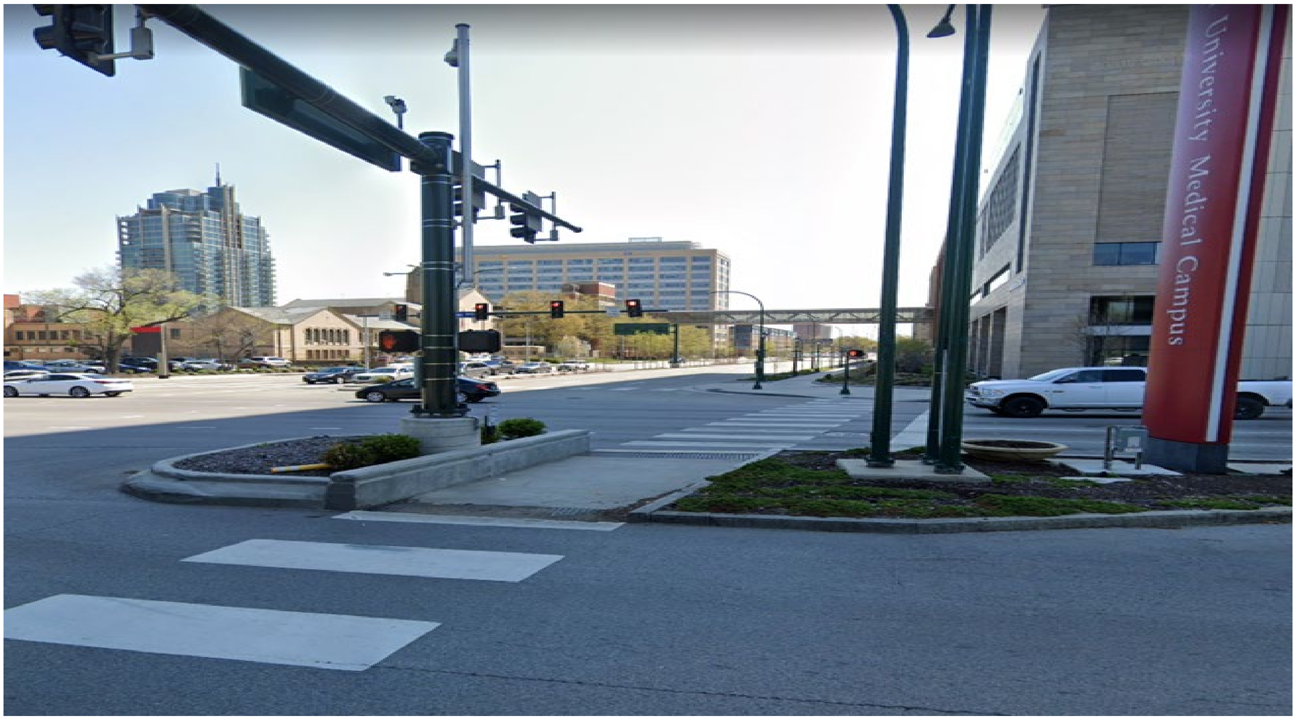
Missouri Systemic Countermeasures to Improve Pedestrian Safety



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16. Abstract

Missouri Department of Transportation (MoDOT) has successfully implemented systemic safety countermeasures in the past to reduce fatal and serious injury crashes related to roadway departure. MoDOT initiated this research project to address the increasing trend in pedestrian fatalities and serious injuries in Missouri. The focus of the project is to develop a Missouri Pedestrian Safety Countermeasure Tool based on analysis of pedestrian-involved crash data and identification of situational trends. This matrix-based tool identifies those peer groups (segments and intersections) that have the highest risk of pedestrian crashes and the countermeasures based on a particular set of roadway criteria (traffic volume, speed limit, and number of lanes) that can be applied across various jurisdictions. The Pedestrian Safety Countermeasure Tool includes multiple peer groups for road segments, signalized intersections, and unsignalized intersections. Overall, the study found that the following priority peer groups provide the greatest impact for reducing pedestrian crashes through implementation of the Pedestrian Safety Countermeasure Tool.

1. Urbanized 4-Leg Signalized (Z4S) Intersection on Undivided Roads (Priority 1).
2. Urbanized 2-Lane Undivided (Z2U) Road Segments (Priority 1).
3. Rural 2-Lane Undivided (R2U) Road Segments (Priority 1).
4. Urbanized 3-Leg Signalized (Z3S) Intersections on Divided Roads (Priority 2).

Specific traffic volume and speed limit ranges have higher occurrences of pedestrian crashes. GIS maps were developed for each Metropolitan Planning Organization (MPO) area to facilitate implementation. Modifications to policies can further enhance pedestrian safety in Missouri.

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FINAL REPORT
MISSOURI DEPARTMENT OF TRANSPORTATION PROJECT

MISSOURI SYSTEMIC COUNTERMEASURES TO IMPROVE PEDESTRIAN SAFETY

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ABSTRACT

Missouri Department of Transportation (MoDOT) has successfully implemented systemic safety countermeasures in the past to reduce fatal and serious injury crashes related to roadway departure. MoDOT initiated this research project to address the increasing trend in pedestrian fatalities and serious injuries in Missouri. The focus of the project is to develop a Missouri Pedestrian Safety Countermeasure Tool based on analysis of pedestrian-involved crash data and identification of situational trends. This matrix-based tool identifies those peer groups (segments and intersections) that have the highest risk of pedestrian crashes and the countermeasures based on a particular set of roadway criteria (traffic volume, speed limit, and number of lanes) that can be applied across various jurisdictions. The Pedestrian Safety Countermeasure Tool includes multiple peer groups for road segments, signalized intersections, and unsignalized intersections. Overall, the study found that the following priority peer groups provide the greatest impact for reducing pedestrian crashes through implementation of the Pedestrian Safety Countermeasure Tool.

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Specific traffic volume and speed limit ranges have higher occurrences of pedestrian crashes. GIS maps were developed for each Metropolitan Planning Organization (MPO) area to facilitate implementation. Modifications to policies can further enhance pedestrian safety in Missouri.

EXECUTIVE SUMMARY

The main objective of this study is to develop a Pedestrian Safety Countermeasure Tool based on the statewide systemic data analysis of pedestrian-involved crash data in Missouri. Approximately 100 pedestrians are killed each year in Missouri, representing over 10 percent of Missouri's total traffic fatalities. During the last ten years, pedestrian and bicyclist fatalities have increased 79 percent in Missouri while all other traffic fatalities have increased by 20 percent. The Missouri Department of Transportation (MoDOT) has a history of successfully implementing systemic safety improvements to reduce crashes related to roadway departure. The systemic approach to safety manages the potential for crashes where crash densities may be low, making this an ideal method for addressing pedestrian safety across Missouri. The Federal Highway Administration (FHWA) has identified a series of proven safety countermeasures that have been implemented by state and local agencies across the nation. Many of these have been used as part of FHWA's Every Day Counts (EDC) initiative and are considered low cost and easily implemented on a systemic basis.

Existing literature on systemic pedestrian safety analysis and countermeasures was reviewed. A review of past research, reports, and other documents found several methods for data analysis and selection of countermeasures. Three primary methods identified were a matrix-based analysis, a safety performance function (SPF)-based, and a weighted risk factor scoring. The matrix-based method is most commonly used and considers risk factors such as intersection control, number of lanes, and AADT to identify those facility types that are at greater risk for pedestrian crashes. Several publications identified effective pedestrian safety countermeasures that have been implemented by state and local agencies. Effectiveness most often came from FHWA's Crash Modification Factor (CMF) Clearinghouse based on past research from the studies reviewed for this project. Cost was primarily noted as low, median, and high. This is due in part to the ranges of cost that may be dependent on the scope of implementation, especially as new technology decreases in cost over time.

Considering the objective of the research project, various pedestrian safety countermeasures were reviewed for applicability for systemic implementation. They were categorized according to their application at signalized and uncontrolled or unsignalized intersections, mid-block crossings, and for locations where pedestrians are at risk when walking along the roadway. The resulting list of categorized pedestrian safety countermeasures were prioritized by the MoDOT Research Technical Advisory Committee (TAC) and considered for applicability based on the data analysis results. This list was further refined during the Pedestrian Safety Countermeasure Tool development process. Many of those that can be implemented systemically are considered as proven safety countermeasures identified and endorsed by the FHWA through its Every Day Counts (EDC) initiative, Safe Transportation for Every Pedestrian (STEP). These range from reducing speed limits and adding walkways/sidewalks to adding high-visibility crosswalks and enhancements such as lighting and signing. Newer countermeasures such as Rectangular Rapid Flashing Beacon (RRFB), Pedestrian Hybrid Beacon (PHB), and Leading Pedestrian Interval (LPI) were included as well. Not all countermeasures were used during the development of the tool. Some (e.g., adjust transit stops, RSAs) are more applicable to actual implementation. The various signal timing countermeasure treatments (e.g., Pedestrian Phase Recall, All Red Stop Timing, Reduced Signal Cycle, and Permissive Left Turn Phase to Protected) were consolidated

into one countermeasure as more investigation would be required to determine the appropriate treatment based on existing conditions.

Statewide geolocated pedestrian crash data were provided for a nine-year period, from 2013 to 2021. Overall, the crash records contain information on crash severity, temporal and environmental conditions, roadway characteristics, crash type, among other several variables. There was a total of 822 fatal crashes, 9,388 injury crashes, and 774 property damage only. Pedestrian crashes on freeway segments were excluded from the analysis, however, crashes on freeway ramps within the intersection area were included in the analysis. Additionally, crashes in parking lots and on driveways were excluded from the analysis. The data analysis included roadway segments and intersections (signalized, unsignalized, and roundabouts) where at least one pedestrian crash occurred. The roadway segments and intersections were categorized into peer groups. Peer groups represent homogeneous characteristics so that sites with similar safety risk profiles are compared. Segment peer groups were defined based on land use (rural (R), urban (U), and urbanized (Z)), number of lanes, and median type (divided (D) or undivided (U)). Intersection peer groups were also grouped based on land use, number of legs, and traffic control type (signalized (S), minor leg stop control (M), all-way stop control (A), roundabout (R)). Distribution plots for traffic volume and speed limits were also used to partition each peer group into a different volume/speed bins for both roadway segments and intersections.

The statewide systemic data analysis results were interpreted for roadway segment and intersection peer groups to identify situational trends in pedestrian crashes in Missouri. These were used to establish roadway types and thresholds for traffic volumes and speed limits and identify countermeasures to guide the development of the Missouri Pedestrian Safety Countermeasure Tool. The data analysis results indicate 86 percent of the roadway segment pedestrian crashes are within the top five peer groups (urbanized 2-lane undivided (Z2U), rural 2-lane undivided (R2U), urbanized 5-lane undivided (Z5U), urban 2-lane undivided (U2U), and urbanized 4-lane undivided (Z4U)), all of which are undivided roadways. Although the R2U roadway segment peer group has the lowest total crash rate per mile, it has the largest number of fatal and serious injury pedestrian crashes among all segment peer groups. The thresholds for traffic volumes for road segments are as follows:

- Less than 5,000 vehicles per day (vpd)
- 5,000 – 10,000 vpd
- 10,000 – 20,000 vpd
- 20,000 vpd and greater

The speed limit threshold for analysis used less than 25 miles per hour (mph) to greater than 45 mph in 5 mph increments. For purposes of the tool, the following ranges were applied:

- 30 miles per hour (mph) or less
- 35 mph-45 mph
- Greater than 45 mph

The statewide analysis determined that intersections represented approximately 50 percent of the locations with at least one pedestrian crash and 63 percent of the total pedestrian crashes when compared to roadway segments. Of the study group, intersections represented 33 percent of the fatal crashes and 63 percent of the serious injury crashes. The analysis results identified four signalized intersection peer groups (Z4S, Z3S, U4S, and Z5S) and four unsignalized intersection peer groups (Z4M, R4M, U4M, and Z3M) with the highest number of pedestrian crashes where the systemic safety approach could be applied and have benefit. The urbanized 4-leg signalized (UZ4) represented 59 percent of the fatal pedestrian crashes, 65 percent of the serious injury crashes, and 67 percent of all pedestrian crashes at intersections. Based on the analysis, given the varying volume and speed distributions, the most appropriate traffic volume thresholds for the intersection peer groups in the tool are as follows:

Traffic Volume:
- Less than 10,000 vpd
- 10,000 – 20,000 vpd
- 20,000 – 30,000 vpd
- Greater than 30,000 vpd

Speed Limit:
- 30 mph or less
- 35 mph – 45 mph
- Greater than 45 mph

The Missouri Pedestrian Safety Countermeasure Tool was developed based on the data analysis results. It represents three Excel spreadsheet matrices for signalized intersections, unsignalized intersections, and segments-midblock (undivided roads), a table for segments (corridor/parallel walking along the roadway), and the associated countermeasures that can be implemented systemically on a corridor or across a roadway network to reduce pedestrian-related crashes. The tool identifies two priority peer groups based on the analysis results. Priority 1 represents those peer groups categories with at least 20 percent of the total number of pedestrian crashes. Priority 2 represents those peer group categories with at least 10 percent but less than 20 percent of the pedestrian crashes. The countermeasures identified in the tool can be systemically implemented individually, in combination with other treatments, or as a required suite of treatments. To facilitate implementation, a series of pedestrian crash maps were developed using Geographical Information System (GIS) mapping for each Metropolitan Planning Area (MPO) in Missouri.

In conclusion, although the Missouri Pedestrian Safety Countermeasure Tool includes multiple peer groups for road segments, signalized intersections, and unsignalized intersections, implementation should focus on the following priority peer groups for the most impact.

Priority 1 Peer Groups:
1. Urbanized 4-Leg Signalized (Z4S) Intersection on Undivided Roads.
2. Urbanized 2-Lane Undivided (Z2U) Road Segments.
3. Rural 2-Lane Undivided (R2U) Road Segments.

Priority 2 Peer Groups:
1. Urbanized 3-Leg Signalized (Z3S) Intersections on Divided Roads.
2. Urban 2-Lane Undivided (U2U) Road Segments.
3. Urbanized 4-Lane Undivided (Z4U) Road Segments.
4. Urbanized 5-Lane Undivided (Z5U) Road Segments.

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1. Introduction

1.1 Background

More than 6,000 pedestrians were killed in traffic related crashes each year between 2019 and 2021 in the United States (U.S.). Early estimates of 2021 fatality data projected an increase of over 16 percent to 7,485 pedestrians killed on the nation's roadways [15]. Furthermore, pedestrian fatalities increased 54 percent in the U.S. between 2010 and 2020 while all other traffic related fatalities increased by 13 percent. As shown in Figure 1-1, during the time period of 2011 to 2020, pedestrian and bicyclist fatalities have increased 79 percent in Missouri while all other traffic fatalities have increased by 20 percent. Approximately 100 pedestrians are killed each year in Missouri, representing over 10 percent of Missouri's total traffic fatalities [21]. The Missouri Department of Transportation (MoDOT) and its county, city and other local agency stakeholders are committed to driving Missouri toward zero deaths on all roadways for all users, including pedestrians.

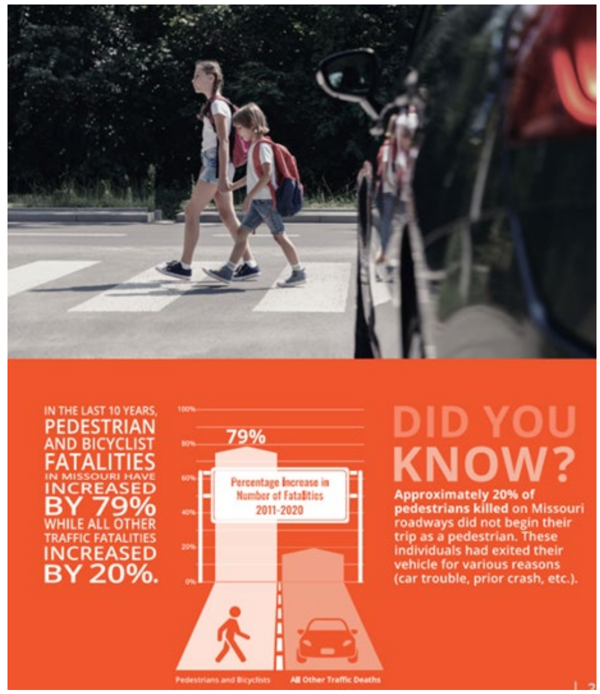

Figure 1-1 Missouri Strategic Highway Safety Plan 2021-2025

MoDOT has successfully implemented systemic safety improvements, such as cable median barriers and rumble strips. A systemic approach to safety involves analyzing safety data for a roadway network system, identifying those roadway attributes across the system that potentially increase the frequency and severity of crashes, and implementing strategies systemically on the roadway network based on those attributes. This approach was helpful in reducing roadway departure-related traffic crashes in Missouri, particularly those resulting in fatalities and serious injuries.

In the systemic approach to pedestrian safety, locations with a high probability of pedestrian crashes are identified based on exposure and risk factors, and countermeasures are implemented across the network based on those crash risks. MoDOT initiated this project to identify those crash risks specific to Missouri and provide an easy-to-use tool for local and state selection and consistent application of pedestrian safety countermeasures.

1.2 Project Objectives and Scope

The objectives of this project are to:

- Analyze pedestrian-involved crash data in Missouri for situational trends.

- Maintain consistency in approved products (countermeasures) and application across various jurisdictions.
- Evaluate countermeasures to determine potential lives saved, serious injuries reduced, and benefit-cost ratio, based on a particular set of roadway criteria.
- Develop a pedestrian crash countermeasure tool based on Missouri road and traffic data, to be used by various jurisdictions.

This scope of this project focuses on statewide data analysis and identification of infrastructure related safety countermeasures for all public roads in Missouri except freeways and interstates. Countermeasures investigated for implementation will include those that can be implemented systemically. It will not include countermeasures such as pedestrian bridges that are higher cost and targeted at specific locations. The project includes a review of literature to identify systemic safety analysis approaches, potential pedestrian safety countermeasures, and formats for a countermeasure tool. Based on the data analysis results, the appropriate pedestrian safety countermeasures will be selected, and an easy-to-use tool will be developed to facilitate implementation.

1.3 Study Methodology

The study methodology includes the following tasks to meet the project objectives:
Task 1: Project Management. The project team works closely with the MoDOT research Technical Advisory Committee (TAC) to obtain guidance and feedback on the data analysis procedures, countermeasure selection, and development of the Missouri Pedestrian Safety Countermeasure Selection Tool.

Task 2: Literature Review. In this task, a comprehensive review of the state of practice for systemic pedestrian safety analysis and countermeasure selection is carried out. This includes identifying current proven as well as emerging solutions and consideration of their effectiveness.

Task 3: Generate List of Approved Countermeasures. In executing this task, the project team collaborates with TAC to identify pedestrian safety countermeasures that merit further investigation for systemic implementation in Missouri. Using the outcomes of Task 2, the project team prepares a list of pedestrian safety countermeasures that includes FHWA's Proven Pedestrian Safety Countermeasures, pedestrian countermeasures currently installed in Missouri, and innovative and promising countermeasures. This list of potential countermeasures includes the effectiveness as demonstrated with a crash modification factor (CMF), if available, and the level of cost (low, medium, high). This information is provided to the TAC to rank for potential use and is the basis for consideration when evaluating the data analysis results and developing the Missouri Pedestrian Safety Countermeasure Tool.

Task 4: Evaluation of Data and Distinguishing of Thresholds. Statewide crash and roadway data are prepared and analyzed in this task. The roadway segments and intersections are separated into peer groups for data analysis which allows for comparison of similar roadways for crash risks. The analysis results are evaluated for crash risk, situational trends, and identification of countermeasures that provide the highest cost-benefit.

Task 5: Development of Pedestrian Crash Countermeasure Selection Tool. Based on the results from the previous tasks, a table or matrix-type tool is developed to aid local, county, and state jurisdictions in Missouri in the selection of the most appropriate pedestrian safety countermeasures for different roadway and crossing scenarios. This Pedestrian Safety Countermeasure Tool is similar to the Federal Highway Administration (FHWA) "Field Guide for Selecting Countermeasures at Uncontrolled Pedestrian Crossing Locations" and addresses the needs of Missouri.

Task 6: Develop Report, Research Summary, and Presentation. This report reflects the results of the tasks completed to perform the research. This includes a summary document and a presentation that can be used to highlight the important details of the project.

1.4 Report Organization

The following chapters of this report are organized as follows:

Chapter 2 provides a summary of the literature review results focused on systemic pedestrian safety analysis. It includes sources of where the pedestrian safety countermeasures were identified and considered for potential use in the tool.

Chapter 3 provides a consolidated list of pedestrian safety countermeasures considered for inclusion in the Missouri Pedestrian Safety Countermeasure Tool. These focus on pedestrians walking along the roadway, mid-block crossings, and signalized and unsignalized/uncontrolled intersections.

Chapter 4 provides the methodology used for performing the statewide systemic data analysis to determine crash risks associated with pedestrians.

Chapter 5 provides the results of the systemic data analysis and the evaluation of those results.

Chapter 6 discusses the development of the Missouri Pedestrian Safety Countermeasure Tool. It includes the tool. Microsoft Excel spreadsheets will be provided separately to MoDOT for use. This chapter also includes discussion on pedestrian crash maps that can be used to facilitate implementation of the tool.

Chapter 7 provides the conclusions of the research project.

Chapter 8 provides the references used in the research report.

The following information is included in the appendices.

Appendix A provides the maps in pdf format for each of the Metropolitan Planning Organizations (MPOs) in Missouri. These will be provided separately as Geographical Information System (GIS) files.

Appendix B provides the spreadsheet listing the summary of ranked potential pedestrian safety countermeasures with the CMF values, if available, and cost range (low, medium, high).

2. Literature Review

A literature review was performed to identify practices related to systemic pedestrian safety analysis and countermeasure implementation.

2.1 Systemic Methods

A review of the past research on systemic pedestrian safety found several methods for data analysis and selection of countermeasures. Three primary methods identified were a matrix analysis, a safety performance function (SPF)-based, and a weighted risk factor score.

2.1.1 Matrix Approach

Matrix approaches use crash type and another set of factors, such as roadway facility type, to create a matrix that displays the number of crashes for each combination of crash type and factor. This helps to easily illustrate which factors are present in high crash frequency sites and what crash types are common at those sites. The most well-known matrix approach was developed by the California Department of Transportation (Caltrans). The matrix method was developed by Caltrans through two different studies in 2013 [3] and 2017 and focused on analysis of urban arterials. The 2013 study focused on a 16.5-mile section of an arterial corridor in San Francisco. Facility types with high crash frequencies were identified based on risk factors such as intersection control, number of lanes, and AADT. The matrix was assembled with the first column displaying crash types and the first row displaying facility types. Each of the cells within the matrix displays the number of pedestrian related crashes that occurred corresponding to the facility type and crash type in the cell's column and row number. This provides the user with a heat map of pedestrian crashes sorted by crash and facility type. Figure 2-1 below displays an example of the facility type matrix.

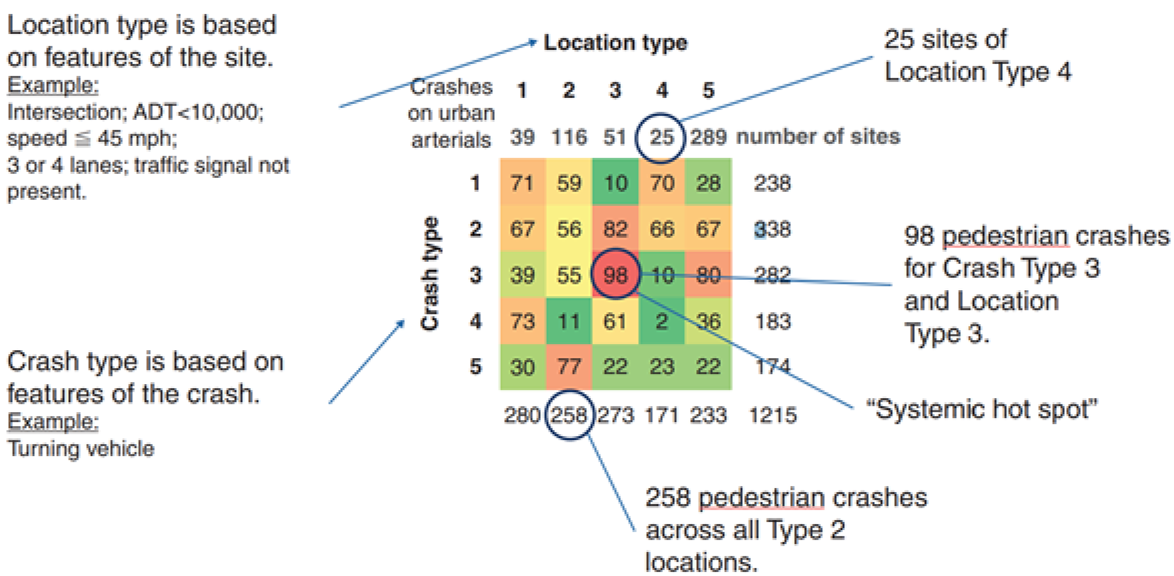

Figure 2-1 Caltrans Crash Frequency Matrix **[3]**

This method helps to identify which facility types are at more risk for various crash types and the most common crash types occurring at those facilities. Caltrans created a list of candidate countermeasures for addressing crash types at various facilities. The selected countermeasures were placed in a matrix of the same size and matched with crash and facility type combinations where the countermeasure was most applicable. The countermeasure matrix is shown below in Figure 2-2.

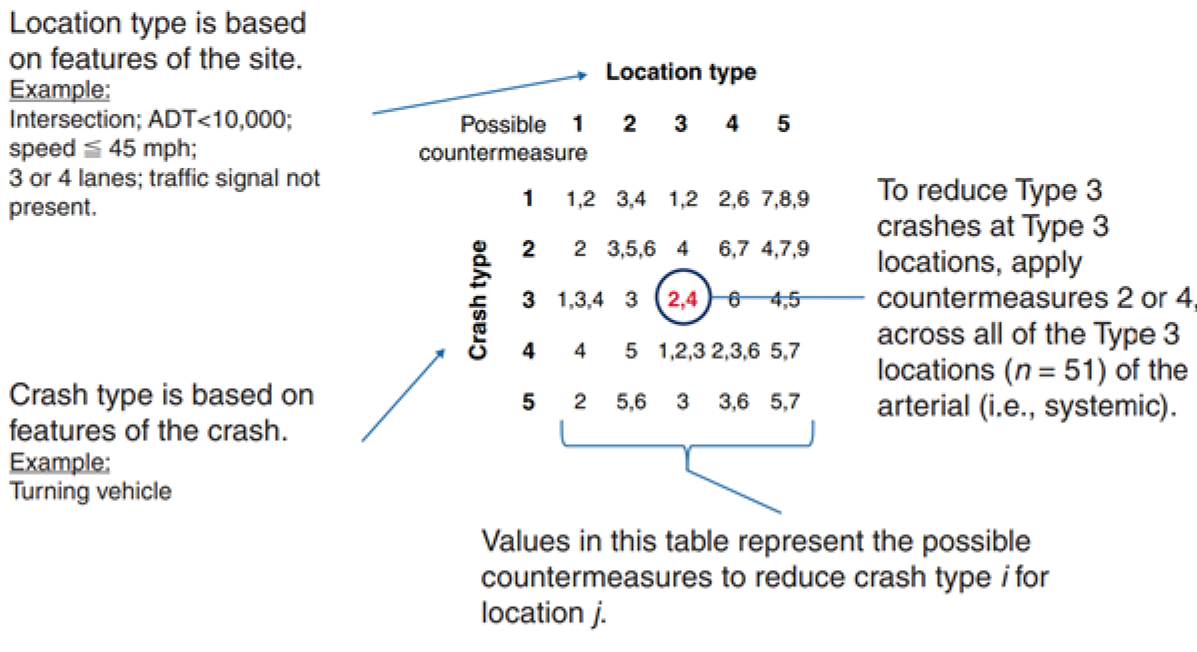

Figure 2-2 Caltrans Countermeasure Matrix [3]

The 2017 study expanded upon the methods used for the 2013 study and included data for the state highway system. The increased database allowed for a more robust tool to be created. A Microsoft Excel spreadsheet tool was created based upon the matrix methodology developed in the studies.

The City of San Diego applied a similar matrix approach and started by grouping locations with various traits into broader facility types [22]. Low-cost countermeasures were prioritized in order to be cost effective at as many locations as possible. San Diego noted the low-cost countermeasure may not be as effective as more expensive options at one location, but the goal of using low-cost countermeasures was to achieve a higher return on investment across the network. In order to create the method for their matrix approach, San Diego utilized FHWA's Systemic Safety Project Selection Tool [14] and Caltrans Systemic Pedestrian Safety Analysis [19]. Variables for the analysis were selected based on existing information included in crash reports, GIS databases, and aerial imagery review.

2.1.2 Safety Performance Functions (SPF) Approach

The second method reviewed included the creation of SPFs for the purpose of systemic countermeasure selection. While this is the recommended systemic approach for pedestrian safety in NCHRP Report 893: Systemic Pedestrian Safety Analysis [19], SPF creation is not a common approach used as it requires extensive exposure data to accurately conduct analyses. The City of Seattle was able to collect and estimate sufficient counts for the number of bicycles, pedestrians, and cars at all intersections of the study network due to the smaller network scope of their study. Seattle issued two studies to address pedestrian crash issues. The first of these studies used multivariate statistical analysis to identify and measure the significance of various risk factors for two different pedestrian crash types at intersections. The exposure data available was insufficient for analysis of midblock crossings and were not included in the analysis. The results of this study led to the subsequent study in 2020 which collected additional exposure data and added an additional three years of crash data to create pedestrian SPFs using binomial regression. SPFs were created for four different crash types at intersections: all pedestrian crashes, crashes involving motorists turning left, crashes involving motorists turning right, and crashes involving motorists proceeding straight. The SPFs created were able to identify and measure the significance of risk factors and allow for before-after studies of countermeasure implementation. The SPFs were used to identify which countermeasures were most effective at reducing three types of pedestrian related crash types. Risk factors found to be significant were then used as a basis for a GIS based tool created to identify high risk sites in the city.

2.1.3 Weighted Risk Factors Score

The third systemic pedestrian safety approach identified was a weighted risk factor score. This method was the most common and used by four different entities: the Virginia Department of Transportation (VDOT), the Oregon Department of Transportation (ODOT), the Arizona Department of Transportation (ADOT), and the New York State Department of Transportation (NYSDOT). VDOT utilized the methods outlined in FHWA-SA-17-50 How to Develop a Pedestrian and Bicycle Safety Action Plan [11] as a basis for their approach [23]. VDOT chose to address pedestrian crash issues from a number of different angles including policy evaluation, crash history analysis, and systemic analysis to identifying high priority corridors. To conduct a systemic approach, VDOT identified twelve different risk factors: AADT, Posted Speed Limit, Number of Lanes and Presence of a Median, Zero Vehicle Households, Population below the Poverty Line, Population Density, Density of Employed Persons, Existing Pedestrian Crash History, Urban/Rural Context, Proportion of Alcohol-Related Crashes, Proximity to a Park, and Proximity to a School. Each risk factor was given sub-scores for the levels of each measure present at the site, and each risk factor was given a percentage weight of the overall score in context to the other risk factors. For example, AADT was given a weight of 14 percent of the overall score. An AADT of less than 500 was given a score of 2, less than 1500 a score of 4, and so on. Scores were then assigned to sites based on the risk factor presence and levels at the site. These scores were used as the basis for site selection for countermeasure implementation.

The Oregon Department of Transportation (ODOT) identified risk factors and weighted scores from a panel of experts. Similar to the VDOT approach, ODOT used the presence and level of the identified risk factors and their weighted scores to analyze the crash potential of the roadways in the project scope. ODOT made the decision to only consider state-maintained roadways due to a lack of data on local roads.

ADOT identified risk factors based on past research. Similar to VDOT and ODOT, ADOT applied weighted scores to the risk factors identified. These risk factor scores were then used in

GIS to create location scores. ADOT only applied this method only to state highways as it was incorporated into their highway safety action plan.

NYSDOT identified risk factors through the use of a state-wide review of crash data using ArcGIS. NYSDOT found several compounding factors such as signage, markings, and transit location were not available or incomplete in the crash data to a degree that it was harmful to analysis. To counteract this, NYSDOT sampled 100 crashes and used Google Earth to gather the missing data. This random sample of 100 crashes was then used to determine countermeasures suitable for systemic implementation. A systemic safety program was included in engineering solutions of the state pedestrian safety action plan specifically for uncontrolled marked pedestrian crosswalks on state roads in urban areas. Two packages of countermeasures were created; a basic sign and pavement treatment to be applied where engineering judgment felt the package was warranted, and an enhanced treatment package to be implemented in future years.

2.2 Countermeasure Identification and Selection

Review of past research and literature produced several methods for the identification and selection of countermeasures for systemic implementation. Several national programs were found to be used and listed here:

- FHWA Road Diet Informational Guide [13]
- PEDSAFE, Pedestrian Safety Guide and Countermeasure Selection System [12]
- Manual on Uniform Traffic Control Devices (MUTCD) [8]
- PBCAT [9]
- BikeSAFE [10]

Effectiveness of countermeasures most often came from FHWA's CMF Clearinghouse [6] in the studies reviewed for this project. Additional research published by FHWA and TRB were used occasionally to fill the reduction factor gaps.

Research studies were utilized for countermeasure identification and selection in this project. The most prominent of these studies were the Transportation Research Board *NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways* [16], *NCHRP Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments* [17], and *NCHRP Report 926: Guidance to Improve Pedestrian and Bicyclist Safety at Intersections* [18].

2.3 Benefit Cost Analysis Methods

Several benefit cost analysis methods were identified in review of the literature. In a traditional benefit-cost analysis, dollar values are assigned to crashes, lives, or injuries with the cost of the treatment or countermeasure. NCHRP Report 896 [20] notes that traditional benefit-cost analysis can be more difficult to apply to pedestrian safety analysis as observed sites with little to no crash history, but high crash potential is overlooked for selection in crash-based benefit-cost analysis.

ADOT applied crash cost on average severity outcomes to counteract variability in injury outcomes due to individual crash factors such as age and health condition of the pedestrian struck in the crash. ADOT also incorporated service life, operating costs, and construction costs to the countermeasures in their benefit-cost analysis. ADOT calculated benefit-cost ratios for each high-crash and high-risk segment on state highways. A benefit-cost ratio was calculated for both pedestrian crashes and vehicle crashes of the identified segments.

Cost-Effectiveness Index (CEI), detailed in NCHRP Report 896, is another form of benefit cost analysis that does not use assigned monetary values for crash severity but instead estimates which locations have the largest reduction in expected crashes for the dollar value needed for the improvements. CEI is the inverse of traditional benefit-cost analysis where CEI is equal to the Project Cost divided by the Expected Reduction in Pedestrian Crashes. This method was used by ODOT in their systemic pedestrian safety approach as they compared predicted crashes using SPFs in Part C of the Highway Safety Manual (HSM) and the number of observed crashes. The higher value of the two was used in a CEI analysis to understand the cost benefits of countermeasures at identified locations.

The research reports reviewed for identification of various potential countermeasures provided a range of costs in terms of low, medium, and high along with the crash modification factors (CMFs), if available. These were used to develop a list of potential countermeasures for the Missouri DOT Research Technical Advisory Committee (TAC). Most of the treatments recommended are low cost as they are most conducive to systemic implementation.

3. Approved Pedestrian Countermeasures

Several countermeasures that address pedestrian safety were identified during the literature review. These range from low-cost easily implemented systemically to higher cost standalone treatments that may be constructed at a spot location. Many of those that can be implemented systemically are considered as proven safety countermeasures identified and endorsed by the FHWA through its Every Day Counts Safe Transportation for Every Pedestrian (STEP). They have been used by many State Departments of Transportation, and county and local governments to improve pedestrian safety.

3.1 Education and Outreach

Although the focus of the research project was on infrastructure-related safety countermeasures, education and outreach play an important role with reducing pedestrian crashes. Efforts to develop a public service announcement campaign should target motorists and pedestrians. This includes developing campaign materials including audio, television, social media, and dynamic message sign messages. Education in targeted high pedestrian crash locations or corridors is an effective countermeasure to increase the awareness of pedestrians and motorists of increased risk and safe behaviors. Public education messaging should be developed using a positive approach rather than a fear-based approach to engage community acceptance that will lead to cultural change. The education and outreach efforts should target communities with high-speed corridors that may have a higher presence of pedestrians, especially in dark conditions.

Studies have revealed that a high percentage of pedestrian crashes are identified as "walking with traffic and pedestrian hit from behind." Missouri law states "Where sidewalks are provided it shall be unlawful for any pedestrian to walk along and upon an adjacent roadway. (2) Where sidewalks are not provided any pedestrian walking along and upon a highway shall when practicable walk only on the left side of the roadway or its shoulder facing traffic, which may approach from the opposite direction." Educating the public of the risk of walking in the roadway and, if they must, the proper way as required by law can enhance pedestrian safety. The outreach effort should also include messaging to encourage motorists to slow down and give the pedestrian space. These can be further expanded to address circumstances where pedestrians are not expected and are at higher risk (e.g., interstates and freeway, disabled vehicles).

In targeted areas where a mid-block pedestrian crash history is validated, education and outreach to pedestrians and motorists of the crossing laws and the responsibilities can enhance pedestrian safety. Missouri law states "Every pedestrian crossing a roadway at any point other than within a marked crosswalk or within an unmarked crosswalk at an intersection shall yield the right-of-way to all vehicles upon the roadway. Any pedestrian crossing a roadway at a point where a pedestrian tunnel or overhead pedestrian crossing has been provided shall yield the right-of-way to all vehicles upon the roadway." Based on research, older pedestrians in high-speed corridors were found to be the most vulnerable.

3.2 Identification and Ranking of Possible Pedestrian Safety Countermeasures

Considering the objective of the research project, various pedestrian safety countermeasures were reviewed for applicability for systemic implementation. They were categorized according to their application at signalized and uncontrolled or unsignalized intersections, mid-block crossings, and for locations where pedestrians are at risk when walking along the roadway. The resulting list of categorized pedestrian safety countermeasures were prioritized by the research TAC and considered for applicability during the Missouri Pedestrian Safety Countermeasure Tool development process. Table 3-1 lists the ranked possible pedestrian safety countermeasures for signalized and uncontrolled/unsignalized intersections. Table 3-2 lists the results of the TAC ranking for segments/midblock crossings.

Table 3-1 TAC Ranking of Possible Pedestrian Safety Countermeasures for Intersections

Possible Pedestrian Safety Countermeasures for Intersections	Ranking Score
Add Overhead Lighting or Enhance Existing Lighting	18
Leading Pedestrian Interval (LPI)	17
Pedestrian Countdown Signals / Replace Existing "Walk/Don't Walk" Signals with Pedestrian Countdown Signal Head	16
Signal Timing	16
High-Visibility Crosswalk Markings (Continental or Ladder Style)	15
Road Diet/Re-Channelization	15
Enhanced Pedestrian signing (Advance pedestrian warning signs, new fluorescent yellow/green color, reflective strip on posts)	15
Curb Extensions	14
Parking Restrictions at Crossing/Daylighting	14
All-Walk Phase / Exclusive Pedestrian Phase (AKA Pedestrian Scramble)	13
Crossing Islands	13
Curb Radius Reduction	13
Continuous Raised Medians or Hardened Centerlines	12
Protected Phases	12
Adjust Transit Dropoff/Pickup Locations	12
Active Warning Beacons (Low Cost, User-Activated Flashing Lights)	11
Advance Stop/Yield Lines	11
Pedestrian Hybrid Beacon (PHB) and Advanced Yield/Stop Markings/Signs	11
Raised Crosswalk	11
Walkways	10
Bus Bulb Outs	10
Rectangular Rapid Flash Beacon (RRFB)	9
Improve Pavement Friction (Skid Treatment with Overlay)	9
Gateway Treatments (R1-6 Signs) (In-Street Pedestrian Crossing Signs)	7
NO RIGHT TURN ON RED Signs (Or Limit Using Blankout Signs)	7

Table 3-2 TAC Ranking of Possible Pedestrian Safety Countermeasures for Segments/Midblock Crossings

Possible Pedestrian Safety Countermeasures for Segments/Midblock Crossings	Ranking Score
Add Overhead Lighting or Enhance Existing Lighting at Crosswalk Locations	18
Rectangular Rapid-Flashing Beacon (RRFB)	18
High-Visibility Crosswalk Markings (Continental or Ladder Style)	16
Improved Conspicuity of Signs (Advance Pedestrian Warning Signs, New Fluorescent Yellow/Green Color, Reflective Strip on Posts)	16
Pedestrian Hybrid Beacons (PHB)	16
Pedestrian Crossing/Refuge Island	16
Road Diet	16
Smart/Dynamic Lighting (Pedestrian Actuated Lighting at Crosswalk Locations)	15
Active Warning Beacons	15
Chokers / Curb Extension	15
Improved Right-Turn Slip-Lane Design	15
Transit Stop Improvements (Adjust Transit Dropoff/Pickup Locations, Improve Pedestrian Conspicuity)	15
Danish Offset Pedestrian Crossing (Modified Refuge Island)	14
Raised Crosswalk	14
Install Sidewalk	14
Lane Narrowing	14
Advanced Stop/Yield Sign	13
Provide Paved Shoulder	13
School Zone Improvement	13
Provide Segment Lighting	12
Mid-Block Pedestrian Actuated Traffic Signal (High Volume Pedestrian Locations)	12
Raised Median or Hardened Centerline at Unsignalized Crossing	12
Curb Radius Reduction	12
Parking Restrictions (At Crossing Locations)	12
Pedestrian Safety Zones	12
Chicanes	10
Improve Pavement Friction (Skid Treatment with Overlay)	9
Lower Speed Limits	9
Bus Bulb Outs	9
Speed-Monitoring	7
Gateway Treatments (R1-6 Signs) (In-Street Pedestrian Signs)	6

Countermeasures that were ranked low by the TAC and not considered as applicable for systemic implementation included the following:

- Colored Pavers/Pavement Crosswalks.
- In-Pavement Warning Lights
- Speed Humps
- Speed Tables
- Serpentine Design
- Pedestrian Barriers
- Install Pedestrian Overpass/Underpass
- Transverse Rumble Strips
- Mini-Circles
- Puffin Crossing
- Automated Enforcement Systems
- Pedestrian Safety at Railroad Crossings
- Neighborhood Identity

3.3 Roadway Segment Countermeasures

The ranked countermeasures for roadway segments were further reviewed to develop a refined list of low-cost treatments that could be easily implemented systemically and be effective at reducing pedestrian crashes given the data analysis results.

3.3.1 Roadway Segment - Corridor/Parallel Walking

Countermeasures to address crashes that are a result of a pedestrian walking immediately adjacent to or in the travel lane are limited but ideal candidates for systemic application. These types of crashes often involve factors such as unexpected presence of pedestrians, speed, lack of sidewalks or walkways, and lighting conditions (darkness)/poor visibility of the pedestrian. These factors were considered when identifying the following potential countermeasures for consideration in the Pedestrian Safety Countermeasure Tool.

- **Reduce Speed Limit –** As speeds increase, the risk of death and serious injury dramatically increase. This is especially true for pedestrians where the risk of death doubles for a pedestrian when speeds increase from 32 mph to 42 mph, and triples at 50 mph. Safe speeds increase the likelihood of an individual surviving a crash. Transportation system owners should consider pedestrian activity and pedestrian generators adjacent to the roadway, including potential crossing locations, when evaluating speed limits. Application of this countermeasure would target corridors and include conducting a speed study to determine the speed distribution and the 85th percentile speed. Speed limits could be reduced in 5 mph increments, for example, from 45 mph to 40 mph, and advance Reduced Speed Limit Ahead signs (W3-5) installed. After a trial period of implementation of a lower speed limit, a speed limit enforcement program may be used to achieve speed limit compliance. This can be reinforced through the supplemental use of speed radar feedback “Your Speed” signs at strategic locations.

- **Walkways –** A high percentage of crashes occur due to a lack of pedestrian walkways (sidewalks/shoulders) thereby forcing pedestrians to walk immediately adjacent to or in the travel lane. Installation of continuous sidewalk is the primary countermeasure to address this. Where the installation of sidewalk is not practical and cost prohibitive, the alternative is to provide paved shoulders with a minimum width of four (4) feet. An eight (8) inch solid white edge line should be installed to separate the travel lane from the walkable shoulder. Walkways improve visibility of pedestrians and reduce vehicle-pedestrian conflicts.

- **Narrowing of Travel Lanes –** Narrower lanes have been proven to decrease vehicular speeds and acts as a traffic calming measure. Narrower lanes reduce pedestrian crossing distances and subsequent exposure risk. They can be accomplished through low-cost systemic restriping of the roadway. A minimum 10' lane may be used in traffic calming areas. Narrowing of the travel lane can minimize the right of way impact when providing a paved shoulder as a walkway.

- **Road Diets** – Reducing the roadway from four lanes to three lanes encourages slower speeds, reduces the crossing distance for the pedestrian, and reduces total crashes between 19 percent and 47 percent.

- **Shoulder Rumble Strips –** Shoulder rumble strips provide an audible alert to motorists when they leave the lane of travel. Use of these in rural areas can provide a physical and audible delineation to alert inattentive drivers of intrusion into the shoulder area where pedestrians and bicyclist may be present. This may also discourage aggressive drivers from using the shoulders to pass other vehicles. Missouri has implemented shoulder rumble strips systemically and can compare and evaluate pedestrian crashes on corridors with and without rumble strips to determine if this countermeasure has potential benefit for pedestrian safety. Shoulder rumble strips should not be constructed 100 feet in advance of and beyond all street intersections and commercial driveways. The minimum length of rumble strips measured longitudinally along the shoulder should be 100 feet. Rumble strips are not recommended in residential areas due to potential nighttime noise levels.

- **Highway Lighting –** A high percentage of fatal pedestrian crashes involving a pedestrian walking in or along the roadway often occur during the early hours of darkness, especially in winter months. This may occur when pedestrian activity is expected to occur (e.g., after work hours). Lighting as a countermeasure increases pedestrian conspicuity along the roadway. Continuous lighting along a corridor, particularly in higher pedestrian activity areas, can reduce nighttime crashes along roadway segments by 28 percent [5]. Lighting of horizontal curves improves driver sight distance beyond the vehicle headlights and increases pedestrian conspicuity along the roadway where known pedestrian crash hot spots exist.

- **Signing –** Installation of Pedestrian warning signs (W11-2) with supplemental distance warning plates such as W16-4P (NEXT X Miles) or W16-9P (AHEAD) in advance of know pedestrian areas or crash hot spots provides an alert to driver of the expectation of pedestrians along the roadway.

- **Road Safety Audit (RSA) –** RSAs are conducted by an independent multidisciplinary team that can target high crash corridors or spot locations, identify safety issues, and collaborate on countermeasure selection to improve safety for all road users. The RSAs can focus on pedestrian crashes and be used to systemically identify common risk factors and potential strategies to be applied across multiple locations on the network.

3.3.2 Roadway Segment - Mid-Block

- **High-Visibility Crosswalks –** High-visibility crosswalks include a variety of crosswalk striping designs, such as ladder, continental, or bar pairs and are much easier for an approaching motorist to see than the traditional parallel lines. Striping patterns and materials affect a crosswalk's visibility and effectiveness. A "piano key" pattern of longitudinal white stripes, parallel to the travel lanes and the driver's field of vision, and made of retroreflective thermoplastic, enhances crosswalk visibility. The recommended layout uses a 24" wide stripe with 24" space. These should be used at all midblock crossings and uncontrolled intersections as they can reduce pedestrian-involved injury crashes by 40 percent [4]. The high-visibility markings may be supplemented with the pedestrian crossing warning signs (sign W11-2 in the MUTCD) on each approach to the crosswalk and enhanced with other treatments such as lighting, signing, and pavement markings. An ADA compliant ramp with tactile warning treatment should be installed wherever there is a high-visibility crosswalk. This directs pedestrians to the appropriate place to cross the road.

- **Enhanced Signing and Pavement Markings –** As part of high visibility crosswalk enhancement at multi-lane midblock crossings, "YIELD Here to Pedestrians" or "STOP Here for Pedestrians" signs can be placed 20 to 50 feet in advance of a marked crosswalk to indicate where a driver should stop or yield to pedestrians. This may be supplemented with a STOP or YIELD bar pavement markings. These countermeasures can reduce pedestrian crashes by 25 percent [17]. At locations where pedestrian crossings should be prohibited due to limited sight distance (e.g., hills) between the pedestrian and approaching motorist, the "No Pedestrian" symbol sign (R9-3) is a countermeasure that can be considered. They can be installed at spot locations within a segment. Alternative signing can be installed directing pedestrians to a crossing location such as at intersections where pedestrians are expected to be crossing.

- **Enhanced Crosswalk Lighting** – Enhanced crosswalk lighting increases the visibility of pedestrians crossing in dark conditions at midblock locations. Design and placement of luminaires shall provide lighting across the entire crosswalk area. This requires the lighting to have a 25-feet. maximum offset in advance of the crosswalk. Enhanced crosswalk lighting can be further expanded along corridors for systemic improvements.

- **Narrowing of Travel Lanes –** Narrower lanes have been proven to decrease vehicular speeds and acts as a traffic calming measure. Narrower lanes reduce pedestrian crossing distances and subsequent exposure risk. They can be accomplished through low-cost systemic restriping of the roadway. A minimum 10' lane may be used in traffic calming areas. Narrowing of the travel lane can minimize the right of way impact when providing a paved shoulder as a walkway.

- **Road Diets** – Reducing the roadway, for example, from four lanes to three lanes encourages slower speeds, reduces the crossing distance for the pedestrian, and reduces total crashes between 19 percent and 47 percent.

- **Rectangular Rapid Flashing Beacon (RRFB) –** The RRFB is a pedestrian-actuated conspicuity enhancement used in combination with a pedestrian, school, or trail crossing warning sign to improve safety at uncontrolled, marked crosswalks on multi-lane roadways with speed limits less than 40 mph. The device includes two rectangular-shaped yellow indications, each with an LED-array-based light source, that flash with high frequency when activated. The RRFB may be manually activated by a pedestrian push-button or activated passively with video detection. It returns to a dark state once the crossing cycle is complete. When used the RRFB is to be installed with high-visibility crosswalk markings and warning signs per the recommendations contained in the MUTCD. The RRFB can be installed with either pedestrian warning or school crossing signs as appropriate. For multi-lane applications of two or more lanes in each direction the RRFB should be mounted overhead and advance RRFBs should be considered. RRFB should not be considered on a 6-lane undivided cross section due to the pedestrian crossing distances. The RRFB helps pedestrians decide where better to cross the roadway. The use of RRFB can reduce pedestrian crashes by 47 percent.

- **Pedestrian Hybrid Beacon (PHB or HAWK Signal) –** The PHB is the recommended countermeasure for midblock crossings (non-intersection locations) on multi-lane roadways with speeds at 40 mph or greater with ADT over 9,000, particularly where gaps in traffic are not adequate to permit pedestrians to cross. The PHB as referred to in the MUTCD is also known as the High-Intensity Activated Crosswalk (HAWK) beacon. A PHB head consists of two red lenses above a single yellow lens and must be used in conjunction with a marked crosswalk and pedestrian countdown signal heads installed at each end of a marked crosswalk. It is an intermediate traffic control device between flashing beacons and full traffic signals. Unlike a traffic signal, the PHB rests in dark until a pedestrian activates it via pushbutton or other form of detection. When activated, the beacon displays a sequence of flashing and solid lights that control vehicular traffic while the pedestrian signal heads indicate the pedestrian walk interval and a pedestrian clearance interval. The PHB should meet the installation guidelines based on speed, pedestrian volume, vehicular volume, and crossing length. The PHB and RRFB are not both installed at the same crossing location. The PHB is a consideration where a full traffic signal is not warranted and can reduce pedestrian crashes by 55 percent [17].

- **Curb Extensions –** In areas where there is full width shoulder or where parking is permitted curb extensions can be considered to reduce the crossing distance for pedestrians. Curb extensions also allow pedestrians to be seen by approaching vehicles when parked vehicle obscure the pedestrian from approaching motorists at a crossing.

- **Medians or Pedestrian Refuge Islands –** Medians and pedestrian refuge islands provide a landing spot to reduce pedestrian crossing distances and provide a safe place for pedestrians to wait before crossing the remaining portion of roadway. These reduce pedestrian crashes by 46 to 56 percent. The Danish Offset can be added as an option to this countermeasure to ensure pedestrians face oncoming traffic.

- **Danish Offset –** The Danish Offset is the use of an offset at the middle of a multilane crossing to ensure pedestrians are facing the next half of traffic being crossed. It is recommended to be used in conjunction with pedestrian refuge islands where possible.

3.4 Intersection Countermeasures

The ranked countermeasures for intersections were further reviewed to develop a refined list of low-cost treatments that could be easily implemented systemically at unsignalized/uncontrolled and signalized intersections and be effective at reducing pedestrian crashes given the data analysis results.

3.4.1 Unsignalized Intersections

- **High-Visibility Crosswalks –** High-visibility crosswalks include a variety of crosswalk striping designs, such as ladder, continental, or bar pairs and are much easier for an approaching motorist to see than the traditional parallel lines. Striping patterns and materials affect a crosswalk's visibility and effectiveness. A "piano key" pattern of longitudinal white stripes, parallel to the travel lanes and the driver's field of vision, and made of retroreflective thermoplastic, enhances crosswalk visibility. The recommended layout uses a 24" wide stripe with 24" space. These should be used at all midblock crossings and uncontrolled intersections as they can reduce pedestrian involved injury crashes by 40 percent [4]. The high-visibility markings may be supplemented with the pedestrian crossing warning signs (sign W11-2 in the MUTCD) on each approach to the crosswalk and enhanced with other treatments such as lighting, signing, and pavement markings.

- **Signing –** Where marked crosswalks are established across a main roadway pedestrian warning signs (W11-2) with the appropriate advisory plate should be installed to alert approaching drivers of the possible presence of pedestrians in the crosswalk.

- **Advance Stop Bar –** The installation of stop bars at least 4 feet in advance of a marked or unmarked crosswalk reduces conflict with pedestrians from vehicles encroaching into the crosswalk area. The stop bar can be enhanced by installing a "STOP" pavement marking per the MUTCD.

- **Advance Yield Markings –** Advance yield markings that are placed 20 to 50 feet in advance of a pedestrian crossing can increase the visibility of a pedestrian in the crosswalk and reduce the possibility of a crash.

- **Restrict Parking –** Removing parking at intersections to increase the visibility between drivers and pedestrians is a cost-effective safety countermeasure. It is beneficial to young and old, but is especially helpful to children, who often cannot see, or be seen by, oncoming traffic. By removing parking adjacent to the crosswalk, the child does not have to wade into the street to see vehicles entering the intersection. At the same time, drivers do not have to roll into the crosswalk to see if pedestrians are waiting to cross.

- **Reduced Curb Radii** – Curb radii should be designed to be as small as possible considering all intersection users, rather than designing for the largest possible vehicle.

Smaller turning radii require vehicles to turn at lower speeds and decrease pedestrian crossing distance. Both factors improve pedestrian safety and comfort. This also improves sight distance between pedestrians and motorists. Because tighter curb radii reduce the speed of turning vehicles, the severity of crashes involving pedestrians decrease if they occur.

- **Curb Extensions –** Extensions of the curb line into the street and reallocating a portion of street space to pedestrians or ancillary uses improve pedestrian safety. Curb extensions are one of the most effective traffic calming tools, and can be used in a variety of ways, both at corners and mid-block. Also known as bulb outs or neckdowns, curb extensions narrow the roadway, slow turning vehicles, prevent drivers from parking on or near a crosswalk, reduce crossing distances and pedestrian exposure to conflicts with motor vehicles. This design also enables pedestrians to stand out from behind parked motor vehicles, helping pedestrians and drivers to better see each other. Smaller children who are often invisible behind parked motor vehicles and who may take longer to cross the street would particularly benefit from curb extensions.

- **ADA Ramps –** An ADA compliant ramp with tactile warning treatment should be installed wherever there is a high-visibility crosswalk. This identifies where pedestrians are to cross roadways, provides access for the pedestrian for safe crossing, and makes the crossing visible to drivers.

- **Install Sidewalks –** The installation of sidewalks provides a walkway and the space for pedestrian travel approaching an intersection and leads them to the appropriate crossing location. Sidewalks separate pedestrians from vehicles and keep pedestrians from walking in the roadway where they are more vulnerable.

- **Remove Channelized Right Turn –** At intersections, a channelized right turn lane is typically "YIELD" controlled and poses a conflict point for pedestrian crossing to the channelized island. Where feasible, the removal of this slip lane results in shorter crossings for pedestrian, reduced speed for turning vehicles, and increased sight lines.

- **Convert Two-Way Stop Intersections to All-Way Stop –** Where feasible and based on an engineering study, the conversion to an all-way stop intersection prevents motorist, bicyclists, and pedestrians from having to cross free flow lanes of traffic and reduces the risk of crashes.

3.4.2 Signalized Intersections

- **High-Visibility Crosswalks –** High-visibility crosswalks include a variety of crosswalk striping designs, such as ladder, continental, or bar pairs and are much easier for an approaching motorist to see than the traditional parallel lines. Striping patterns and materials affect a crosswalk's visibility and effectiveness. A "piano key" pattern of longitudinal white stripes, parallel to the travel lanes and the driver's field of vision, and made of retroreflective thermoplastic, enhances crosswalk visibility. The recommended layout uses a 24" wide stripe with 24" space. These should be used at all midblock crossings and uncontrolled intersections as they can reduce pedestrian-involved injury crashes by 40 percent [4]. The high-visibility markings may be supplemented with the pedestrian crossing warning signs (sign W11-2 in the MUTCD) on each approach to the crosswalk and enhanced with other treatments such as lighting, signing, and pavement markings.

- **ADA Ramps-** Install ADA compliant ramps with tactile warning treatment at signalized intersections with High-Visibility crosswalk markings, Pedestrian signals, and pedestrian push-buttons in compliance with the MUTCD. This identifies where pedestrians are to cross roadways and makes the crossing visible to drivers.

- **Restrict Parking –** Removing parking at intersections to increase the visibility between drivers and pedestrians is a cost-effective safety countermeasure. It is beneficial to young and old, but is especially helpful to children, who often cannot see, or be seen by, oncoming traffic. By removing parking adjacent to the crosswalk, the child does not have to wade into the street to see vehicles entering the intersection. At the same time, drivers do not have to roll into the crosswalk to see if pedestrians are waiting to cross.

- **Pedestrian Signal Timing –** Pedestrians need sufficient time to cross the roadway based on the width of the roadway and an assumed pedestrian walking speed. The MUTCD assumes a walking speed of 3.5 feet per second. However, for slower pedestrians, such as those in wheelchairs or who are visually impaired, a slower walking speed of 3 feet per second may be assumed. Pedestrian Clearance intervals should be calculated using the curb to curb or edges of roadway widths. Where pedestrian signals are not present the minimum green phase should be calculated based on the curb-to-curb width of the roadway leg being crossed. If pedestrian signals are present the minimum "WALK" phase should be 7 seconds or longer to accommodate pedestrian walking startup.

- **Leading Pedestrian Interval (LPI) –** The LPI provides pedestrians an advanced walk signal, giving pedestrians several seconds, usually 3 to 7 seconds, to start and establish their place in the crosswalk before motor vehicles start their advance. Pedestrians are made more visible particularly to right turning motorists who are thereby more likely to yield to pedestrians in the crosswalk. A NO RIGHT TURN blank out sign can be used as a supplement to restrict right-turning vehicles until it is safe for the pedestrians. LPI reduces vehicle pedestrian conflicts and enhances safety for slower moving pedestrians, reducing crashes by 13 percent.

- **All Red Stop** – Signal timing can be modified to stop all vehicular traffic and allow pedestrians an exclusive interval to cross an intersection in every direction, including diagonally, at the same time. This is known as a pedestrian scramble, a diagonal crossing, or a Barnes Dance. This application virtually eliminates pedestrian-vehicle conflicts and makes sense where large numbers of pedestrians are expected, and where there is enough space to enable pedestrians to gather on the sidewalks in larger numbers.

- **Additional Signal Heads with Reflective Backplates –** Additional signal heads (e.g., one per lane) with reflective backplates allow approaching drivers to anticipate signal changes further in advance of the intersection and reduces the possibility of a driver entering an intersection on red that could result in a pedestrian conflict.

- **Pedestrian Phase Recall –** In high volume pedestrian areas where key time periods of pedestrian activity are known (e.g., business hours or school drop off/pick up times) a traffic signal can be programmed to be placed on pedestrian recall. This programmed pedestrian phase would be actuated every cycle without a pedestrian manually actuated the push-button.

- **Reduced Signal Cycle –** During known periods of high pedestrian activity the cycle length of the signal could be reduced to reduce pedestrian wait times to cross roadways. Pedestrians may be inclined to ignore the pedestrian signal indications when they have a significant delay to crossing a roadway and potentially place themselves in harm's way.

- **Permissive Left-Turn Phasing to Protected –** A change from permissive left-turn phasing to protected-only left-turn phasing eliminates pedestrian conflicts with left-turning vehicles by holding the "WALK" phase for the pedestrian until the protected left-turn phase terminates.

- **Pedestrian Countdown Timers –** Pedestrian countdown timers are designed to enhance the effectiveness of pedestrian signals in clearing the crosswalk by showing the number of seconds remaining until the signal changes. Surveys show that most people misinterpret the meaning of the flashing hand of the traditional pedestrian signal. Providing the pedestrian countdown device helps pedestrians better interpret the pedestrian signals. Countdown timers also enable pedestrians to stop on a median refuge, where provided, and wait for the next signal phase if they believe that there is insufficient time for them to complete their crossing. The use of pedestrian countdown timers is important when signal timing is complex (e.g., there is a dedicated left-turn signal for motorists), at established school zone crossings, when an exclusive pedestrian interval is provided, and where streets are wide.

- **Passive Pedestrian Detection System –** With advancement in Intelligent Transportation System (ITS) hardware the use of "Fisheye" camera systems such as the Gridsmart Bell camera system are being used for passive pedestrian detection at signalized intersections. A two-camera system is used, one for vehicle detection and one for pedestrian and bicycle detection. This is effective in areas of high pedestrian crossing and at traffic signals near schools where children and young adults may not activate manual pedestrian push-buttons. The system can extend pedestrian clearance time if it detects a slow traveler in a crosswalk area of detection.

- **Reduced Curb Radii** – Curb radii should be designed to be as small as possible considering all intersection users, rather than designing for the largest possible vehicle. Smaller turning radii require vehicles to turn at lower speeds and decrease pedestrian crossing distance. Both factors improve pedestrian safety and comfort. This also improves sight distance between pedestrians and motorists. Tighter curb radii reduce the speed of turning vehicles and severity of crashes if they occur.

- **Curb Extensions –** Extensions of the curb line into the street and reallocating a portion of street space to pedestrians or ancillary uses improve pedestrian safety. Curb extensions are one of the most effective traffic calming tools, and can be used in a variety of ways, both at corners and mid-block. Also known as bulb-outs or neckdowns, curb extensions narrow the roadway, slow turning vehicles, prevent drivers from parking on or near a crosswalk, and reduce crossing distances and pedestrian exposure to conflicts with motor vehicles. This design also enables pedestrians to stand out from behind parked motor vehicles, helping pedestrians and drivers to better see each other. Smaller children who are often invisible behind parked motor vehicles and who may take longer to cross the street would particularly benefit from curb extensions.

- **No Right Turn on Red Sign –** Unless a No Right Turn on Red (RTOR) sign is posted a motorist can execute a right turn on a red light after they have come to a full stop and checked for traffic. A motorist must yield to all crossing traffic and stop for pedestrians before turning right at a red light. RTOR prohibitions can be an important tool for increasing pedestrian safety at certain intersections. Under some circumstances, prohibiting RTOR can reduce conflicts and collisions, and it deters motorists from blocking the perpendicular crosswalk while they inch forward to turn. The MUTCD and the Institute of Transportation Engineers (ITE) suggest considering the prohibition of RTOR under the following circumstances:

    1. Inadequate sight distance to vehicles approaching from the left (or right, if applicable).
    2. Geometrics or operational characteristics of the intersection that might result in unexpected conflicts.
    3. An exclusive pedestrian phase.
    4. An unacceptable number of pedestrian conflicts with right-turn-on-red maneuvers. Heavy volume of pedestrian crossings.
    6. Request from pedestrians with disabilities using the intersection.
    7. School crossings.
    8. Traffic signals with three or more phases.

- **Remove Channelized Right Turn –** At signalized intersections, a channelized right turn lane is typically “YIELD” controlled and poses a conflict point for pedestrians crossing to the channelized island. Where feasible the removal of this slip lane results in shorter crossings for pedestrian, reduced speed for turning vehicles, and increased sight lines.

- **Bus Transit Access –** Providing safe and convenient pedestrian access to available transit is important to communities. Creating safe access often requires collaboration between local governments, transit operators, and property owners along the walking routes to bus stops and rail stations. Numerous factors impact safe pedestrian access to each bus stop, including the directness of the walking route, safety and security, and pedestrian-friendly design. Bus stop location is an important factor. Passenger demand, transit operations, traffic operations, and pedestrian safety are all considered when locating a bus stop. A complete sidewalk network should be provided to bus stops within the catchment area. Along walking routes, the number of driveways should be minimized to reduce the number of conflict points between pedestrians and motorists, particularly in the vicinity of bus stops. Driveways should be no closer than 100 feet from signalized intersections. At driveways, the sidewalk should continue through the driveway rather than being segmented by the driveway opening. Bus stops are often placed in pairs (i.e., northbound/southbound, or eastbound/westbound), generating pedestrian crossing activity on one leg of a passenger's round trip. Pedestrian crossing facilities should be provided to link the bus stop pair, including a marked crossing and enhancements such as high-visibility striping, curb extensions, pedestrian refuge islands, signage, beacons, or traffic signals, as appropriate. Depending on the roadway type, traffic calming measures may also be appropriate. Traffic signals should have pedestrian actuation capabilities in the absence of a pre-timed signal. Pedestrian countdown signals should be provided at all traffic signals near bus stops to facilitate safer crossings. An LPI should be considered at high volume bus stops near traffic signals.

3.5 Pedestrian Lighting

Darkness is a well-documented factor correlated with more severe pedestrian crashes. It significantly reduces pedestrian visibility to motorists, and hence reduces driver reaction time in a crash event. Providing appropriate lighting is an important pedestrian safety countermeasure. In general, lighting should be provided wherever pedestrians are present during nighttime hours. Lighting falls into two of categories: pedestrian crossings and corridor lighting.

3.5.1 Crosswalk Lighting

Lighting targeted at spot locations is considered as crosswalk lighting. It can substantially enhance pedestrian safety. Illumination from vehicle headlights alone often does not provide sufficient reaction time for motorists to identify and react to pedestrians crossing the roadway. Crossing lighting should be provided at signalized, unsignalized, and midblock crossings, particularly at:

1. Locations where the speed limit is greater than 40 mph and the roadway does not have adequate pedestrian conflict elimination.
2. Intersections, access points, and decision points adjacent to changes in roadway alignment and cross section.
3. Connections to transit.
4. Areas adjacent to pedestrian generators (e.g., eating establishments, shops, schools, parks, community centers, and places of worship) and parking lots.
5. Integrated into all traffic signal designs.
6. Pedestrian refuge islands and medians.
7. Locations where problems with nighttime visibility have resulted in more frequent vehicle-pedestrian conflicts.

Crossing lighting should be installed at least 10 feet ahead of the crosswalk rather than overhead. This design will light the side of the pedestrian facing the driver (i.e., front lit rather than back lit), increasing contrast, enhancing visibility, and facilitating facial communication between the pedestrian to the driver.

3.5.2 Corridor Lighting

Continuous lighting along a segment of roadway is considered as corridor lighting. This type of lighting can be placed on rural, urban, and urbanized roadways to enhance visibility of the roadway. This also increases the visibility of pedestrians walking along the roadway as well as crossing the roadway. Illumination from vehicle headlights alone often does not provide sufficient reaction time for motorists to identify and react should a pedestrian cross the roadway. Corridor lighting enhances pedestrian safety, particularly along higher speed facilities such as arterials with pedestrian generators. The potential for a crash involving a pedestrian that results in injury is higher at these locations.

3.6 Summary

The ranked countermeasures for roadway segments and intersections were reviewed to develop a refined list of low-cost treatments that could be easily implemented systemically and be effective at reducing pedestrian crashes given the data analysis results. These were considered during the development of the Missouri Pedestrian Safety Countermeasure Tool. Not all countermeasures were used. Some (e.g., adjust transit stops, RSAs) are more applicable to actual implementation. The various signal timing countermeasure treatments (e.g., Pedestrian Phase Recall, All Red Stop Timing, Reduced Signal Cycle, and Permissive Left Turn Phase to Protected) were consolidated into one countermeasure as more investigation would be required to determine the appropriate treatment based on existing conditions.

4. Data Analysis Methodology

MoDOT provided various statewide geographic datasets for state and locally owned and maintained roadways that were used for the systemic safety analysis. These included crashes, roadway inventory, and intersection data. In the following subsections the preparation and analysis of each dataset are described. **Crash Data**

Statewide geolocated pedestrian crash data were provided for a nine-year period, from 2013 to 2021. Overall, the crash records contain information on crash severity, temporal and environmental conditions, roadway characteristics, crash type, among other several variables. Crash severity is based on the assessment of the responding law enforcement officer using the KABCO injury scale as follows:

- Fatality (K).
- Suspected serious injury (A).
- Suspected minor injury (B).
- Possible injury (C).
- Property damage only (O).

4.1.1 Crash Data Preparation

A total of 15,032 records were provided for the study period, out of which 10,986 were geocoded with latitude/longitude. The crash dataset was first filtered to only select geolocated pedestrian-involved crashes by using the ACCIDENT_TYPE field. There was a total of 822 fatal crashes, 9,388 injury crashes, and 774 property damage only crashes. Pedestrian crashes on freeway segments were excluded from the analysis, however, crashes on freeway ramps within the intersection area were included in the analysis. Additionally, crashes in parking lots and on driveways were excluded from the analysis. The resulting dataset, *Crashes (Ped_Crash_Locations_2013_2021),* was used for analysis. The pedestrian crashes geospatial database did not include movement and actions of the vehicle(s) and pedestrian(s) before a crash. This information is typically included in the crash report narratives and crash diagram.

4.2 Roadway Segment Data

Roadway segment data were furnished for all the state and local owned and maintained roads in Missouri. The roadway data contained information on roadway characteristics including, but not limited to, functional classification, length, and cross-sectional features. The dataset, *Segments (SS_Pavement_History_2021)* contains geolocated directional road segment data originally used for pavement maintenance purposes. Each direction of a roadway is represented by a segment.

4.2.1 Roadway Segment Data Preparation

To obtain an undirected road network that can be used for analysis, the segments dataset was partitioned into two sets: one set with all segments with TRAVELWAY_DIR='N' and 'TRAVELWAY_DIR='E,' the other set with all segments with TRAVELWAY_DIR='S' and TRAVELWAY_DIR='W.' After comparing and determining that both sets were mostly similar, the set with north and east directed segments was labeled as the undirected segment for analysis.

4.2.2 Roadway Segment Data Limitations

Although the segments did have divided/undivided median information associated with them, the median width was not available in the data.

4.3 Intersection Data

An intersection is defined as a node where two or more road segments meet. With this definition, roadway merges and diverges, such as on and off ramps, are also included as intersections. Additional data attributes provided were used to identify signalized intersections and stop-controlled intersections. The dataset, *Intersections (SS_Intersection_History_2021)*, contains geolocated statewide intersection data.

4.3.1 Intersection Data Preparation

Each intersection is represented by one record, therefore all fields associated with the intersection correspond to the main leg of the intersection only (SS_INTRSC_LEG=1). The intersections dataset was first filtered to exclude unsignalized intersections on interstates and freeways by using the following SQL-like filter clause:

LEG_FUNC_CLASS NOT IN (‘INTERSTATE','FREEWAY') OR SIGNALIZED_FLAG = 'Y'

The role of this filter was to exclude on- and off-ramps on freeways or interstates. Intersections in this filtered dataset were flagged as “study intersections.”

4.3.2 Intersection Data Limitations

There were intersections in the filtered dataset that still corresponded to roadway merges/ diverges and not actual intersections. For example, on segments with LEG_FUNC_CLASS = 'PRINCIPAL ARTERIAL', the filter used in the preparation section did not apply and so some merges/diverges or driveways are still present in the data.

4.4 Roundabout Data

Roundabout data were provided as a separate dataset containing geolocated points representing roundabouts, usually at the approach/exit locations but also on the perimeter of the roundabout in between two legs. The dataset, *Roundabouts (Roundabouts_06082022)* contains geolocated points on roundabouts, usually at the leg locations but also on the perimeter of the roundabout in between two legs.

4.5 Data Summary

There was a total of 10,986 geocoded pedestrian-involved crashes in Missouri between the years 2013 and 2021. Fifteen percent of the crashes occurred on segments, seventy percent at intersections and the rest were unassigned due to missing geographic coordinates. Table 4-1 shows the breakdown of the roadway network with at least one pedestrian crash and the number of pedestrian crashes for each roadway network element. For example, of the 4,793 signalized intersections, at least one pedestrian crash occurred at 1,431 intersections, and a total of 2,713 pedestrian crashes. This represents a ratio of approximately 2:1 for signalized intersections, whereas for unsignalized intersections, the ratio is approximately 1:1.

Table 4-1 Pedestrian crashes by roadway network element

Roadway Network Element	Total Count/Mileage	Analysis Count/Mileage	Sites Analyzed (%)	Number of Pedestrian Crashes
Intersection	301, 365	5,663	1.88%	7,705
Signalized	4,793	1,431	29.86%	2,713
Unsignalized	296,211	4,211	1.42%	4,961
Roundabout	361	21	5.82%	31
Segment	145,617	-	-	2,363
Interstate and Freeway	3,432	-	-	755
Other	142,185	441	0.31%	1,608

4.6 Analysis Methodology

The systemic safety analysis consists of the following steps:

1. Identify roadway segment and intersection characteristics to be used for determining treatments.
2. Assign crashes to intersections and roundabouts.
3. Assign crashes to the undirected roadway segment network.
4. Determine peer groups for intersections and segments.

Each step was implemented in Python via Jupyter notebooks using the GeoPandas geospatial analysis package. Jupyter notebooks follow the literate programming paradigm, where documentation and code are in the same file. In this manner, each step in the analysis methodology is documented in detail next to the code which implements the methodology. The following subsections explain each step.

4.6.1 Step 1 - Identify Roadway Segment and Intersection Characteristics

The characteristics (or fields names of each dataset) associated with intersections and roadway segments shown in Table 4-1 were used for the analysis. Although several other fields were present in the datasets, the fields shown in Table 4-1 are the most correlated with safety. It is also important to note that some of these fields only provide information for a general analysis. For example, the roadway segments dataset contains a field that labels the road as divided or undivided. For a more accurate analysis, the width of the median would have been required to be known, as well as knowing if a pedestrian refuge was present. Table 4-2 identifies the roadway segment characteristics and Table 4-3 identifies the intersection characteristics.

Table 4-2 Roadway Segment Characteristics

Field Name	Description
NUMBER_OF_LANES	Number of lanes per pavement record.
AREA_DESG_NAME	The name of the area designation for this intersection record.
DIVIDED_UNDIVIDED	Indicates if the travel way is divided or undivided. A divided travel way is a travel way with any type of barrier or four-foot or greater flush median.
TOTAL_AADT	The volume for both sides of a travel way added together (divided and undivided).
TW_SPEED_LIMIT_CD	The speed limit assigned to the pavement record.
LENGTH	Length of pavement segment.

Table 4-3 Intersection Characteristics

Field Name	Description
SIGNALIZED_FLAG	Indicates if this intersection is signalized.
NO_OF_APPRCH_LEGS	The number of approach legs for this intersection leg.
ENTERING_VOLUME	A range of entering volume for a particular intersection record.
LEG_DIVIDED_UNDIVD	Indicates if the travel way is divided or undivided. A divided travel way is a travel way with any type of barrier or four-foot or greater flush median.
AREA_DESG_NAME	The name of the area designation for this intersection record.

These characteristics are used in the analysis for the following reasons:

- Signalized Flag: Used to partition the intersections into two groups, signalized and unsignalized.
- Number of Approach Legs: It has been shown that more conflict points are associated with higher number of crashes. Therefore, this is an important factor to include in the analysis.
- Entering Volume: It has been shown that larger vehicle volumes are associated with higher number of crashes. Therefore, this is an important factor to include in the analysis.
- Leg Divided/Undivided: It has been shown that intersections near roadways without appropriate pedestrian refuges are associated with higher number of crashes. Therefore, this is an important factor to include in the analysis.
- Area Designated Name (intersections and segments): Used to develop peer groups.

- Number of Lanes: It has been shown that wide roadways with many lanes that a pedestrian must cross without appropriate refuge associated with higher number of crashes. Therefore, this is an important factor to include in the analysis.
- Divided/Undivided: It has been shown that roadways without appropriate pedestrian refuges are associated with higher number of crashes. Therefore, this is an important factor to include in the analysis.
- Total AADT: It has been shown that roadways with higher vehicle volumes are associated with greater number of crashes. Therefore, this is an important factor to include in the analysis.
- Speed Limit: It has been shown that roadways with higher speed limits are associated with more severe crashes. Therefore, this is an important factor to include in the analysis.
- Length: This value is used to normalize certain calculations, such as crashes/mile.

4.6.2 Step 2 - Assign Crashes to Intersections and Roundabouts

Crashes were assigned to intersections and segments using GIS. Crashes within 150' of an intersection or roundabout were assigned to that intersection or roundabout using a nearest spatial join. For each intersection with assigned pedestrian crashes, the number and severity of the crashes were recorded in a separate field for later analysis. In addition, to associate a speed limit with each intersection, a 100' buffer was created around each intersection and the maximum and minimum values of the speed limits associated with the segments intersecting the buffer were recorded. The maximum speed limit was assumed to correspond to the 'major approach,' while lowest speed limit was assumed to correspond to the 'minor approach.' These two speed limits were appended to the intersections table for further analysis.

4.6.3 Step 3 - Assign Crashes to the Undirected Segment Network

The crashes that remained after assigning some of them to intersections and roundabouts were assigned to the nearest segment of the undirected roadway segment network using a nearest spatial join. For each roadway segment with assigned crashes, the number and severity of crashes were recorded in a separate field for later analysis. In addition, for the undirected roadway segments with assigned crashes, the TOTAL_NUMBER_OF_LANES field was created by adding the number of lanes of the 'NE' segments partition and the 'SW' partition based on the criteria discussed in Section 4.3.1.

4.6.4 Step 4 - Determine Peer Groups for Roadway Segments and Intersections

The roadway segments and intersections were categorized into peer groups. Peer groups represent homogeneous characteristics so that sites with similar safety risk profiles are compared. There were 36 peer groups for segments and 36 for intersections. Segment peer groups were defined based on land use, number of lanes, and median type. Intersection peer groups were also grouped based on land use, as well as the number of legs and traffic control type. The land use was established based on the Census urban areas definition. The Census defines Urbanized Areas (UZA) as areas with populations of 50,000 residents or more, and Urban Clusters (UC) as areas with populations of 2,500 to 49,999 residents. All portions of the state that are not included in the Urban Areas are considered rural (with population less of 2,500).

For the roadway segment peer group, the first letter represents the land use setting, the number in the middle is the number of lanes, and the last letter indicates whether the segment is divided or undivided. For example, using the labeling below, R4U is a rural 4-lane undivided roadway segment.

Land Use Type	Number of Lanes	Median Type
Rural (R), Urban (U), Urbanized (Z)	2, 3, 4, 5+	Divided (D), Undivided (U)

Table 4-4 lists the segment peer groups with at least one pedestrian crash. The total number and length of segments with at least one pedestrian crash are provided as well as a breakdown of the total number of pedestrian crashes by severity for each peer group.

Table 4-4 Segment peer groups and pedestrian crashes by severity

Peer Group	Segment Count	Total Length (mi)	K	A	B	C	O	Total Crashes	Total Crashes/Mile	Percent
R2U	340	230.6	72	78	38	144	22	354	1.5	**23%**
R3U	10	4.6	2	4	0	4	0	10	2.2	1%
R4D	1	0.2	0	1	0	0	0	1	4.6	0%
R4U	5	1.2	0	1	0	4	0	5	4.3	0%
R5U	1	0.2	0	0	0	0	1	1	4.6	0%
U2U	151	40.3	12	21	17	98	9	157	3.9	**10%**
U3U	26	5.3	2	6	5	17	1	31	5.9	2%
U4D	3	0.3	0	0	0	3	0	3	9.0	0%
U4U	7	1.2	0	0	0	7	0	7	5.9	0%
U5U	25	3.7	1	4	6	13	4	28	7.5	2%
U6D	3	0.2	0	0	0	3	0	3	12.0	0%
U7D	1	0.0	0	0	0	1	0	1	23.8	0%
U7U	2	0.2	0	1	0	2	0	3	12.2	0%
Z2D	3	0.3	0	1	0	1	1	3	8.8	0%
Z2U	390	80.4	34	60	39	276	31	440	5.5	**29%**
Z3D	1	0.1	0	1	0	0	0	1	12.5	0%
Z3U	34	6.9	6	7	5	21	3	42	6.1	3%
Z4D	2	0.3	0	0	0	2	0	2	7.3	0%
Z4U	132	16.9	19	25	13	90	6	153	9.0	**10%**
Z5D	1	0.2	0	0	0	1	0	1	6.4	0%
Z5U	169	26.9	31	28	29	119	10	217	8.1	14%
Z6U	44	5.0	5	2	5	35	3	50	10.0	3%
Z7U	18	1.7	0	5	2	14	2	23	13.9	1%
Total	**1,369**	**426.7**	**184**	**245**	**159**	**855**	**93**	**1,536**	**3.6**	**100%**

For the intersection peer groups, the first letter indicates the land use type, the number in the middle indicates the number of legs, and the last letter represents the control type. Using the labeling below, for example, an urban 4-legged signalized intersection is U4S.

Land Use Type	Number of Legs	Traffic Control Type
Rural (R), Urban (U), Urbanized (Z)	3, 4, 5+	Signalized (S), Minor Leg Stop Control (M), All-way Stop Control (A), Roundabout (R)

Table 4-5 summarizes the intersection peer groups with at least one pedestrian crash and includes the distribution of pedestrian crashes by severity.

Table 4-5 Intersection peer groups and pedestrian crashes by severity

Peer Group	Intersection Count	K	A	B	C	O	Total Crashes	Percent
R3S	1	1	0	0	0	0	1	0%
R4A	3	0	0	0	2	1	3	0%
R4M	46	3	8	3	29	4	47	2%
R4S	6	0	3	1	5	0	9	0%
U3M	1	0	1	0	0	0	1	0%
U3S	6	0	2	0	4	0	6	0%
U4A	4	0	0	1	3	0	4	0%
U4M	63	4	14	6	41	5	70	3%
U4S	61	3	7	3	63	12	88	3%
U5S	2	1	0	1	0	0	2	0%
Z3M	32	5	5	6	23	1	40	2%
Z3S	188	9	37	25	261	29	361	**14%**
Z4A	1	0	0	0	1	0	1	0%
Z4M	81	7	18	3	86	12	126	5%
Z4S	849	54	200	94	1,245	126	1,719	**67%**
Z5S	40	1	10	3	44	8	66	3%
R3R	3	2	3	1	5	1	12	0%
R4R	12	1	1	0	8	3	13	1%
R5R	3	0	0	0	3	0	3	0%
Total	**1,402**	**91**	**309**	**147**	**1,823**	**202**	**2,572**	**100%**

Distribution plots for vehicle volume and speed limits were also used to partition each peer group into a different volume/speed bins for both roadway segments and intersections. An example of the graphical methods used to determine the bins are shown in Figure 4-1 and Figure 4-3 for the urbanized 2-lane undivided (Z2U) segments. The concentration of pedestrian crashes occurred below 15,000 AADT and speeds of 30 mph to 50 mph. Figure 4-3 shows a similar example for an urbanized 4-leg signalized intersection.

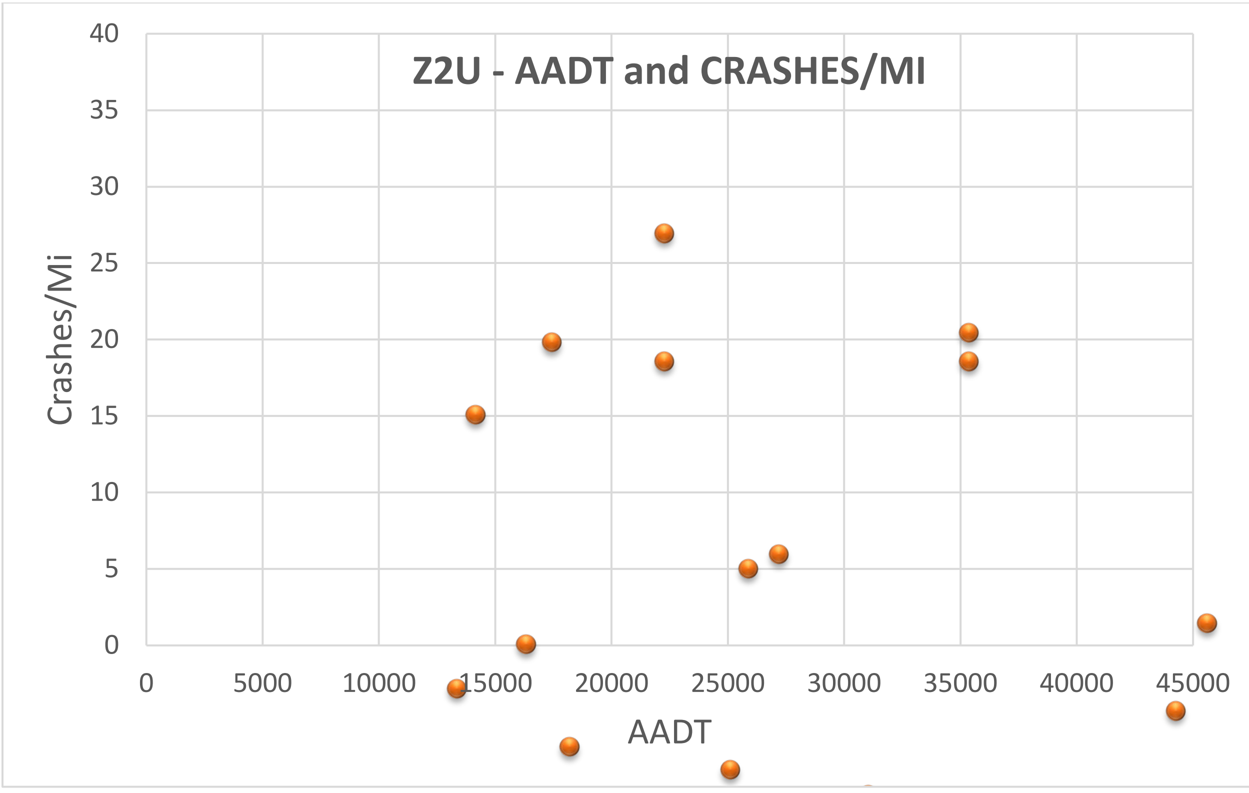

Figure 4-1 Example of binning method using AADT and crashes/mile distribution for segments

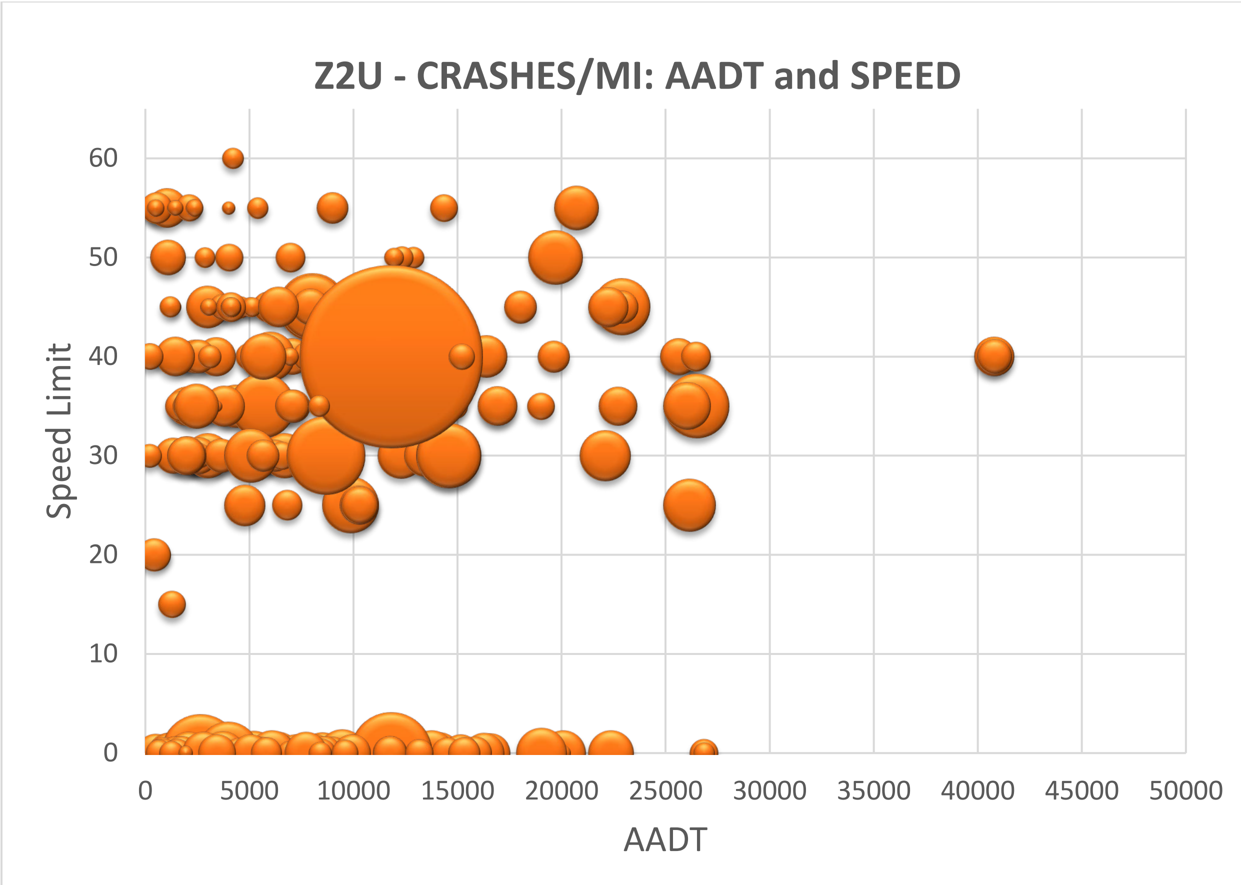

Figure 4-2: Binning method using AADT, speed, and crashes/mile distribution for segments

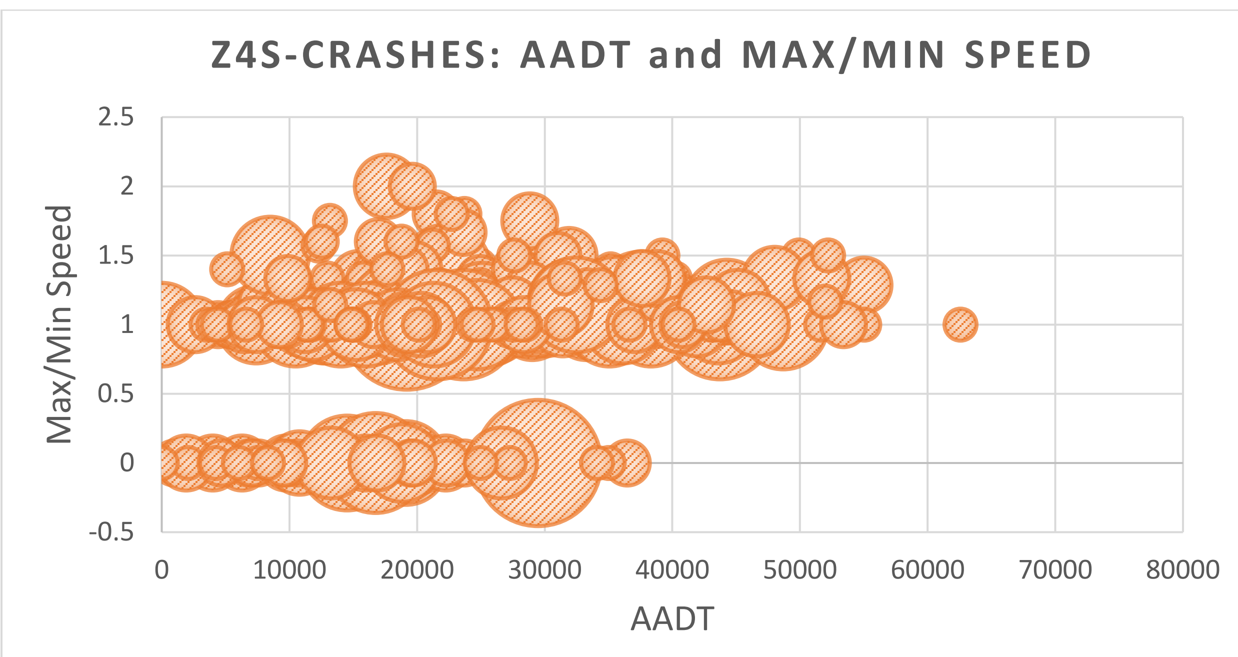

Figure 4-3: Binning method for intersections using speed differential and AADT

5. Systemic Data Analysis Results

The statewide systemic data analysis results were interpreted for roadway segment and intersection peer groups to identify situational trends in pedestrian crashes in Missouri. These were used to establish roadway types and thresholds for traffic volumes and speed limits and identify countermeasures to guide the development of the Missouri Pedestrian Safety Countermeasure Tool. Based on crash severity, two priority peer group categories were established. Priority 1 represents those peer groups categories with at least 20 percent of the total number of pedestrian crashes. Priority 2 represents those peer group categories with at least 10 percent but less than 20 percent of the pedestrian crashes. MoDOT and the local agencies should focus their initial implementation efforts on Priority 1 and Priority 2 peer groups.

5.1 Roadway Segment Statewide Systemic Analysis Results

The roadway segment data analysis results identified the peer groups with the highest number of pedestrian crashes. The available data did not allow for distinguishing the difference between crashes resulting from a pedestrian crossing the roadway (e.g., midblock crossings) or walking along the roadway. Roadway segments represented approximately 50 percent of the locations with at least one pedestrian crash but 37 percent of the total pedestrian crashes when compared to intersections. However, 67 percent of the pedestrian fatal crashes and 44 percent of the serious injury crashes occurred on roadway segments. This demonstrates an opportunity to focus efforts on these roadway facilities to address pedestrian safety.

Table 5-1 shows the road segment peer groups with the highest number of pedestrian crashes. The complete list of segments is shown in Table 4-4. The segment peer groups listed in Table 5-1 are all undivided roadways and have the highest segment counts, total length in mileage, and total crashes. The top five (Z2U, R2U, Z5U, U2U, and Z4U) represent 86 percent of the roadway segment pedestrian crashes.

Table 5-1 Highest ranking road segment peer groups for pedestrian crashes

Segment Peer Group	Number of Analysis Segments	Miles of Analysis Segment	Total Number of Pedestrian Crashes	Fatal (K) Crashes (184)	Serious Injury (A) Crashes (245)	Crash Rate (Crashes/ Mile)	Percent Segment Total Crashes
Z2U	390	80.4	440	34 (18%)	60 (24%)	5.5	29%
R2U	340	230.6	354	72 (39%)	78 (32%)	1.5	23%
Z5U	169	26.9	217	31 (17%)	28 (11%)	8.1	14%
U2U	151	40.3	157	19 (10%)	25 (10%)	3.9	10%
Z4U	132	16.9	153	12 (6%)	21 (8%)	9.0	10%
Z6U	44	5	50	5 (3%)	2 (1%)	10.0	3%
Z3U	34	6.9	42	6 (3%)	7 (3%)	6.1	3%
U3U	26	5.3	31	2 (1%)	6 (2%)	5.9	2%
U5U	25	3.7	28	1 (0%)	4 (2%)	7.5	2%

The R2U segment peer group has the lowest crash rate per mile based on total crashes and appears to be the safer peer group. However, the R2U peer group has 72 fatal (K) crashes and 78 serious injury (A) crashes which are by far the highest of any roadway segment peer group. The 72 fatal crashes represent 39 percent of the 184 total fatal crashes for all roadway segment peer groups. The 78 serious injury crashes represent 32 percent of the 245 total serious injury crashes for all roadway segment peer groups. The 150 fatal and serious injury crashes in the R2U segment peer group represent 42 percent of the 354 total crashes of all types in this peer group. Based on crash severity, two priority peer group categories were established. Priority 1 represents those peer groups categories with at least 20 percent of the total number of pedestrian crashes. This group includes Z2U and R2U segment peer groups. Priority 2 represents those peer group categories with at least 10 percent but less than 20 percent of the pedestrian crashes. This includes U2U, Z4U, and Z5U. MoDOT and the local agencies should focus their initial implementation efforts on Priority 1 and Priority 2 peer groups.

Given the varying volume and speed distributions, the most appropriate traffic volume and speed thresholds used for analysis purposes are as follows:

Traffic Volumes:

- Less than 5,000 vpd
- 5,000 – 10,000 vpd
- 10,000 – 20,000 vpd
- Greater than 20,000 vpd

Speed Limits:

- Less than 25 mph
- 25 – 35 mph
- 35 – 45 mph
- Greater than 45 mph

The speed limits categories were consolidated during the development of the matrix to provide more distinct categories for selection of countermeasures. The speed limits used in the matrix for segments are as follows:

- ≤ 30 mph
- 35 mph – 45 mph
- > 45 mph

The distribution of the pedestrian crashes for each segment peer group and the speed limits and volumes is shown in Table 5-2. Closer examination of the R2U segment crash data indicates that 108 (72 percent) of the 150 fatal (K) and serious injury (A) crashes in this peer group have occurred on roadways with less than 5,000 vpd and on roadways with posted speed limits greater than 45 mph.

Table 5-2 Total pedestrian crashes per segment peer group per volume and per speed

	Roadway ADT (vehicles per day, vpd) and Posted Speed (mph)																Missing Data	Total
	<=5,000 vpd				5,000 - 10,000 vpd				10,000 - 20,000 vpd				> 20,000 vpd					
Peer Group	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph		
Z2U Urbanized 2-lane Undivided	4	29	17	13	3	25	28	3	2	18	17	5	1	18	11	1	245	440
R2U Rural 2-lane Undivided	2	20	32	219	0	9	1	31	0	4	3	9	0	0	0	0	24	354
Z5U Urbanized 5-lane Undivided	0	0	0	0	1	11	2	0	0	32	39	4	0	21	99	0	8	217
U2U Urban 2-lane Undivided	4	15	20	24	1	10	6	8	0	1	4	0	0	0	1	0	63	157
Z4U Urbanized 4-lane Undivided	0	1	1	0	1	13	6	0	2	52	15	1	0	6	14	3	38	153
Z6U Urbanized 6-lane Undivided	0	0	0	0	0	3	1	0	0	10	4	1	0	20	9	0	2	50

	Roadway ADT (vehicles per day, vpd) and Posted Speed (mph)																	
	<=5,000 vpd				5,000 - 10,000 vpd				10,000 - 20,000 vpd				> 20,000 vpd					
Peer Group	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	<=25 mph	25 - 35 mph	35 - 45 mph	45+ mph	Missing Data	Total
Z3U Urbanized 3-lane Undivided	0	2	0	0	0	6	6	0	0	8	5	4	0	0	2	0	9	42
U3U Urban 3-lane Undivided	0	0	2	0	0	3	4	3	0	14	4	0	0	0	1	0	0	31
U5U Urban 5-lane Undivided	0	0	0	0	0	1	0	0	0	4	14	0	0	6	3	0	0	28

5.2 Intersection Statewide Systemic Analysis Results

The statewide analysis determined that intersections represented approximately 50 percent of the locations with at least one pedestrian crash and 63 percent of the total pedestrian crashes when compared to roadway segments. Of the study group, intersections represented 33 percent of the fatal (K) crashes and 63 percent of the serious injury (A) crashes. The analysis results identified the intersection peer groups shown in Table 5-3 with the highest number of pedestrian crashes. This represents four signalized intersection peer groups (Z4S, Z3S, U4S, and Z5S) and four unsignalized/uncontrolled intersection peer groups (Z4M, R4M, U4M, and Z3M).

Table 5-3 Highest intersection peer groups for pedestrian crashes

Peer Group	Intersection Count (1,402)	Fatal Crashes (K) (91)	Serious Injury Crashes (A) (309)	Total Number of Pedestrian Crashes (2,572)	Percent of Total Pedestrian Crashes
Z4S	849	54 (59%)	200 (65%)	1,719	67%
Z3S	188	9 (10%)	37 (12%)	361	14%
Z4M	81	7 (8%)	18 (6%)	126	5%
R4M	46	3 (3%)	8 (3%)	47	2%
U4S	61	3 (3%)	7 (2%)	88	3%
U4M	63	4 (4%)	14 (5%)	70	3%
Z5S	40	1 (1%)	10 (3%)	66	3%
Z3M	32	5 (5%)	5 (1%)	40	2%

The Z4S intersection peer group had a total number of 1,719 pedestrian crashes, the highest of all intersection peer groups. This represents 67 percent of the total number of pedestrian crashes for intersections. A total of 849 intersections (61 percent of the total intersection analysis locations) are represented in this peer group. Within the Z4S intersection peer group 54 (59 percent) fatal (K) crashes and 200 (65 percent) severe injury (A) crashes occurred, significantly higher than all other intersection peer groups combined. Based on the analysis, given the varying volume and speed distributions, the most appropriate traffic volume and speed thresholds are as follows:

Traffic Volumes:

- Less than 10,000 vpd
- 10,000 – 20,000 vpd
- 20,000 – 30,000 vpd
- Greater than 30,000 vpd

Speed Limits:

- Less than 30 mph
- 30 – 40 mph
- 40 – 50 mph
- Greater than 50 mph

Table 5-4 provides the distribution of the total number of pedestrian crashes for the highest ranked intersection peer groups. This uses the traffic volume and speed distribution thresholds identified. Table 5-5 provides a similar information for the same intersection peer groups using the pedestrian-related fatal and serious injury crashes. Each intersection peer group was further segregated into two categories (undivided and divided) to better determine what type of intersection configuration had a higher risk of pedestrian crashes. These are as follows:

Unsignalized/Uncontrolled Intersections:

- Rural 4-Leg Minor Stop (R4M) – Undivided
- Urban 4-Leg Minor Stop (U4M) – Undivided
- Urbanized 3-Leg Minor Stop (Z3M) – Undivided
- Urbanized 4-Leg Minor Stop (Z4M) – Undivided

Signalized Intersections:

- Urban 4-Leg Signalized (U4S) – Undivided
- Urbanized 3-Leg Signalized (Z3S) – Divided
- Urbanized 4-Leg Signalized (Z4S) – Undivided
- Urbanized >4-Leg Signalized (U4S) – Undivided

The number of missing data elements (e.g., divided/undivided road) is identified in each table for the various peer groups. Urbanized intersections represent the largest land use area for pedestrian crashes. The Urbanized 4-Leg Signalized (Z4S) intersection peer group has the highest number of total pedestrian crashes as well as fatal (K) and serious injury (A) crashes compared to any other intersection peer group. Of the 1719 total crashes of all types in this peer group, 261crashes had missing data. From the remaining crashes 1436 (84 percent) occurred on undivided roads. Combined, this peer group represents 254 total fatal and serious injury pedestrian crashes. Of these 254 crashes, 36 had missing data regarding if the roadway was divided or not. Of the 218 fatal and serious injury crashes with a known roadway configuration, 212 (83 percent) occurred on undivided roads and the remaining six (2 percent) occurred on divided roadways.

Looking at speed, traffic volume, and the number of lanes for this undivided Z4S intersection peer group, more fatal and injury crashes occurred in the speed range of 30 to 40 mph, with the next highest range of speeds being under 30 mph. The number of fatal and serious injury crashes varied across the two-lane to five-lane configurations, 30 to 40 mph speed range, and 10,000 vpd to 20,000 vpd ranges. The highest number of fatal and serious injury crashes for Z4S, based on lane configuration and traffic volume, occurred undivided intersections with six or more lanes and an ADT greater than 30,000 vpd. The fewest crashes occurred in the less than 10,000 vpd categories. These factors were similar for all of the crashes for this peer group.

The eight intersection peer groups were used when developing the Pedestrian Safety Countermeasure Tool. Based on crash severity and the two established priority peer group categories, Priority 1 (at least 20 percent of the total number of pedestrian crashes) includes the Z4S peer group on undivided roads. Priority 2 (at least 10 percent but less than 20 percent of the pedestrian crashes) includes the Z3S peer group on divided roads. MoDOT and the local agencies should focus their initial implementation efforts on Priority 1 and Priority 2 peer groups.

Table 5-4 Distribution of the total number of pedestrian crashes for the highest ranked intersection peer groups

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Rural 4 Legs Minor stop		**R4M Sub-total**	16	15	2	11	0	1	1	1	0	0	0	0	0	0	0	0	47	0	47
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	12	12	2	10	0	0	1	1	0	0	0	0	0	0	0	0	47		
		3	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0			
		4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Urban 4 Legs Minor stop		**U4M Sub-total**	17	10	5	0	5	27	1	0	0	5	0	0	0	0	0	0	70	0	70
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	12	6	2	0	2	1	0	0	0	0	0	0	0	0	0	0	70		
		3	1	3	3	0	0	7	0	0	0	0	0	0	0	0	0	0			
		4	2	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0			
		5	2	0	0	0	3	12	1	0	0	5	0	0	0	0	0	0			
		6+	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urbanized 3 Legs Minor stop		**Z3M Sub-total**	2	10	5	2	0	7	8	1	0	1	0	0	0	0	0	0	36	4	40
Divided	Max Number of Lanes	2	1	5	4	1	0	5	5	1	0	0	0	0	0	0	0	0	36		
		3	1	5	0	1	0	1	3	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			
		5	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Urbanized 4 Legs Minor stop		**Z4M Sub-total**	3	1	2	0	15	56	8	0	0	27	1	0	0	12	0	0	125	1	126
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	3	0	2	0	0	4	2	0	0	0	0	0	0	0	0	0	125		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	6	17	0	0	0	1	0	0	0	0	0	0			
		5	0	1	0	0	9	17	6	0	0	24	1	0	0	10	0	0			
		6+	0	0	0	0	0	18	0	0	0	2	0	0	0	2	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urban 4 Legs Signalized	**U4S Sub-total**		7	3	1	2	7	35	9	2	1	13	2	2	0	0	1	0	85	3	88
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	7	3	0	2	2	7	1	0	0	0	0	0	0	0	0	0	84		
		3	0	0	0	0	2	11	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	1	7	1	1	0	0	2	0	0	0	0	0			
		5	0	0	1	0	1	7	1	0	0	9	0	2	0	0	0	0			
		6+	0	0	0	0	1	3	6	0	1	4	0	0	0	0	1	0			
Urbanized 3 Legs Signalized	**Z3S Sub-total**		40	36	3	0	39	76	11	3	6	57	4	2	0	10	3	1	291	70	361
Divided	Max Number of Lanes	2	5	2	1	0	2	3	0	0	0	9	0	0	0	0	0	0	220		
		3	9	18	0	0	5	19	1	0	0	2	2	0	0	0	0	0			
		4	16	11	1	0	16	23	3	0	0	27	0	0	0	3	1	0			
		5	0	3	0	0	0	8	1	3	4	4	1	1	0	0	0	1			
		6+	2	0	0	0	2	2	1	0	0	2	1	1	0	2	2	0			
Undivided	Max Number of Lanes	2	3	0	0	0	0	1	2	0	1	0	0	0	0	0	0	0	71		
		3	0	1	1	0	5	3	1	0	0	4	0	0	0	0	0	0			
		4	3	1	0	0	7	6	2	0	0	0	0	0	0	0	0	0			
		5	2	0	0	0	1	10	0	0	1	7	0	0	0	2	0	0			
		6+	0	0	0	0	1	1	0	0	0	2	0	0	0	3	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urbanized 4 Legs Signalized		**Z4S Sub-total**	47	56	8	1	257	327	31	5	82	259	44	3	26	282	29	1	1458	261	1,719
Divided	Max Number of Lanes	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	22		
		3	0	0	0	0	3	3	0	1	0	0	0	0	0	0	0	0			
		4	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0			
		5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0			
		6+	0	0	0	0	1	0	0	0	0	1	1	0	0	2	0	0			
Undivided	Max Number of Lanes	2	28	29	0	1	115	78	16	2	19	28	11	0	0	4	0	0	1436		
		3	2	5	6	0	31	7	3	1	18	1	3	1	0	1	0	0			
		4	8	14	1	0	61	105	2	1	23	95	9	0	14	62	7	0			
		5	6	5	0	0	30	50	8	0	12	51	11	1	7	65	9	0			
		6+	3	2	0	0	16	79	2	0	10	83	9	1	3	148	12	1			
Urbanized > 4 Legs Signalized		**Z>4S Sub-total**	3	7	1	0	7	14	5	1	1	3	1	0	0	7	2	0	52	14	66
Divided	Max Number of Lanes	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	19		
		3	2	2	0	0	2	1	0	1	0	1	0	0	0	0	0	0			
		4	0	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0			
		5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	33		
		3	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0			
		4	1	2	0	0	0	10	0	0	0	0	0	0	0	2	0	0			
		5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			
		6+	0	0	0	0	4	1	0	0	1	0	0	0	0	4	2	0			
		Total	135	138	27	16	330	543	74	13	90	365	52	7	26	311	35	2		353	2,517

Table 5-5 Distribution of the fatal and serious injury pedestrian crashes for the highest ranked intersection peer groups

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Rural 4 Legs Minor stop	R4M Sub-total		4	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	11	0	11
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	4	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	11		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Urban 4 Legs Minor stop	U4M Sub-total		1	4	2	0	1	7	1	0	0	2	0	0	0	0	0	0	18	0	18
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	18		
		3	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0			
		4	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	1	1	0	0	2	0	0	0	0	0	0			
		6+	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urbanized 3 Legs Minor stop		**Z3M Sub-total**	0	5	1	1	0	1	1	0	0	0	0	0	0	0	0	0	9	1	10
Divided	Max Number of Lanes	2	0	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	9		
		3	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Urbanized 4 Legs Minor stop		**Z4M Sub-total**	1	0	0	0	2	10	1	0	0	9	0	0	0	2	0	0	25	0	25
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	1	5	0	0	0	1	0	0	0	0	0	0			
		5	0	0	0	0	1	4	1	0	0	7	0	0	0	1	0	0			
		6+	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urban 4 Legs Signalized		**U4S Sub-total**	3	1	0	1	0	3	0	0	0	2	0	0	0	0	0	0	10	0	10
Divided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	10		
		3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			
		6+	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0			
Urbanized 3 Legs Signalized		**Z3S Sub-total**	1	3	1	0	4	11	2	0	0	9	2	2	0	1	0	1	37	9	46
Divided	Max Number of Lanes	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	30		
		3	0	1	0	0	2	2	0	0	0	0	1	0	0	0	0	0			
		4	1	1	0	0	1	3	1	0	0	4	0	0	0	0	0	0			
		5	0	1	0	0	0	2	1	0	0	1	1	1	0	0	0	1			
		6+	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0			
Undivided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7		
		3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			
		4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

ADT (vpd)			≤ 10,000				10,000 - 20,000				20,000 - 30,000				> 30,000				Subtotal	Missing Data	Total
Speed (mph)			≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+	≤ 30	30 - 40	40 - 50	50+			
Urbanized 4 Legs Signalized	**Z4S Sub-total**		1	9	3	0	35	50	4	2	10	47	8	1	6	35	7	0	218	36	254
Divided	Max Number of Lanes	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6		
		3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			
		5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	1	5	0	0	15	4	0	2	3	11	1	0	0	0	0	0	212		
		3	0	1	2	0	6	1	0	0	2	0	0	0	0	0	0	0			
		4	0	3	0	0	10	12	0	0	2	14	3	0	3	4	3	0			
		5	0	0	0	0	3	15	3	0	1	8	1	1	1	9	3	0			
		6+	0	0	0	0	1	14	1	0	2	14	3	0	1	22	1	0			
Urbanized > 4 Legs Signalized	**Z>S Sub-total**		0	3	1	0	0	2	3	0	0	0	0	0	0	0	0	0	9	2	11
Divided	Max Number of Lanes	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4		
		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0			
Undivided	Max Number of Lanes	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		
		3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		4	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0			
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
		6+	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0			
	Total		11	29	9	4	42	84	12	2	10	69	10	3	6	38	7	1		48	385

5.3 Mapping of Pedestrian Crashes

To facilitate implementation, a series of pedestrian crash maps were developed using GIS mapping for each Metropolitan Planning Organizations (MPO) in Missouri. Figure 5-1 shows an example of a pedestrian hot spot crash map for the Capital Area MPO. The intersection and segments are identified where these pedestrian crashes have occurred. Figure 5-2 shows an example of a heat map for fatal and serious injury (KA) crashes for segments in the Capital Area MPO.

These maps and files will be made available to each MPO through MoDOT. The GIS format allows MoDOT, the MPOs, and the local agencies to use them to screen for and identify corridors (segments and intersections) to focus systemic efforts. The pdf version of each map for the each of the MPOs are included in Appendix A.

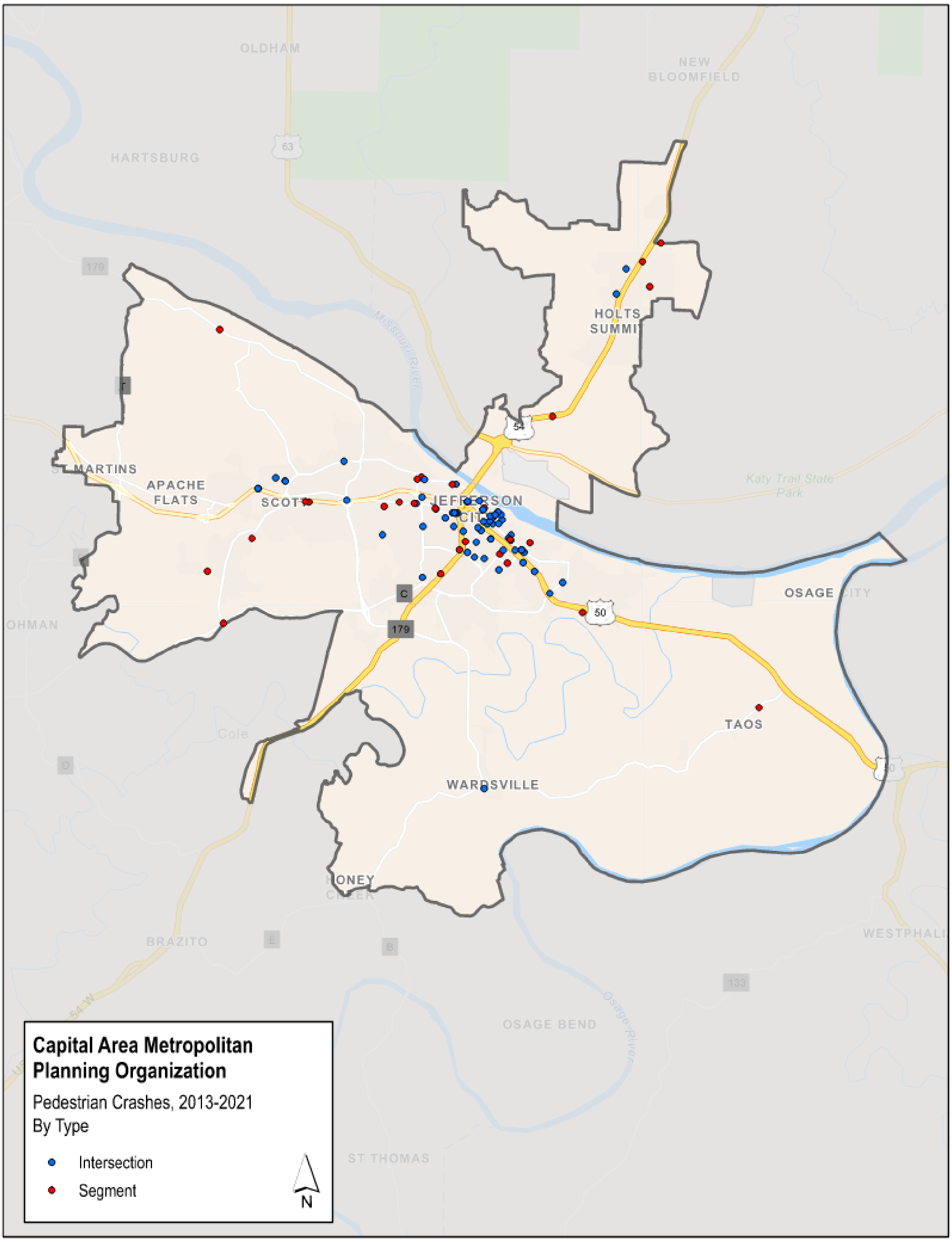

Figure 5-1 Pedestrian crash map for Capital Area MPO

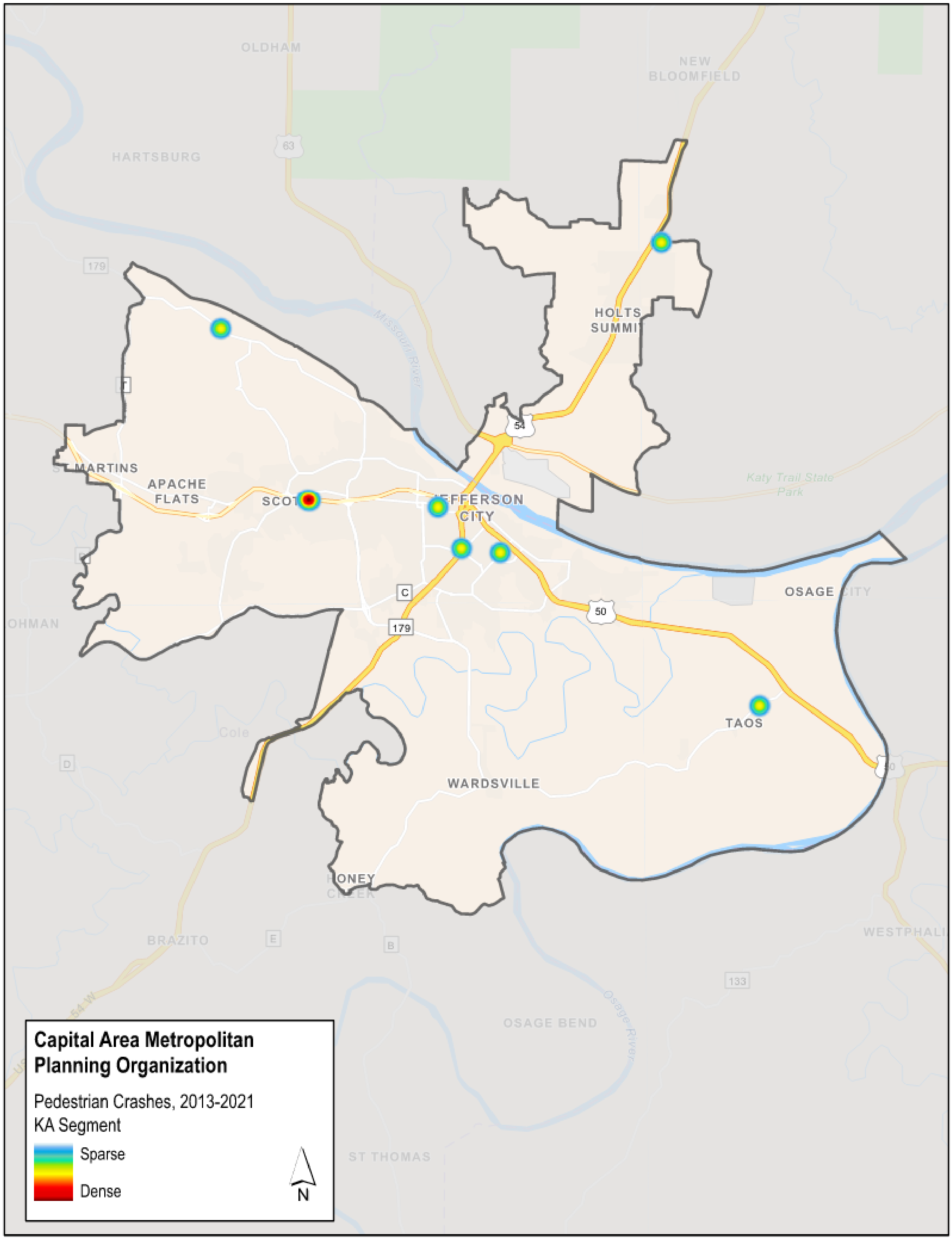

Figure 5-2 Capital Area MPO KA Segment Heat Map

6. Pedestrian Safety Countermeasure Tool Development

The Missouri Pedestrian Safety Countermeasure Tool represents a series of pedestrian crash heat maps for each MPO area in Missouri, three Excel spreadsheet matrices for signalized intersections, unsignalized intersections, and segments-midblock (undivided roads), a table for segments (corridor/parallel walking along the roadway), and the associated countermeasures that can be implemented systemically to reduce pedestrian-related crashes. The products of the Missouri Pedestrian Safety Countermeasure Tool were developed based on the pedestrian crash analysis results identified in Table 5-2 through Table 5-5.

Each matrix and the table target the peer groups that have the highest number of pedestrian crashes. The Priority 1 and Priority 2 peer groups and the subcategories (divided/undivided, speed limit, traffic volume) with the higher number of pedestrian crashes have been color coded to distinguish those that should be the primary focus for initial implementation. Countermeasures that should be considered as a minimum are shaded. All countermeasures, as appropriate, can be considered for use even if it is not listed in the matrix. Used in combination with the heat maps, the Pedestrian Safety Countermeasure Tool provides a mechanism for MoDOT and the local agencies to identify and implement systemic countermeasures that can have the greatest impact on reducing pedestrian crashes.

6.1 Signalized Intersection Matrix

The Signalized Intersection Matrix shown in Figure 6-1 includes the four peer groups: urbanized 4-leg (Z4S), urbanized 3-leg (Z3S), urban 4-leg (U4S), and urban greater than 4-leg. These four peer groups have with the highest total number of pedestrian crashes for signalized intersection during the study period.

The Signalized Intersection Matrix is further separated into two categories: divided and undivided roadway. The urbanized 4-leg signalized (Z4S) peer group represents 67 percent of all pedestrian-related intersection crashes. Of those crashes, 98 percent occurred on undivided roadways, making this a Priority 1 peer group for targeted systemic implementation of pedestrian countermeasures. The urbanized 3-leg signalized (Z3S) intersections represent 14 percent of the total pedestrian-related intersection crashes, making this a Priority 2 peer group. Of those with that peer group, 76 percent of the pedestrian crashes occurred on divided roads.

The Signalized Intersection Matrix uses the following traffic volumes thresholds:

- Less than 10,000 vpd
- 10,000 – 20,000 vpd
- 20,000 – 30,000 vpd
- Greater than 30,000 vpd

Speed thresholds are as follow:

- 30 mph or less
- 35 – 45 mph
- Greater than 45 mph

The following signalized intersections peer groups and categories are Priority 1 and Priority 2.

Priority 1:

- Urbanized 4-Leg Signalized (Z4S) Intersection on Undivided Roads.
    - Less than 10,000 vpd
        - 30 mph or less (2-lane)
        - 35 – 45 mph (2 - 4 lane)
    - 10,000 – 20,000 vpd
        - 30 mph or less (2 – 6 lane)
        - 35 – 45 mph (2 – 6 lane)
    - 20,000 – 30,000 vpd
        - 30 mph or less (2 – 6 lane)
        - 35 – 45 mph (2 - 6 lane)
        - Greater than 45 mph (2 – 6 lane)
    - Greater than 30,000 vpd
        - 35 – 45 mph (4 – 6 lane)

Priority 2:

- Urbanized 3-Leg Signalized (Z3S) Intersections on Divided Roads.
    - Less than 10,000 vpd
        - 30 mph or less (3-4 lane)
        - 35 – 40 mph (3 - 4 lane)
    - 10,000 – 20,000 vpd
        - 30 mph or less (3 - 4 lane)
        - 35 – 45 mph (3 - 4 lane)
    - 20,000 – 30,000 vpd
        - 30 mph or less (4-lane)
        - 35 – 40 mph (4-lane)

6.1.1 Signalized Intersection Countermeasures

The following is the list of identified countermeasures included in the matrix for signalized intersections. Each countermeasure is numbered accordingly. The number in the matrix is shaded if it should always be considered.

1. High-Visibility Crosswalks with ADA ramps (reduces up to 40 percent of pedestrian injury crashes), parking restrictions at crosswalk approach, and crosswalk lighting (reduces up to 42 percent of nighttime pedestrian crashes).

2. Signal Timing (Exclusive Pedestrian Phase, Pedestrian Phase Recall, Reduced Signal Cycle, Permissive Left Turn Phasing to Protected). These countermeasures put the pedestrian as a priority and provides enhanced pedestrian safety.

3. Leading Pedestrian Interval (LPI) (Consider using with NO RIGHT TURN Blank Out Sign). The LPI gives priority to the pedestrian by allowing them to enter the crosswalk 3

to 7 seconds before the vehicle is given a green light. The LPI pedestrian crashes up to 13 percent at intersections.

4. Passive Pedestrian Detection. Using infrared, ultrasonic, microwave radar, video imaging, or piezometric sensors to detect pedestrians and provides an alternative to activate pedestrian crossing traffic control devices. It is used with traffic signals near schools or designated school crossings and high-volume pedestrian crosswalks to enhance pedestrian safety.

5. Push Button Pedestrian (PPB) Detection. Installing PPBs in compliance with current MUTCD guidelines increases pedestrian actuation usage.

6. Curb Extensions. These reduce the pedestrian crossing distance, make pedestrians more visible, especially when there is on-street parking, to approaching motorists, and encourage slower speeds by the motorists.

7. Reduced Curb Radii. This requires motorists to reduce their speed when turning toward pedestrian crosswalks, enhancing pedestrian safety.

8. Medians and Pedestrian Refuge Islands. This countermeasure breaks up the crossing distance required of a pedestrian and safely separates pedestrians from vehicles while waiting to cross the remaining portion of a multi-lane roadway. This has been shown to reduce up to 56 percent of pedestrian crashes.

9. Pedestrian Countdown Timers. Pedestrian countdown timers show the number of seconds remaining until the signal changes and help pedestrians better interpret the pedestrian signals. Countdown timers also enable pedestrians to stop on a median refuge, where provided, and wait for the next signal phase if they believe that there is insufficient time for them to complete their crossing.

6.2 Unsignalized Intersection Matrix

The Unsignalized Intersection Matrix shown in Figure 6-2 includes the four peer groups: urbanized 4-leg minor stop, urban 4-leg minor stop, rural 4-leg minor stop, and urban 3-leg minor stop. The Unsignalized Intersection Matrix is further categorized by divided/undivided roadway, traffic volume, and speed, similar to that of the Signalized Intersection Matrix. None of these peer groups fall into Priority 1 or Priority 2 peer groups. The urbanized 4-leg minor stop peer group has the highest number of pedestrian-related crashes at unsignalized intersections, representing 5 percent of the total number of pedestrian-related crashes at intersections.

6.2.1 Unsignalized Intersection Countermeasures Selection

The following is the list of identified countermeasures included in the matrix for unsignalized intersections. Each countermeasure is numbered accordingly. The number in the matrix is shaded if it should always be considered.

1. High-Visibility Crosswalks with ADA ramps (reduces up to 40 percent pedestrian injury crashes), Parking Restrictions (at crosswalk approach), and Crosswalk Lighting (reduces up to 42 percent of pedestrian crashes).

2. Advanced Stop Bars. This countermeasure reduces pedestrian crashes by up to 25 percent.

3. Sidewalks/Walkways. Sidewalks reduce crashes related to pedestrians walking along the roadway between 65 percent to 89 percent. Paved Shoulders, as walkways, similarly, can reduce up to 71 percent of pedestrian crashes.

4. Rectangular Rapid Flashing Beacon (RRFB). The RRFB is used at uncontrolled intersections with speed limits less than 40 mph. It requires high-visibility crosswalks and signing. The RRFB can reduce pedestrian crashes by up to 47 percent and increase motorist compliance rates up to 98 percent. Consideration of sight distance and terrain (e.g., hills) is necessary. Educating the public is an important aspect of successful implementation.

5. Curb Extensions. These reduce the speed of vehicles turning toward the pedestrian crosswalk and reduce the crossing distance for the pedestrian, overall, decreasing the potential for pedestrian crashes.

6. Reduced Curb Radii. This reduces the speed of vehicles turning toward pedestrian crosswalks and the potential for crashes.

7. Medians or Pedestrian Refuge Islands. This countermeasure breaks up the crossing distance required of a pedestrian and safely separates pedestrians from vehicles while waiting to cross the remaining portion of a multi-lane roadway. This has been shown to reduce up to 56 percent of pedestrian crashes.

6.3 Road Segment - Midblock (Undivided Roads) Matrix

The Segment-Midblock (Undivided Roads) Matrix shown in Figure 6-3 includes four peer groups: urbanized 2-lane undivided (Z2U), rural 2-lane undivided (R2U), urbanized 5-lane undivided (Z5U), and urbanized 4-lane undivided (Z4U). Divided roadways segments did not meet the criteria for systemic safety improvements based on the underrepresentation of pedestrian crashes and therefore were not included in the matrix.

The matrix identifies two priority peer groups based on the analysis results. Priority 1 represents those peer groups categories with at least 20 percent of the total number of pedestrian crashes. For Segment-Midblock (Undivided Roads), Priority 1 includes Z2U and R2U. Priority 2 represents those peer group categories with at least 10 percent but less than 20 percent of the pedestrian crashes. This includes the remaining three peer groups in the matrix: U2U, Z4U, and Z5U.

The Segment-Midblock (Undivided Roads) Matrix uses similar speed thresholds as the other matrices but uses lower traffic volume thresholds, starting at less than 5,000 vehicles per day. The traffic volume thresholds are as follows:

- Less than 5,000 vpd
- 5,000 – less than 10,000 vpd
- 10,000 – less than 20,000 vpd
- Greater than 20,000 vpd

The speed thresholds are as follows:

- ≤ 30 mph
- 35 mph – 45 mph
- > 45 mph

The following segment midblock peer groups and categories are Priority 1 and Priority 2.

Priority 1:

- Urbanized 2 Lane Undivided (Z2U)-all AADT and speed limit thresholds

- Rural 2 Lane Undivided (R2U)
    - Less than 5,000 vpd
        - ≤ 30 mph
        - 35 mph - 45 mph
        - Greater than 45 mph (primary focus)
    - 5,000 – 10,000 vpd
        - Greater than 45 mph

Priority 2:

- Urban 2 Lane Undivided (U2U)
    - Less than 5,000 vpd
        - 35 mph - 45 mph
        - Greater than 45 mph (primary focus)
    - 5,000 – 10,000 vpd
        - 35 mph - 45 mph,
        - Greater than 45 mph

- Z4U Urbanized 4 lane undivided
    - 5,000 – 10,000 vpd
        - ≤ 30 mph
        - 35 mph - 45 mph
    - 10,000 – 20,000 vpd
        - ≤ 30 mph
        - 35 mph - 45 mph
    - Greater than 20,000 vpd
        - Greater than 45 mph

- Z5U Urbanized 5 lane undivided
    - 10,000 – 20,000 vpd
        - ≤ 30 mph

        - 35 mph - 45 mph
    - Greater than 20,000 vpd
        - Greater than 45 mph

6.3.1 Road Segment - Midblock (Undivided Roads) Countermeasures Selection

The following is the list of identified countermeasures included in the matrix for road segment-midblock (undivided roads). Each countermeasure is numbered accordingly. The number in the matrix is shaded if it should always be considered.

1. High-Visibility Crosswalks with ADA ramps (reduces up to 40 percent pedestrian injury crashes), Parking Restrictions (at crosswalk approach), and Crosswalk Lighting (reduces up to 42 percent of pedestrian crashes).

2. Advanced Stop/Yield Bars and Signs. This countermeasure reduces pedestrian crashes by up to 25 percent.

3. Sidewalks/Walkways. Sidewalks reduce crashes related to pedestrians walking along the roadway between 65 percent to 89 percent. Paved Shoulders as walkways, similarly, can reduce up to 71 percent of pedestrian crashes.

4. Rectangular Rapid Flashing Beacon (RRFB). The RRFB is used for midblock locations with speed limits less than 40 mph. It requires high-visibility crosswalks and signing. RRFBs can reduce pedestrian crashes by up to 47 percent and increase motorist compliance rates up to 98 percent. Consideration of sight distance and terrain (e.g., hills) is necessary. Educating the public is an important aspect of successful implementation.

5. Pedestrian Hybrid Beacon (PHB). The PHB is used for midblock locations with speed limits of 40 mph or greater. It requires high-visibility crosswalks and signing. PHBs reduce pedestrian crashes up to 55 percent, total crashes up to 29 percent, and up to a 15 percent reduction in serious and fatal crashes. Consideration of sight distance and terrain (e.g., hills) is necessary. Educating the public is an important aspect of successful implementation.

6. Curb Extensions. These reduce the speed of vehicles turning toward the pedestrian crosswalk and reduce the crossing distance for the pedestrian, overall, decreasing the potential for pedestrian crashes.

7. Medians or Pedestrian Refuge Islands. This countermeasure breaks up the crossing distance required of a pedestrian and safely separates pedestrians from vehicles while waiting to cross the remaining portion of a multi-lane roadway. This has been shown to reduce up to 56 percent of pedestrian crashes.

8. Road Diets. Reducing the roadway from four lanes to three lanes encourages slower speeds, reduces the crossing distance for the pedestrian, and reduces total crashes between 19 percent and 47 percent.

9. Narrowing of Travel Lanes. Narrower lanes have been proven to decrease vehicular speeds and acts as a traffic calming measure. Narrower lanes reduce pedestrian crossing distances and subsequent exposure risk. They can be accomplished through low-cost systemic restriping of the roadway. A minimum 10-feet lane may be used in traffic calming areas.

6.4 Road Segment - Corridor/Parallel Walking Table

The pedestrian crash data obtained from MoDOT did not distinguish crash types between the pedestrian crossing the roadway midblock or walking along or in the roadway. The Segment-Corridor/Parallel Walking Table shown in Table 6-1 was developed to supplement the Road Segment-Midblock (Undivided Roads) Matrix. It includes the three highest pedestrian crash segment peer groups (rural 2-lane undivided, urbanized 2-lane undivided, and urbanized 5-lane undivided) with a list of countermeasures that can be considered to reduce this type of pedestrian crash. This can be applied to corridors that may be at higher risk for pedestrian crashes due to pedestrian generators (e.g., businesses, restaurants and food services, convenience stores, recreational facilities). A more in-depth review of crash reports can determine the number and location of parallel walking pedestrian crashes to identify the magnitude of this type of crash, locations, roadway types, speed and ADT and select countermeasures from the countermeasure list to implement. It is intuitive that crashes involving pedestrians would be occurring on rural two-lane high-speed roadways where sidewalks and adjacent shoulder areas do not exist resulting in pedestrians walking close or in the travel way.

Table 6-1 Segment-Corridor/Parallel Walking Pedestrian Safety Countermeasure Tool

Segment - Corridor/Parallel Walking	
Rural 2 - Lane Undivided	**5000 ADT, > 45 mph**
Urbanized 2 - Lane Undivided	**All ADT, 25 - 45 mph**
Urbanized 5 - Lane Undivided	**> 10,000 ADT, 25 - 45 mph**

6.4.1 Road Segment - Corridor/Parallel Walking Countermeasures Selection

The following is the list of identified countermeasures for road segment-corridors/parallel walking. Each countermeasure improves safety for pedestrians by increasing the visibility of pedestrians to motorists, providing separation between the two road users, and reducing the potential impact speeds should a pedestrian crash occur.

1. Signing (Advance Pedestrian Warning). These signs alert approaching motorist of the potential for pedestrians to be crossing or walking along the roadway and enhances pedestrian safety.

2. Reduce Speed Limit. Based on engineering judgment and pedestrian generators, consider speed reduction in 5 mph increments. Speed has an impact on the severity of all crashes especially pedestrian-vehicle crashes. Addressing speed is fundamental to the Safe System Approach to safer streets for all users.

3. Walkways (Sidewalks/ Shoulders). Sidewalks reduce crashes related to pedestrians walking along the roadway between 65 percent to 89 percent. Paved Shoulders, similarly, can reduce up to 71 percent of pedestrian crashes.

4. Narrow Travel Lanes. This countermeasure can be accomplished through re-striping of a roadway. It encourages reduction of motorists' speeds and may provide added shoulder width (4 feet or greater) for a pedestrian walkway on rural roadways. When evaluating the appropriate width of the shoulder to be used as a walkway, consideration should be given to the potential of aggressive drivers using the shoulders to illegally pass other vehicles. Also, the potential for illegal parking on shoulders needs to be evaluated. Signing prohibiting passing and parking may be necessary. Sidewalks are more appropriate as a countermeasure for providing for safe travel for pedestrians on urban and urbanized roads.

5. Highway Lighting (Targeted Corridors). The addition of highway lighting increases the visibility of pedestrians to motorists and reduces up to 28 percent of pedestrian-related injury crashes on rural and urban highway segments. The maps can help guide selection of locations.

6.5 Pedestrian Safety Countermeasure Tool Implementation

Implementation of the Pedestrian Safety Countermeasure Tool will help MoDOT and the local agencies to systemically reduce pedestrian crashes in Missouri. Each matrix and table that comprise the Pedestrian Safety Countermeasure Tool include categories/cells that contain numerous countermeasures while other categories/cells do not. Those that have more countermeasures are the categories that are identified as having a high number of pedestrian crashes. Countermeasures may not be included in the category or cell if the analysis did not warrant inclusion. For example, signal timing is not included as a potential countermeasure for signalized urban 4-leg undivided intersections with an ADT of 10,000 or less because the number of pedestrian-related crashes is low. However, because of the higher number of crashes, it is included as a countermeasure for the same peer group with an ADT range of 10,000 to less than 20,000 and range of speed between 35-40 mph.

Systemic application of FHWA Proven Safety Countermeasures such as enhanced high-visibility crosswalks should be considered as a minimum. Implementation should focus on the following Priority 1 and Priority 2 peer groups first for the most impact.

The heat maps can help guide MoDOT and the local agencies to locations to target implement efforts.

		Signalized Intersections											
ADT Range (vpd)		< 10,000			10,000 - < 20,000			20,000 - < 30,000			≥ 30,000		
Speed Limit (mph)		≤ 30	35-45	> 45	≤ 30	35-45	> 45	≤ 30	35-45	> 45	≤ 30	35-45	> 45
Urban 4 - Leg	Divided	1 5 9	1 5 9	1 5 9	1 5 6 7 9	1 5 6 7 9	1 5 6 7 9	1 5 9	1 5 6 7 9	1 5 9	1 5 9	1 5 9	1 5 9
	Undivided	1 5 9	1 5 9	1 5 9	1 5 9	1 2 5 9	1 5 9	1 5 9	1 2 5 9	1 5 9	1 5 9	1 5 9	1 5 9
Urbanized 3 - Leg	Divided	1 2 4 5 6 7 9	1 2 4 5 6 7 9	1 5 9	1 2 5 6 7 8 9	1 2 5 6 7 8 9	1 5 9	1 5 6 7 8 9	1 2 5 9	1 5 9	1 5 9	1 5 9	1 5 9
	Undivided	1 2 9	1 2 9	1 5 9	1 2 5 6 7 9	1 2 5 9	1 5 9	1 5 9	1 2 5 6 7 8 9	1 5 9	1 5 9	1 5 9	1 5 9
Urbanized 4 - Leg	Divided	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9
	Undivided	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 5 9	1 2 3 4 5 9	1 2 3 4 5 9	1 5 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 5 6 7 8 9	1 5 9	1 2 3 4 5 6 7 8 9	1 5 9
Urbanized > 4 - Leg	Divided	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9
	Undivided	1 5 9	1 5 9	1 5 9	1 5 9	1 2 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9	1 5 9

Priority 1   Priority 2

A. A shaded number represents a countermeasure that should always be considered, but is not required, for systemic installation. The decision to use a particular countermeasure should be based on an engineering study or application of engineering judgement.

B. An unshaded number represents a countermeasure that is a potential candidate for consideration for systemic implementation for that specific Peer Group and in its speed and ADT ranges.

C. The absence of a countermeasure number in a Peer Group cell represents a category that has a low crash history associated with the conditions (e.g., ADT, speed). Higher level countermeasures may be considered for low crash cells based on engineering judgement.

1. High-Visibility Crosswalks with ADA ramps, Parking Restrictions at crosswalk approach, and Crosswalk Lighting
2. Signal Timing (Exclusive Pedestrian Phase, Pedestrian Phase Recall, Reduced Signal Cycle, Permissive Left Turn Phasing to Protected)
3. Leading Pedestrian Interval (LPI) (Consider using with NO RIGHT TURN Blankout Sign)
4. Passive Pedestrian Detection
5. Push Button Pedestrian Detection per MUTCD Compliance
6. Curb Extensions
7. Reduced Curb Radii
8. Medians and Pedestrian Refuge Islands
9. Pedestrian Countdown Signals

Figure 6-1 Signalized intersection matrix

Unsignalized Intersections													
ADT Range (vpd)		< 10,000			10,000 - < 20,000			20,000 - < 30,000			≥ 30,000		
Speed Limit (mph)		≤ 30	35-45	> 45	≤ 30	35-45	> 45	≤ 30	35-40	≥ 45	≤ 30	35-45	> 45
Rural 4 - Leg Minor Stop	Divided	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
	Undivided	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 5 6 7	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Urban 4 - Leg Minor Stop	Divided	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
	Undivided	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3	1 2 3	1 2 3 4 5 6 7	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Urbanized 3 - Leg Minor Stop	Divided	1 2 3 4	1 2 3 4	1 2 3	1 2 3	1 2 3 4 5 6 7	1 2 3 5 6 7	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
	Undivided	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Urbanized 4 - Leg Minor Stop	Divided	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2
	Undivided	1 2 3	1 2 3	1 2 3	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2	1 2	1 2 3 4 5 6 7	1 2	1 2	1 2 3 4 5 6 7	1 2

A. A shaded number represents a countermeasure that should always be considered, but is not required, for systemic installation. The decision to use a particular countermeasure should be based on an engineering study or application of engineering judgement.

B. An unshaded number represents a countermeasure that is a potential candidate for consideration for systemic implementation for that specific Peer Group and in its speed and ADT ranges.

C. The absence of a countermeasure number in a Peer Group cell represents a category that has a low crash history associated with the conditions (e.g., ADT, speed). Higher level countermeasures may be considered for low crash cells based on engineering judgement.

1. **High-Visibility Crosswalks with ADA ramps, Parking Restrictions (at crosswalk approach), and Crosswalk Lighting**
2. **Advanced Stop Bars**
3. **Sidewalks/Walkways**
4. **Rectangular Rapid Flashing Beacon (RRFB) (Less than 40 mph)**
5. **Curb Extensions**
6. **Reduced Curb Radii**
7. **Medians or Pedestrian Refuge Islands**

Figure 6-2 Unsignalized intersection matrix

Segment - Midblock (Undivided Roads)												
ADT Range (vpd)	< 5,000			5000 - <10000			10,000 - < 20,000			≥ 20,000		
Speed Limit (mph)	≤ 30	35-45	> 45	≤ 30	35-45	> 45	≤ 30	35-45	> 45	≤ 30	35-45	> 45
Rural 2 - Lane Undivided	1 2 3 4 9	1 2 3 4 5 9	1 2 3 5 9	1 2 3	1 2 3	1 2 3 5 9	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Urban 2 - Lane Undivided	1 2 3	1 2 3 4 5 6 9	1 2 3 5 9	1 2 3	1 2 3 4 5 6 9	1 2 3 5 9	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Urbanized 2 - Lane Undivided	1 2 3 4 6 9	1 2 3 4 5 6 9	1 2 3 5 6	1 2 3 4 6 9	1 2 3 4 5 6 9	1 2 3 5 6 9	1 2 3 4 6 9	1 2 3 4 5 6 9	1 2 3 5 6	1 2 3	1 2 3 4 5 6 9	1 2 3
Urbanized 4 - Lane Undivided	1 2 3	1 2 3	1 2 3	1 2 3 4 6 7 8	1 2 3 4 5 6 7 8	1 2 3	1 2 3 4 6 7 8	1 2 3 4 5 6 7 8	1 2 3 4 6 7 8	1 2 3	1 2 3 4 5 6 7 8	1 2 3
Urbanized 5 - Lane Undivided	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3 4 6 7 8	1 2 3 4 5 6 7 8	1 2 3 5 6 7 8	1 2 3	1 2 3 4 5 6 7 8	1 2 3

Priority 1 **Priority 2**

A. A shaded number represents a countermeasure that should always be considered, but is not required, for systemic installation. The decision to use a particular countermeasure should be based on an engineering study or application of engineering judgement.

B. An unshaded number represents a countermeasure that is a potential candidate for consideration for systemic implementation for that specific Peer Group and in its speed and ADT ranges.

C. The absence of a countermeasure number in a Peer Group cell represents a category that has a low crash history associated with the conditions (e.g., ADT, speed). Higher level countermeasures may be considered for low crash cells based on engineering judgement.

1. High-Visibility Crosswalks with ADA ramps, Parking Restrictions at crosswalk approach, and Crosswalk Lighting
2. Advance Yield Here To (Stop Here For) Pedestrians Signs and Yield (Stop) Lines
3. Sidewalks/Walkways
4. Rectangular Rapid Flashing Beacon (RRFB) (Less than 40 mph)
5. Pedestrian Hybrid Beacon (PHB) (40 mph or greater)
6. Curb Extensions
7. Medians or Pedestrian Refuge Island
8. Road Diets
9. Narrow Travel Lanes

Figure 6-3 Segment-midblock (undivided roads) matrix

7. Conclusions

A Pedestrian Safety Countermeasure Tool has been developed that can be applied across jurisdictions to successfully systemically implement a series of countermeasures that will reduce pedestrian crashes. Statewide data analysis identified roadway characteristics that guided the development of the tool.

Peer groups based on land use, number of lanes or number of legs of an intersection, and separation of traffic would allow for comparison of similar characteristics and safety risks. The following conclusions guided the development of the Pedestrian Safety Countermeasure Tool:

Roadway Segments:

1. Undivided roadways represented nearly all of the pedestrian crashes.

2. Urbanized 2-Lane Undivided (Z2U) and Rural 2-Lane Undivided (R2U) roadways represent the two primary roadway segment peer groups with the highest number of pedestrian crashes. Focusing on these two peer groups can have the greatest impact in reducing pedestrian crashes.

3. R2U roadways with posted speed greater than 45 mph and ADT less than 5,000 vpd should be targeted. Motorists may not expect pedestrians on these roadways. Corridors can be identified using GIS maps, considering corridors with a crash history or near communities that have pedestrian generators and narrow or no shoulders.

4. FHWA Proven Safety Countermeasures implemented at midblock crossings and along corridors are recommended for systemic application on these roadways.

Intersections:

1. Urbanized intersections represented a significant number of the pedestrian crashes.

2. Urbanized 4-Leg Signalized (Z4S) intersections on undivided roadways is Priority 1. This peer group had substantially more pedestrian crashes, including fatal and serious injury crashes, than all other types of intersections. This should be the primary focus for systemic implementation of safety countermeasures, at least initially.

3. Urbanized 3-Leg Signalized (Z3S) Intersections on divided roads with speed limits less than 30 mph to 40 mph, and traffic volumes between 10,000 vpd and 20,000 vpd should be the focus. Recommended countermeasures target these intersections.

4. Signal timing should be evaluated for many of the intersections that are Z4S and Z3S to determine if modifications can be made systemically to address pedestrian safety. This would include evaluating start times, current clearance intervals, walk times and flashing “Don’t Walk” times.

5. High-visibility crosswalk enhancement should be systemically applied as a minimum.

Proven Safety Countermeasures identified by FHWA can be implemented systemically to address these locations. Many of these are low-cost and effective. These are included in the Pedestrian Safety Countermeasure Tool.

In conclusion, although the Missouri Pedestrian Safety Countermeasure Tool includes multiple peer groups for road segments, signalized intersections, and unsignalized intersections, implementation should focus on the following two priority peer groups for the most impact.

Priority 1 Peer Groups:

1. Urbanized 4-Leg Signalized (Z4S) Intersection on Undivided Roads.
2. Urbanized 2-Lane Undivided (Z2U) Road Segments.
3. Rural 2-Lane Undivided (R2U) Road Segments.

Priority 2 Peer Groups:

1. Urbanized 3-Leg Signalized (Z3S) Intersections on Divided Roads.
2. Urban 2-Lane Undivided (U2U) Road Segments.
3. Urbanized 4-Lane Undivided (Z4U) Road Segments.
4. Urbanized 5-Lane Undivided (Z5U) Road Segments.

The tables in this report showing the distribution of crashes in combination with the Missouri Pedestrian Safety Countermeasure Tool and the GIS maps can be used to revise policies and help guide MoDOT and the local agencies to locations to target implement efforts.

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