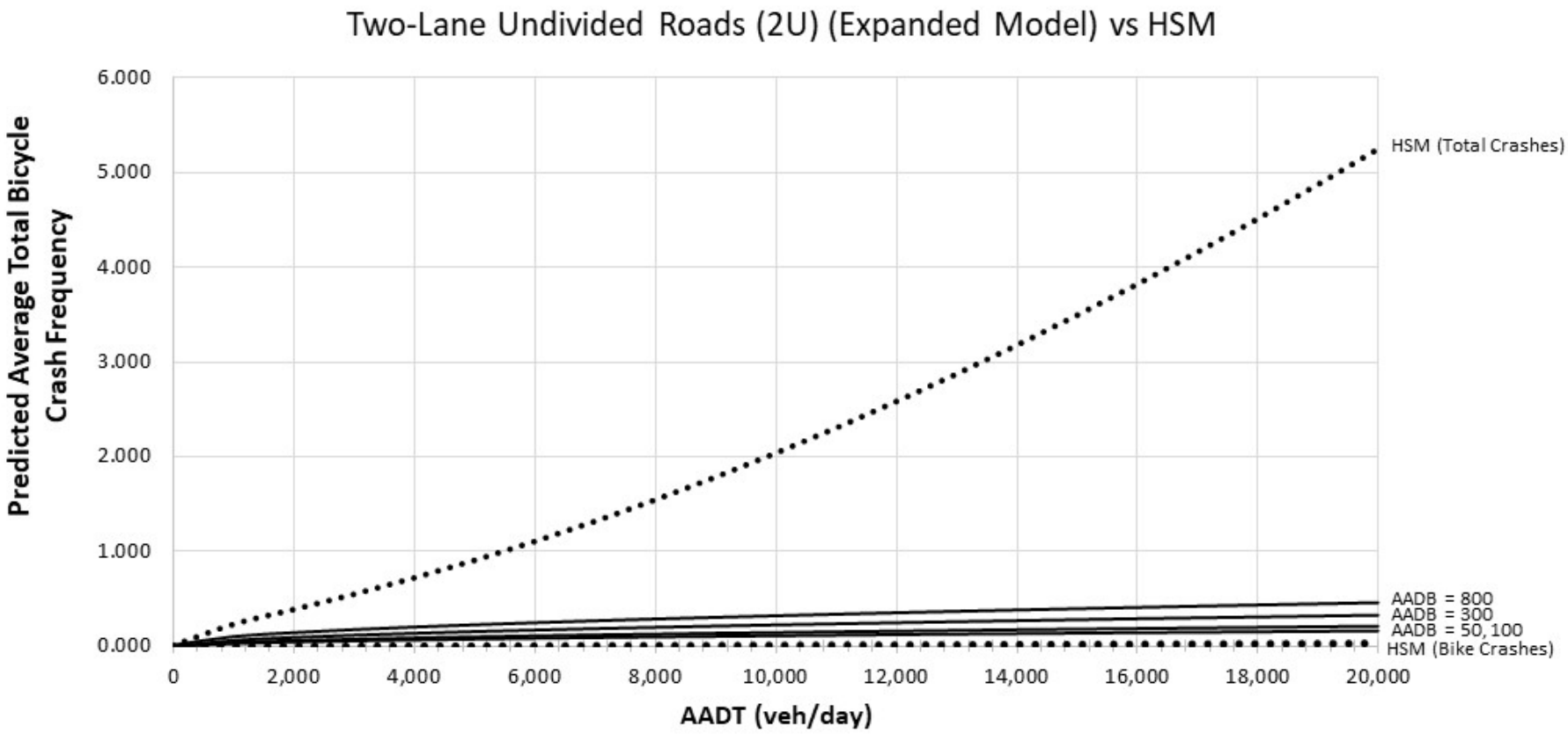
Develop Pedestrian and Bicycle SPFs using Available Exposure Data

- Models for urban roadway segments
  - Two lane roads
  - Four lane roads (divided and undivided)
  - One-way roads (1-ln, 2-ln, and 3-ln)
- Models for urban intersections
  - Three-leg stop controlled
  - Three-leg signalized
  - Four-leg stop controlled
  - Four-leg signalized (2×2 and 2×1)
- Severity levels
  - All injuries
  - Fatal and serious
- Exposure only and expanded models (i.e., include adjustment factors)

Final Pedestrian SPF
(Two-Lane Undivided Roadway Segments) (2U)



Final Bicycle SPF
(Two-Lane Undivided Roadway Segments) (2U)



Adjustment Factors for Segment Models

- Pedestrian models:
  - Presence of sidewalk buffer
  - Lane width
  - Presence of a median
  - Speed limit (greater than 25 mph)
  - Number of lanes (one-way roads)
  - Number of bus stops within 1,000 ft
  - Number of schools within 1,000 ft
  - Number of liquor establishments within 1,000 ft
- Bicycle models
  - Presence of a buffered bike lane
  - Lane width
  - Presence of a median
  - Speed limit (greater than 25 mph)
  - Number of lanes (one-way roads)
  - Number of bus stops within 1,000 ft
  - Number of schools within 1,000 ft
  - Number of liquor establishments within 1,000 ft

Adjustment Factors for Intersection Models (4SG 2×2):

- Pedestrian models
  - Right turn on red
  - Type of left-turn signal phasing
  - Number of liquor establishments within 1,000 ft

- Bicycle models:
  - Presence of bicycle facilities entering the intersection
  - Type of left-turn signal phasing
  - Number of schools within 1,000 ft

Development of Pedestrian and Bicycle Models Incorporating Available Pedestrian and Bicycle Exposure Data (Summary)

- Pedestrian and bicycle SPFs were developed for potential consideration in urban/suburban arterial predictive chapter and network screening chapter of HSM2

- Three levels of models were developed:
  - Reduced model to estimate total ped/bike crashes
  - Expanded model to estimate total ped/bike crashes
  - Reduced model to estimate FS ped/bike crashes

- Comparisons of new pedestrian and bicycle SPFs with existing Part C models showed that several models may not be compatible with existing HSM models

- Calibration of new pedestrian and bicycle SPFs will be critical for compatibility with existing HSM models

Develop Pedestrian and Bicycle Models Based on Road Assessment Program (RAP) Methodology

Summary of the RAP Prediction Model

- Developed by the International Road Assessment Program over the period since 2006
  - Development overseen by iRAP's Global Technical Committee
  - Based on best knowledge from international research literature
  - Applied in at least 70 countries since 2008
- Predicts fatalities and serious injuries per year for a road network based on roadway characteristics data for 100-m road segments
- Separate predictions for:
  - Vehicle occupants
  - Motorcyclists
  - Pedestrians
  - Bicyclists

Separate Predictive Models by Crash Type

VEHICLE-**PEDESTRIAN** MODELS

Roadway Segments:

- Pedestrian movements **along the left side** of the road
- Pedestrian movements **along the right side** of the road
- Pedestrian movements crossing the road at a **midblock location**

Intersections:

- Pedestrian movements **crossing each leg** of an intersection

VEHICLE-**BICYCLE** MODELS

Roadway Segments:

- Bicycle movements **along the road**

Intersections:

- Bicycle movements **through** an intersection

General Form of Roadway Segment Model for Vehicle-Pedestrian Crashes

$$N_{pedr} = \left(N_{alongleft-ped} + N_{alongright-ped} + \sum_{x=1}^{n} N_{midcrossing-ped} \right) \times FT_{pedr} \times C_{pedr}$$

N_{pedr}	=	predicted number of vehicle-pedestrian crashes per year for all crash severity levels combined
$N_{alongleft\text{-}ped}$	=	predicted number of vehicle-pedestrian crashes per year involving pedestrian movements along the left side of the road for a specific roadway segment
$N_{alongright\text{-}ped}$	=	predicted number of vehicle-pedestrian crashes per year involving pedestrian movements along the right side of the road for a specific roadway segment
$N_{midcrossing\text{-}ped}$	=	predicted number of vehicle-pedestrian crashes per year involving pedestrians crossing the road at a specific midblock location on a specific roadway segment
FT_{pedr}	=	facility type factor for vehicle-pedestrian crashes
C_{pedr}	=	calibration factor for vehicle-pedestrian crashes
n	=	maximum number of midblock crossing locations within a specific roadway segment

Vehicle-Pedestrian Crash Prediction Model for Pedestrian Movements Along the Left Side of the Road

$$N_{alongleft-ped} = Likelihood_{alongleft-ped} \times Severity_{alongleft-ped} \times MVTSF_{along-ped} \times MVTFF_{along-ped} \times PFF_{alongleft} \times \left(\frac{L}{0.0622}\right)$$

$Likelihood_{alongleft\text{-}ped}$	=	crash likelihood adjustment factor for vehicle-pedestrian crashes involving pedestrian movements along the **left side of the road** for a specific roadway segment
$Severity_{alongleft\text{-}ped}$	=	crash severity adjustment factor for vehicle-pedestrian crashes involving pedestrian movements along the **left side of the road** for a specific roadway segment
$MVTSF_{alongleft\text{-}ped}$	=	motor-vehicle traffic speed factor for traffic along the **left side of the road** for a specific roadway segment
$MVTFF_{along\text{-}ped}$	=	motor-vehicle traffic flow factor for traffic along the **left side of the road** for a specific roadway segment
$PFF_{alongleft}$	=	pedestrian flow factor for pedestrian flow along the **left side of the road** for a specific roadway segment
L	=	length (mi) of a specific roadway segment

Vehicle-Pedestrian Crash Prediction Model for Pedestrian Movements Along the Left Side of the Road

$$N_{alongleft-ped} = Likelihood_{alongleft-ped} \times Severity_{alongleft-ped} \times MVTSF_{along-ped} \times MVTFF_{along-ped} \times PFF_{alongleft} \times \left(\frac{L}{0.0622}\right)$$

AFs

- $Likelihood_{alongleft-ped}$ = crash likelihood adjustment factor for vehicle-pedestrian crashes involving pedestrian movements along the **left side of the road** for a specific roadway segment
- $Severity_{alongleft-ped}$ = crash severity adjustment factor for vehicle-pedestrian crashes involving pedestrian movements along the **left side of the road** for a specific roadway segment

SPFs

- $MVTSF_{alongleft-ped}$ = motor-vehicle traffic speed factor for traffic along the **left side of the road** for a specific roadway segment
- $MVTFF_{along-ped}$ = motor-vehicle traffic flow factor for traffic along the **left side of the road** for a specific roadway segment
- $PFF_{alongleft}$ = pedestrian flow factor for pedestrian flow along the **left side of the road** for a specific roadway segment
- L = length (mi) of a specific roadway segment

Factors in Portion of Models Analogous to SPFs

Factors	Vehicle-Pedestrian Crashes			Vehicle-Bicycle Crashes	
	Along the road	Midblock crossing	Intersection crossing	Along the road	Through an intersection
Motor-vehicle traffic speed factor	X	X	X	X	X
Motor-vehicle traffic flow factor	X	X	X	X	X
Pedestrian flow factor	X	X	X		
Bicycle flow factor				X	X
Length of roadway segment	X			X	
Facility type factors	X			X	
Calibration factors	X			X	
Proportion of crashes by severity level	X			X	
Number of injuries per crash	X			X	

- SPFs are based on factors from published literature, not on negative binomial regression models
- EB procedure cannot be applied because the SPFs have no overdispersion parameters

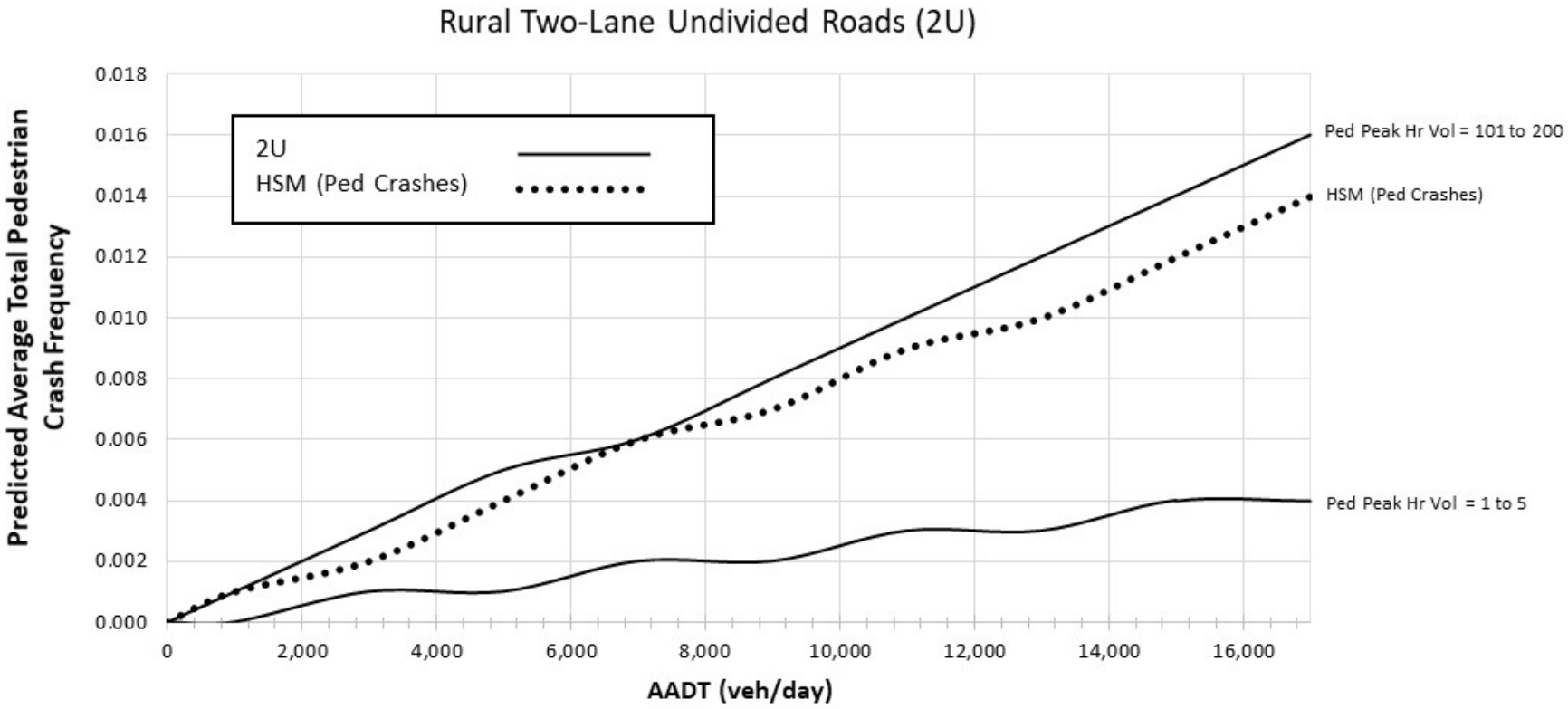
Factors in Portion of Pedestrian Models Analogous to CMFs/AFs

Factor	Along the road	Midblock crossing	Intersection crossing
Presence of sidewalk/distance from traveled way	X		
Presence and width of paved shoulder	X		
Presence of school zone with warning signs	X	X	X
Lane width	X		
Horizontal curvature	X		
Advance visibility of a curve	X		
Percent grade	X		
Presence and condition of delineation	X		
Presence of shoulder rumble strips	X		
Presence of vehicle parking	X	X	X
Presence of street lighting	X	X	X
Pedestrian crossing facility type		X	X
Advance visibility of a pedestrian crossing		X	X
Presence of pedestrian fencing		X	X
Number of lanes to be crossed		X	X
Median type and width		X	X
Intersection type			X

Factors in Portion of Bicycle Models Analogous to CMFs/AFs

Factor	Along the road	Through an intersection
Presence and type of bicycle facilities	X	X
Presence and width of paved shoulder	X	X
Lane width	X	
Horizontal curvature	X	
Advance visibility of a curve	X	
Presence and condition of delineation	X	
Presence of shoulder rumble strips	X	
Presence of vehicle parking	X	
Presence of street lighting	X	
Presence and type of pedestrian crossing facility		X
Intersection type		X
Advance visibility of an intersection		X
Intersection channelization		X

Pedestrian Models
(Two-Lane Undivided Roadway Segments) (2U)



Development of Pedestrian and Bicycle Models Based on RAP Methodology (Summary)

- Pedestrian and bicycle SPFs were developed for potential consideration in Part C predictive chapters of HSM2

- Modified RAP models appear compatible with existing HSM Part C models
  - Note: modified RAP models are based on peak-hour pedestrian and bicycle volumes

- Limitations of modified RAP models:
  - Cannot be directly applied with EB method
  - Do not address roundabouts

Develop Regression Models for Pedestrians and Bicycles Based on Crash Data in the Absence of Pedestrian and Bicycle Volume Data

Development of Pedestrian and Bicycle Models in the Absence of Pedestrian and Bicycle Volume Data

- Models were developed to estimate the potential of a pedestrian or bicycle crash occurring on various roadway segment and intersection types when the associated pedestrian or bicycle exposure data are not available
- Logistic regression models developed for:
  - Rural roadway segments (non-freeways)
  - Urban and suburban roadway segments (non-freeways)
  - Urban and suburban signalized intersections
- Models provide practitioners with a list of factors that either increase or decrease the potential for pedestrian and bicycle crashes
  - Results may be incorporated into forthcoming chapters on pedestrians and bicyclists and systemic safety management planned for HSM2

Conclusions and Recommendations

- Pedestrian and bicycle SPFs presented herein have been developed for use in the HSM to help inform planning, design, and operation decisions by transportation practitioners at all levels
  - SPFs recommended for use in Part C chapters and network screening chapter of HSM2

- SPFs will likely need some level of calibration to be compatible with the existing HSM models for multiple- and single-vehicle crashes

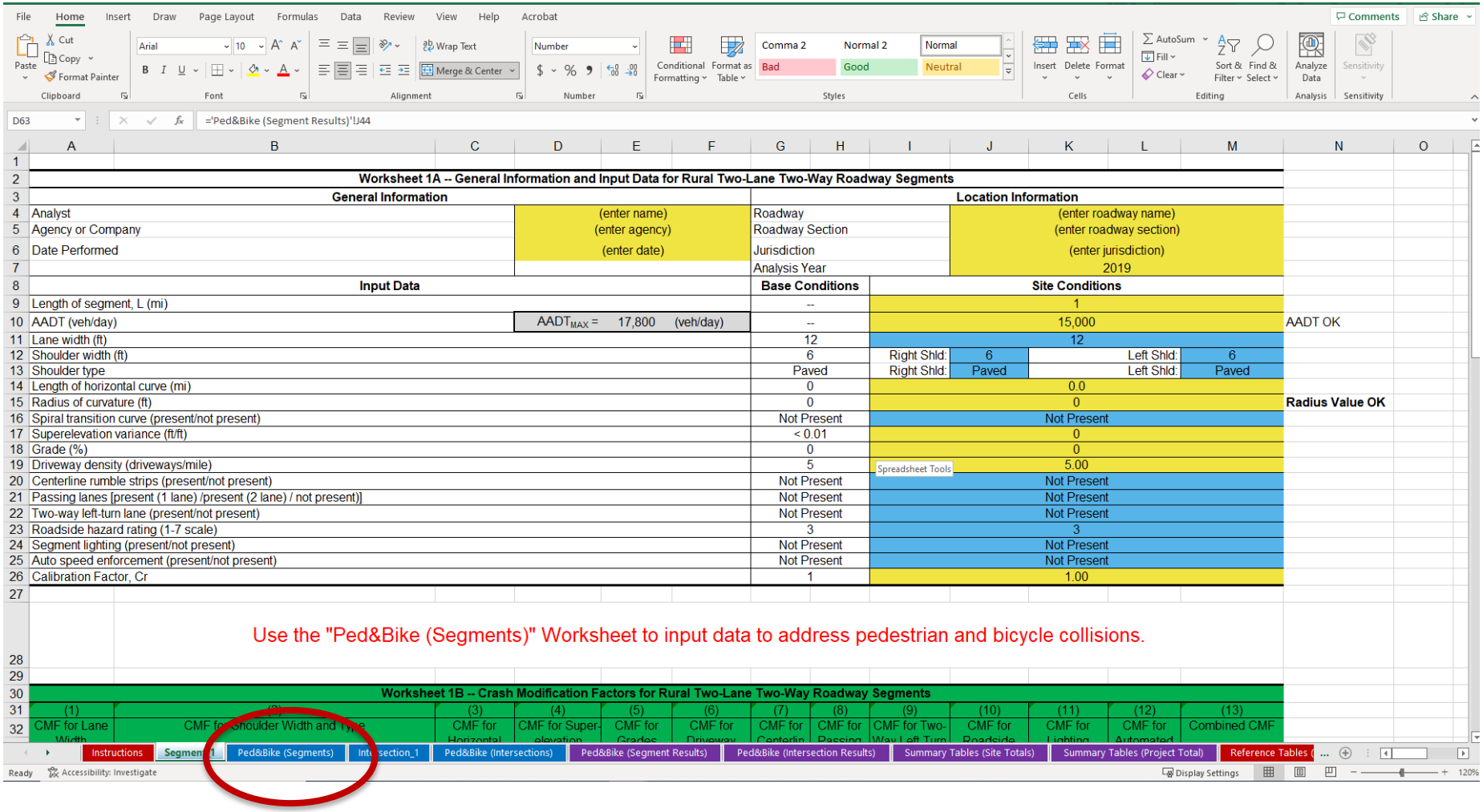
- Results may be incorporated into forthcoming chapters on pedestrians and bicyclists and systemic safety management planned for HSM2

Spreadsheet Tools

- Spreadsheet tools were updated to incorporation pedestrian and bicycle SPFs for use with HSM procedures

- Updated recent versions of HSM spreadsheet tools available from HSM website
  - Rural Two-Lane Roads Spreadsheet v3.0
    - Updated July 2019
  - Rural Multilane Highways Spreadsheet v3.0
    - Updated July 2019
  - Urban and Suburban Arterials Spreadsheet v3.11
    - Updated April 2020

Spreadsheet Tools (Rural Two-Lane)



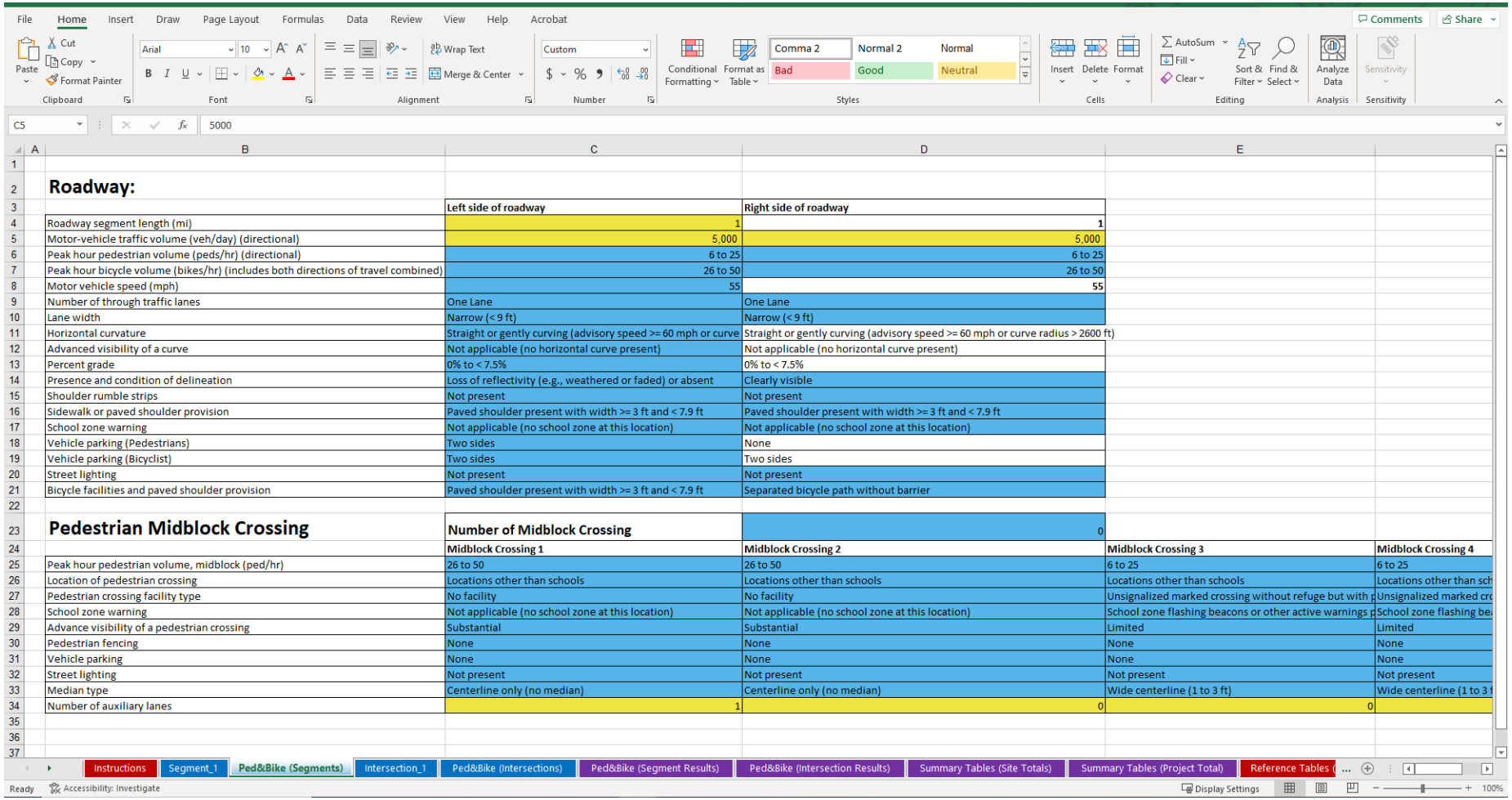
Worksheet 1A -- General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments					
General Information			**Location Information**		
Analyst	(enter name)		Roadway	(enter roadway name)	
Agency or Company	(enter agency)		Roadway Section	(enter roadway section)	
Date Performed	(enter date)		Jurisdiction	(enter jurisdiction)	
			Analysis Year	2019	
Input Data		**Base Conditions**	**Site Conditions**		
Length of segment, L (mi)		--	1		
AADT (veh/day)	$AADT_{MAX}$ = 17,800 (veh/day)	--	15,000		AADT OK
Lane width (ft)		12	12		
Shoulder width (ft)		6	Right Shld: 6	Left Shld: 6	
Shoulder type		Paved	Right Shld: Paved	Left Shld: Paved	
Length of horizontal curve (mi)		0	0.0		
Radius of curvature (ft)		0	0		Radius Value OK
Spiral transition curve (present/not present)		Not Present	Not Present		
Superelevation variance (ft/ft)		< 0.01	0		
Grade (%)		0	0		
Driveway density (driveways/mile)		5	5.00		
Centerline rumble strips (present/not present)		Not Present	Not Present		
Passing lanes [present (1 lane) /present (2 lane) / not present)]		Not Present	Not Present		
Two-way left-turn lane (present/not present)		Not Present	Not Present		
Roadside hazard rating (1-7 scale)		3	3		
Segment lighting (present/not present)		Not Present	Not Present		
Auto speed enforcement (present/not present)		Not Present	Not Present		
Calibration Factor, Cr		1	1.00		

Use the "Ped&Bike (Segments)" Worksheet to input data to address pedestrian and bicycle collisions.

Worksheet 1B -- Crash Modification Factors for Rural Two-Lane Two-Way Roadway Segments												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal	CMF for Super-elevation	CMF for Grades	CMF for Driveway	CMF for Centerlin	CMF for Passing	CMF for Two-Way Left Turn	CMF for Roadside	CMF for Lighting	CMF for Automated	Combined CMF

Instructions | Segment_1 | Ped&Bike (Segments) | Intersection_1 | Ped&Bike (Intersections) | Ped&Bike (Segment Results) | Ped&Bike (Intersection Results) | Summary Tables (Site Totals) | Summary Tables (Project Total) | Reference Tables

Spreadsheet Tools (Rural Two-Lane) (cont.)



Roadway:		
	Left side of roadway	Right side of roadway
Roadway segment length (mi)	1	1
Motor-vehicle traffic volume (veh/day) (directional)	5,000	5,000
Peak hour pedestrian volume (peds/hr) (directional)	6 to 25	6 to 25
Peak hour bicycle volume (bikes/hr) (includes both directions of travel combined)	26 to 50	26 to 50
Motor vehicle speed (mph)	55	55
Number of through traffic lanes	One Lane	One Lane
Lane width	Narrow (< 9 ft)	Narrow (< 9 ft)
Horizontal curvature	Straight or gently curving (advisory speed >= 60 mph or curve	Straight or gently curving (advisory speed >= 60 mph or curve radius > 2600 ft)
Advanced visibility of a curve	Not applicable (no horizontal curve present)	Not applicable (no horizontal curve present)
Percent grade	0% to < 7.5%	0% to < 7.5%
Presence and condition of delineation	Loss of reflectivity (e.g., weathered or faded) or absent	Clearly visible
Shoulder rumble strips	Not present	Not present
Sidewalk or paved shoulder provision	Paved shoulder present with width >= 3 ft and < 7.9 ft	Paved shoulder present with width >= 3 ft and < 7.9 ft
School zone warning	Not applicable (no school zone at this location)	Not applicable (no school zone at this location)
Vehicle parking (Pedestrians)	Two sides	None
Vehicle parking (Bicyclist)	Two sides	Two sides
Street lighting	Not present	Not present
Bicycle facilities and paved shoulder provision	Paved shoulder present with width >= 3 ft and < 7.9 ft	Separated bicycle path without barrier

Pedestrian Midblock Crossing	Number of Midblock Crossing	0		
	Midblock Crossing 1	Midblock Crossing 2	Midblock Crossing 3	Midblock Crossing 4
Peak hour pedestrian volume, midblock (ped/hr)	26 to 50	26 to 50	6 to 25	6 to 25
Location of pedestrian crossing	Locations other than schools	Locations other than schools	Locations other than schools	Locations other than sch
Pedestrian crossing facility type	No facility	No facility	Unsignalized marked crossing without refuge but with p	Unsignalized marked cro
School zone warning	Not applicable (no school zone at this location)	Not applicable (no school zone at this location)	School zone flashing beacons or other active warnings p	School zone flashing bea
Advance visibility of a pedestrian crossing	Substantial	Substantial	Limited	Limited
Pedestrian fencing	None	None	None	None
Vehicle parking	None	None	None	None
Street lighting	Not present	Not present	Not present	Not present
Median type	Centerline only (no median)	Centerline only (no median)	Wide centerline (1 to 3 ft)	Wide centerline (1 to 3 f
Number of auxiliary lanes	1	0	0	

Future Research

- Future research should be undertaken to:
  - Pedestrian and bicycle safety performance at roundabouts
  - Further evaluate approaches to defining boundaries of an intersection for purposes of assigning pedestrian and bicycle crashes to the intersection for model development
  - Develop pedestrian and bicycle SPFs to address additional site types

Future Research (cont.)

- Future research should be undertaken to:
  - Develop pedestrian and bicycle SPFs by crash type for potential consideration in HSM
  - Investigate counterintuitive findings related to installation of sidewalks and pedestrian crashes along the roadway
  - Investigate counterintuitive findings related to motor vehicle speed and pedestrian and bicycle crashes along the roadway
  - Address underreporting of crashes in HSM predictive methods and models

Questions???

Darren Torbic
Research Scientist
Traffic Operations and Roadway Safety Division
Texas A&M Transportation Institute
d-torbic@tti.tamu.edu
814-574-9194