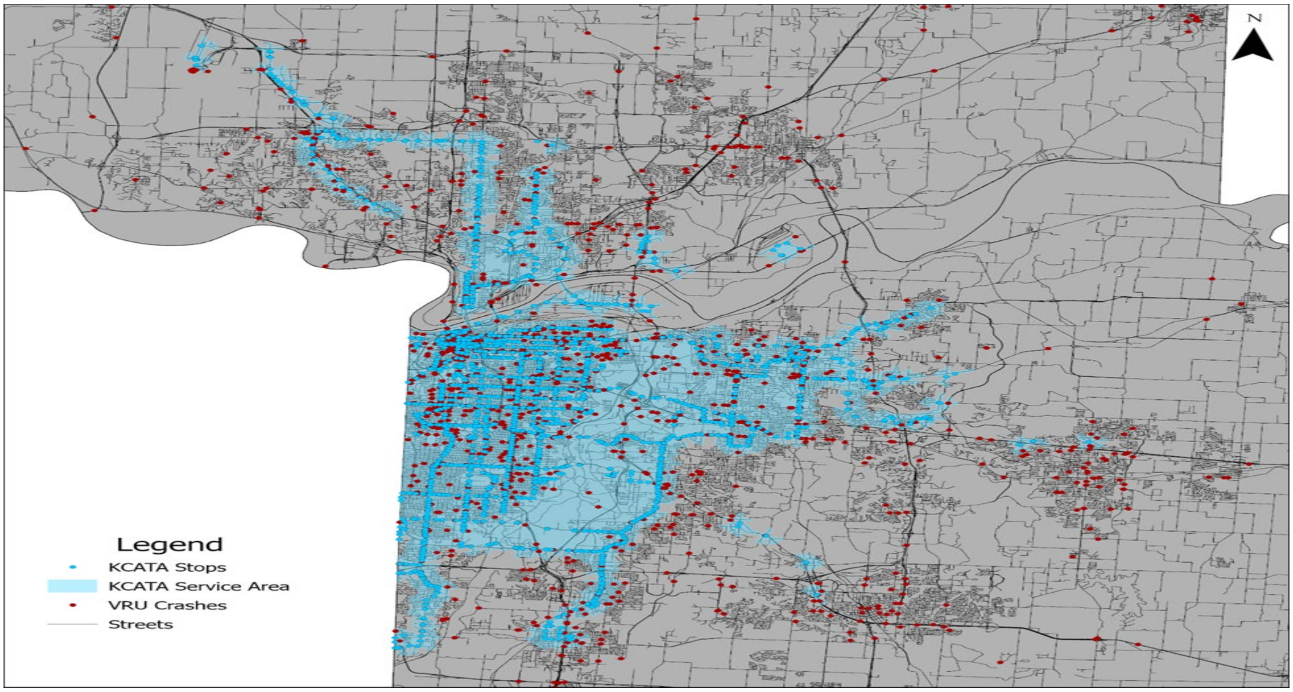
Vulnerable Road User (VRU) Safety Assessment



November 2023
Final Report

Project number TR202322
MoDOT Research Report number cmr 23-015

PREPARED BY:

Carlos Sun, PhD, PE, JD

Henry Brown, PE

Praveen Edara, PhD, PE

Julie Stilley, PhD

Joe Reneker

University of Missouri-Columbia

PREPARED FOR:

Missouri Department of Transportation

Construction and Materials Division, Research Section

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
cmr 23-015		

4. Title and Subtitle Vulnerable Road User (VRU) Safety Assessment	**5. Report Date** October 2023 Published: November 2023 **6. Performing Organization Code**
7. Author(s) Carlos Sun, PhD, PE, JD Henry Brown, PE Praveen Edara, PhD, PE Julie Stilley, PhD Joe Reneker	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Missouri-Columbia E2509 Lafferre Hall Columbia, MO 65201	**10. Work Unit No.** **11. Contract or Grant No.** MoDOT project # TR202322
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR-B) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102	**13. Type of Report and Period Covered** Final Report (January 2023-October 2023) **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/research-publications.

16. Abstract

Vulnerable Road Users (VRUs) are nonmotorized road users, such as pedestrians and bicyclists, who do not have the protection of a vehicle shell. VRU injuries and fatalities have been increasing, leading to various efforts to assess and improve VRU safety. One such state-level effort is the development of a Missouri VRU safety assessment plan. This plan includes systemic analysis of intersection and segments, high-crash analysis of statewide facilities, examination of various contributory factors such as equity, unhoused pedestrians, transit, and lighting, and review of low-cost proven VRU countermeasures. Certain facilities stand out from the crash analysis such as urbanized three-legged and four-legged intersections, rural two-lane undivided highways, urbanized roadways, and controlled access roadways because of secondary crashes. Stakeholders reviewed the data-driven results and were engaged via two meetings as well as an electronic survey. For the near term, there are various low-cost countermeasures that could be deployed over intersections and entire corridors in Missouri, such as beacons and leading signal intervals. For the long term, technological solutions could help to reduce or eliminate human error of both drivers and VRUs.

17. Key Words	18. Distribution Statement
Vulnerable road users; Pedestrians; Bicyclists; Safety	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	143	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Vulnerable Road User (VRU) Safety Assessment

Final Report
October 2023

Principal Investigator
Carlos Sun, PhD, PE, JD, Professor, Civil Engineering
University of Missouri-Columbia

Co-Principal Investigators
Henry Brown, PE, Research Engineer, Civil Engineering
Praveen Edara, PhD, PE, Professor, Civil Engineering
Julie Stilley, PhD, Research Director, Emergency Medicine
University of Missouri-Columbia

Authors
Carlos Sun
Henry Brown
Praveen Edara
Julie Stilley
Joe Reneker, Graduate Research Assistant

Sponsored by
Missouri Department of Transportation

A report from the
Missouri Center for Transportation Innovation
University of Missouri
Department of Civil and Environmental Engineering
E2509 Lafferre Hall
Columbia, MO 65211

COPYRIGHT

DISCLAIMER

ACKNOWLEDGMENTS

The authors would like to thank the Missouri Department of Transportation (MoDOT) and the Missouri Center for Transportation Innovation (MCTI) for sponsoring this research. The authors would also like to acknowledge the assistance provided by MoDOT personnel, including the Technical Advisory Committee (TAC). The TAC members include Jenni Hosey, Research; Katy Harlan, Highway Safety; Carrie Ahart, Highway Safety; Brandon Simpson, Highway Safety, Eddie Watkins, STL Traffic Operations, Joshua Scott, KC Design, and John Miller, FHWA Safety. The authors also appreciate the input from personnel at Metropolitan Planning Organizations, Regional Planning Commissions, counties, and cities who participated in the stakeholder meetings.

EXECUTIVE SUMMARY

According to the Federal Highway Administration (FHWA), a Vulnerable Road User (VRU) is a nonmotorist such as a pedestrian, bicyclist, or highway worker but does not include a motorcyclist. NHTSA (2021) reports that VRU fatalities have been increasing. For example, 2021 NHTSA data shows that pedestrian fatalities are up by 13% and bicyclist up by 5%. The United States Department of Transportation's (USDOT) National Roadway Safety Strategy (NRSS) is advocating for a substantial and comprehensive action to reduce VRU fatalities and injuries by adopting a Safe Systems Approach (SSA) (USDOT, 2022). In contrast to the conventional safety approach, SSA deploys system redundancy to accommodate human mistakes and human vulnerability. VRU crashes impact underrepresented populations disproportionately and inhibit sustainable transportation modes involving VRUs. As described in 23 U.S.C. §148(1), each state is required to produce an initial Vulnerable Road User Safety Assessment as part of the state's Strategic Highway Safety Plan. This report documents Missouri's effort in developing an initial VRU safety assessment plan. Safety planning is a foundational process towards the goal of bringing down VRU deaths and injuries consistent with a vision towards zero fatalities by 2030. The data-driven approach discussed in this report helps to focus on the most vulnerable users and to target the most effective countermeasures.

The methodology used in the VRU safety assessment involves a combination of systemic analysis with high-crash location analysis. These two methods are used by many states such as Texas, Iowa, and North Carolina. Predictive statistical methods are difficult to use for VRU safety assessment because of the lack of VRU demand data. The main sources of data include police crash reports, MoDOT roadway data, and hospital data. The cross-tabulation statistical technique was used for systemic analysis. Cross-tabulation reveals the association of contributory factors to VRU crashes. The initial investigation of hospital data shows that it has the potential for complementing crash data by capturing underreported crashes, acquiring VRU modes not currently recorded in police reports, and yielding insights into user injury and recovery.

The systemic analysis was divided between intersections and segments. For intersections, facilities were divided by density (**R**ural/**U**rban/urbani**Z**ed), the number of intersection legs, and signalization (**Y**es/**N**o). For example, Z4N stands for urbanized 4-legged unsignalized intersections. Table ES-1 shows the intersection facilities with the highest occurrence of VRU crashes. Note that urbanized intersections contain more than 80% of the VRU crashes. For segments, facilities were divided again by density (**R**ural/**U**rban/urbani**Z**ed), the number of lanes, and median type (**D**ivided/**U**ndivided). For example, R2U stands for rural 2-lane undivided roadways. Table ES-2 shows the segment facilities with the highest occurrence of VRU crashes. In contrast to intersections, rural segments captured a large percentage (34.7%) of VRU crashes. Similar to intersections, urbanized facilities dominated, albeit to a lesser extent.

Table ES-1 Condensed Systemic Intersection Results

	Fatal		Serious Injury		Minor Injury		All Severity	
Facility Type	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Rural	26	9.2%	89	7.8%	215	4.6%	330	5.4%
R3N	14	5.0%	52	4.5%	92	2.0%	158	2.6%
R4N	8	2.8%	28	2.4%	110	2.3%	146	2.4%
Urban	29	10.3%	137	12.0%	568	12.1%	734	12.0%
U3N	11	3.9%	57	5.0%	204	4.4%	272	4.5%
U3Y	4	1.4%	6	0.5%	26	0.6%	36	0.6%
U4N	9	3.2%	58	5.1%	248	5.3%	315	5.2%
U4Y	1	0.4%	10	0.9%	70	1.5%	81	1.3%
Urbanized	227	80.5%	918	80.2%	3899	83.3%	5044	82.6%
Z2N	24	8.5%	40	3.5%	117	2.5%	181	3.0%
Z2Y	2	0.7%	11	1.0%	65	1.4%	78	1.3%
Z3N	96	34.0%	332	29.0%	1341	28.6%	1769	29.0%
Z3Y	29	10.3%	129	11.3%	521	11.1%	679	11.1%
Z4N	31	11.0%	186	16.3%	843	18.0%	1060	17.4%
Z4Y	35	12.4%	203	17.7%	960	20.5%	1198	19.6%
Grand Total	282	100.0%	1144	100.0%	4682	100.0%	6108	100.0%

Table ES-2 Condensed Systemic Segment Results

Facility Type	Fatal		Serious Injury		Minor Injury		All Severity	
	Number	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Rural	117	34.7%	164	23.3%	329	16.8%	610	20.4%
R0U	10	3.0%	36	5.1%	106	5.4%	152	5.1%
R2U	59	17.5%	82	11.6%	169	8.6%	310	10.3%
R4D	33	9.8%	28	4.0%	31	1.6%	92	3.1%
Urban	26	7.7%	87	12.4%	216	11.0%	329	11.0%
U2U	7	2.1%	35	5.0%	86	4.4%	128	4.3%
Urbanized	194	57.6%	434	61.6%	1282	65.6%	1910	63.8%
Z0U	10	3.0%	87	12.4%	415	21.2%	512	17.1%
Z2U	29	8.6%	96	13.6%	345	17.6%	470	15.7%
Z4D	26	7.7%	31	4.4%	47	2.4%	104	3.5%
Z4U	19	5.6%	43	6.1%	125	6.4%	187	6.2%
Z6D	31	9.2%	27	3.8%	27	1.4%	85	2.8%
Z6U	16	4.7%	45	6.4%	115	5.9%	176	5.9%
Z8D	16	4.7%	14	2.0%	20	1.0%	50	1.7%
Grand Total	337	100.0%	704	100.0%	1955	100.0%	2996	100.0%

High-crash analysis highlights specific facilities because of a high crash frequency. However, due to lack of demand/exposure data, high-crash should not be equated with high-risk as the high crash frequency may be due to high VRU demand, thus greater VRU exposure. Table ES-3 shows a condensed list of high-crash intersections. As reflected in the systemic analysis, all the high-crash intersections are located in an urbanized area, with eight out of ten of those intersections in the metropolitan St. Louis area.

Table ES-3 Condensed High-Crash Intersection List

	City	Intersection	Functional Class	# of Crashes	Enter AADT
1	Kansas City	Prospect & E31st	Min Art / Min Art	11	17202
2	St. Louis	Washington & Bdwy	Art / Min Art	9	19849
3	Springfield	Campbell & W Grand	Min Art / Min Art	8	23754
4	St. Louis	Bdwy & Walnut	Art / Coll	8	27492
5	St. Louis	Lindell & Whittier	Min Art	8	12741
6	St. Louis	Grand & 115	Art / Art	8	19116
7	St. Louis	366 & Morganford	Min Art / Coll	7	25533
8	St. Louis	30 & Grand	Art / Min Art	7	35811
9	Maplewood	100 & Sutton	Art / Coll	7	17401
10	St. Louis	Lindell & Euclid	Min Art / Coll	7	17228

High crash analysis of road segments revealed that there are a large number of VRU crashes that occur on freeways and controlled-access highways. A common scenario is when the VRUs from a previous incident are injured in a secondary crash, such as when drivers and passengers who have exited a vehicle to change a flat tire are hit by an on-coming vehicle. So even if VRUs do not usually appear in these facilities, they become vulnerable after exiting a vehicle. I-70, I-55, and I-44 were the top three roads in terms of VRU crash frequency. The high crash analysis of corridors produced results similar to intersections, in other words, those segments were located in urbanized areas and eight out of ten of those corridors were in metropolitan St. Louis.

The examination of specific contributory factors revealed that underrepresented neighborhoods were disproportionally affected by VRU crashes. The qualified low-income neighborhoods experienced around 58% of the VRU crashes. A related issue to poverty involves VRU safety for the unhoused and encampments near or on transportation facilities. The investigation of such issues is challenging due to the lack of both safety (e.g., crash, injury) and demand data. Transit stops were found to be correlated with VRU crashes. Around 35% of VRU crashes that occurred in the St. Louis and Kansas City areas occurred within 200 feet of a transit stop or station. In terms of light condition, intersections and segments were affected differently. For intersections, 46.5% of the fatal crashes occurred in lighted locations at night with 20.9% of the crashes occurring in unlit locations. In contrast, 54% of the fatal segment crashes occurred in unlit locations.

Significant engagement with stakeholders occurred via two separate engagement meetings, a special meeting with St. Louis County staff, and an electronic survey. The engagement meetings were hybrid meetings involving both in-person and remote attendees. Over 90 stakeholders attended the meetings or participated in the survey. These stakeholders represented every MoDOT district in Missouri, and they were diverse in terms of the organization they served. The organizations included metropolitan planning organizations, regional planning commissions, counties, cities, and advocacy groups. They provided significant feedback on a list of low-cost countermeasures. These countermeasures include treatments such as raised medians, speed reduction techniques, high-visibility crosswalks, beacons, curb extensions, and signal timing. Stakeholders provided feedback on systemic facilities, high-crash locations, and countermeasure experience. For example, agencies expressed the difficulty in securing funding for improvements and found some treatments to have a conflicting effect such as positively impacting VRU safety while negatively impacting transit service. Many expressed the sentiment that human behavior, for both drivers and VRUs, is a significant factor for crashes. Advanced technologies such as autonomous vehicles, VRU crumble zones, and automated VRU detection could ameliorate human error in the future.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SELECT ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACS	American Community Survey
ADAS	Advanced Driver Assistance Systems
ADT	Average Daily Traffic
AADT	Annual Average Daily Traffic
CDC	Center for Disease Control
CMF	Crash Modification Factor
EDC	Every Day Counts
FHWA	Federal Highway Administration
FI	Fatal and Injury crashes
HAWK	High-Intensity Activated crossWalK beacon
HSM	Highway Safety Manual
KCATA	Kansas City Area Transportation Authority
LPI	Leading Pedestrian Interval
Metro St. Louis	Metropolitan Saint Louis Transit Agency
MPO	Metropolitan Planning Organization
MSHP	Missouri State Highway Patrol
MoDOT	Missouri Department of Transportation
MUCR	Missouri Uniform Crash Report
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NSC	National Safety Council
NTSB	National Transportation Safety Board
PDO	Property Damage Only crashes
RPC	Regional Planning Commission
RRFB	Rectangular Rapid Flashing Beacon
STARS	Statewide Traffic Accident Records System
STEP	Safe Transportation for Every Pedestrian
TMS	Transportation Management System
TWLTL	Two-Way Left-Turn Lane
V2VRU	Vehicle-to-VRU
VRU	Vulnerable Road User
YOLO	You Only Look Once

1. INTRODUCTION

A vulnerable road user (VRU) is a term applied to those most at risk in traffic, mainly those who are unprotected by an outside shield. It most often refers to pedestrians and bicyclists, and excludes motorcyclists, due to the unlikelihood that pedestrians and bicyclists will inflict injury on other road users (FHWA, 1998). VRUs sustain a greater risk of injury in a traffic crash and are therefore in need of greater protection against such crashes. According to National Highway Traffic Safety Administration (NHTSA) (2021), the proportion of traffic fatalities for VRUs has increased from 1980 to 2019 from 28% to 34%. Further, since 2009, VRU fatality rates have an upward trend of 23%. Reports from FHWA show that pedestrian and bicyclist fatalities had a much higher percentage change from 2011 to 2020 compared to the total traffic fatalities (FHWA, 2022).

The same VRU trends can be observed on the state level as well. Approximately, one hundred Missouri pedestrians are killed each year, accounting for approximately 10% of total traffic fatalities. Over the past 10 years, Missouri pedestrian and bicycle fatalities have increased by 79% while other fatalities have increased by 20%. A report by MoDOT examined different roadway segments and ranked them by priority according to the number and severity of pedestrian crashes observed at those locations (Tobias et al., 2022). The researchers found that urbanized 4-legged signalized intersections represented 59% of fatal pedestrian crashes, 65% of serious injury crashes, and 67% of all pedestrian crashes. The report identifies several countermeasures that may aid in reducing VRU crashes. These can be broadly categorized into education and outreach efforts, enhancing crosswalk safety and infrastructure, and changes to policies and design. Examples of enhancements to crosswalks include additional overhead lighting, high visibility crosswalk striping, changes to signal timing, alternative signal types, and construction of refuge islands in midblock crosswalks. Policy and design change examples include reducing speed limits, narrowing of lanes, road diets, and curb extensions. The researchers found that nearly all the high priority road segment categories had the potential for these countermeasures. Reports from federal agencies also include these same countermeasure recommendations for reducing VRU fatalities.

MoDOT had developed an action plan for implementing pedestrian countermeasures (MoDOT, 2021). This action plan was developed in conjunction with FHWA's Every Day Counts (EDC) Round 5 effort of Safe Transportation for Every Pedestrian (STEP) initiative. Several key recommendations resulted from the STEP initiative. Some of these recommendations include tracking the effectiveness of policies, projects, and programs, identifying critical corridors and hotspots, providing guidance for the installation of crosswalks, and incorporating STEP recommendations into the project development process.

This current report builds upon previous efforts on pedestrian safety in Missouri by considering other types of VRUs. The planning process documented in this report seeks to bring down VRU deaths and injuries as consistent with a vision towards zero fatalities by 2030. A data-driven approach was undertaken to focus on the most vulnerable users and to target the most effective countermeasures. This report is an initial Vulnerable Road User Safety Assessment for Missouri as described in 23 U.S.C. §148(1). The report is part of Missouri's Strategic Highway Safety Plan, currently named the Show-Me Zero Plan.

2. LITERATURE REVIEW

This chapter discusses literature that is the most directly on point with respect to VRU safety. The chapter is divided into two major sections. The first concerns the most up-to-date examples of VRU safety assessment since the federal guidance was issued in October, 2022 (Walker, 2022). Illustrative examples are presented from Texas, Iowa, and North Carolina. The second broadly concerns the current research on VRU, broadly. This section is further subdivided into the areas of risk, behavior, alcohol, facilities, countermeasures, information, medical, policy, and technology. These areas are not mutually exclusive but were used as an organizational tool to summarize current research. There is also a large body of literature specific to pedestrian safety and to a lesser extent, bicycle safety. In Missouri, for example, there were recent reports such as the MoDOT pedestrian countermeasures report (Tobias et al., 2022) and the Missouri STEP action plan (MoDOT, 2021). The scope of the present research focuses on VRU, so an extensive literature review of the individual modes of walking, bicycling, wheeling, and rolling was not undertaken.

State VRU Safety Assessment Examples

The most current information concerning VRU safety assessment involves the efforts undertaken by other states to comply with the FHWA requirements for a VRU safety plan. In a FHWA (2023a) webinar conducted on April 3, three states discussed their approaches: Texas, Iowa, and North Carolina[1].

Texas Department of Transportation (TxDOT)

Leticia Estavillo, TxDOT, and Carl Seifort, Jacobs, presented on the TxDOT approach. The approach for VRU safety parallels the one employed in developing the Pedestrian Safety Action Plan in Texas. Figure 2-1 illustrates the TxDOT combined approach. The approach combines two types of analysis. One involves systemic safety analysis. The other involves targeted or hot-spot analysis of specific facilities. Risk factors were identified for analyzing facilities. They employed 32 pedestrian crash risk factors that may or may not be a contributing circumstance. For freeways, they identified 20 risk factors. A sliding windows technique was used to analyze rural versus urban segments, longer segments were used for rural as compared to urban. Segments were analyzed separately within peer groups since rural and urban segments have different characteristics. Crash densities were developed for various facilities.

[1] Permission was secured from all FHWA seminar speakers for the figures cited from the webinar. The email permissions are on file with the authors.

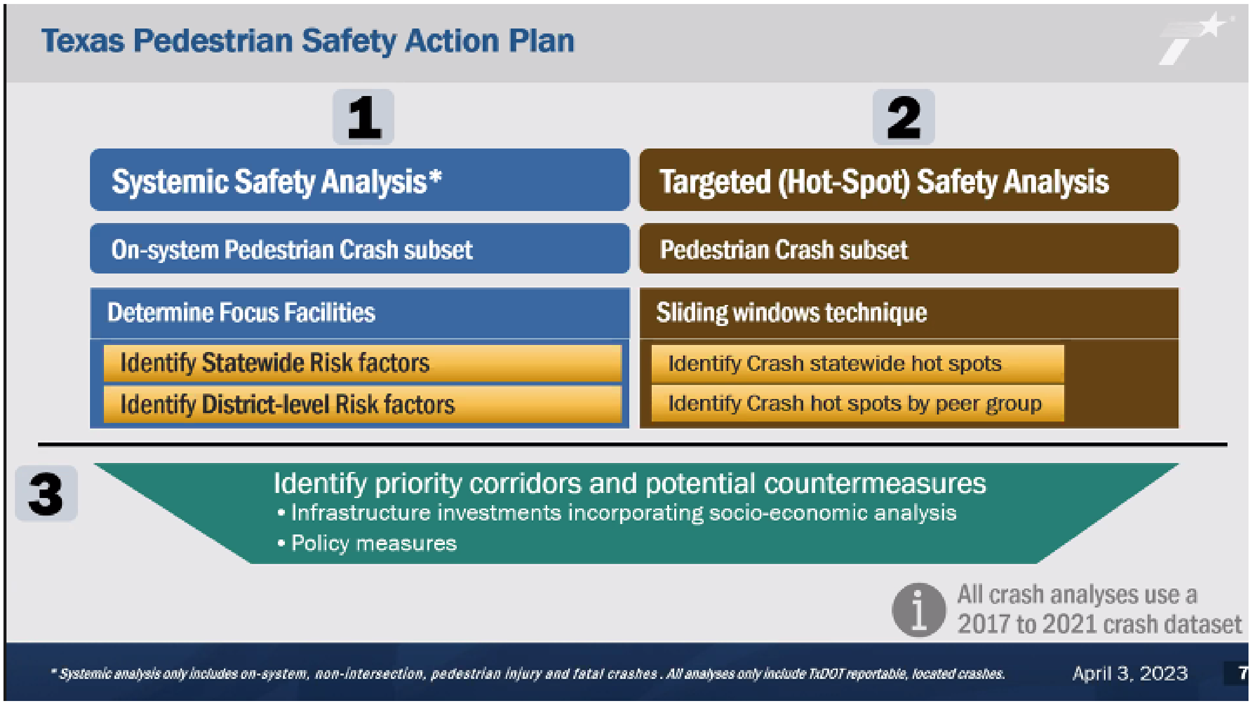


Figure 2-1 Combined Pedestrian Safety Approach (FHWA, 2023a)

TxDOT investigated social-economic factors in pedestrian safety. For equity data, they used the Social Vulnerability Index from the Centers for Disease Control. The index includes a number of factors, including poverty, lack of access to transportation, and crowded housing. The countermeasures they considered were consistent with their Highway Safety Improvement Plan. They focused on countermeasures with documented crash modification factors.

Iowa Department of Transportation (IDOT)

Sam Sturtz, a planner with the IDOT, presented on the Iowa approach. They employed the method documented in the National Cooperative Highway Research Program (NCHRP) (2018), Systemic Pedestrian Safety Analysis, to correlate high risk road features with crashes. They combined three main data sources: crash, intersection, and roadway data. The software tools they used include ArcGIS and SQL Developer. The intersection attributes they examined include AADT, intersection angle, intersection type, number of lanes, number of legs, speed limit, and traffic control. The segment attributes they examined include AADT, median type, number of lanes, parking type, shoulder rumble, shoulder type, shoulder width, and speed limit. To treat attributes simultaneously, they used a composite scoring system. They normalized each attribute based on the number of crashes and the associated mileage. A weighting multiplier was then used to combine various attributes together.

They found that even though bicycling and walking accounts for 4% of travel, they account for 7% of the fatalities and injuries. So bicyclists and pedestrians are overrepresented with respect to serious crashes. The demographic information employed was from the American Community Survey (ACS). The ACS is an annual estimate of social, economic, and housing characteristics conducted by the Census Bureau. For consultation, they leveraged existing agencies and opportunities. These include metropolitan planning organizations and regional planning agencies which meet on a quarterly basis. They also include bicycle and pedestrian committee meetings.

In terms of countermeasures, they developed strategies instead of specific projects. From these strategies, projects can then be implemented at the local level. Figure 2-2 shows an example of a countermeasure strategy matrix for urban and suburban facilities. The figure shows recommendations for various bicycle facilities based on vehicular traffic and speed. The countermeasures range from shared lanes and bike boulevards for low volume and low speed facilities to separated bike lanes, multi-use trails, and sidepaths for high volume and high-speed facilities.

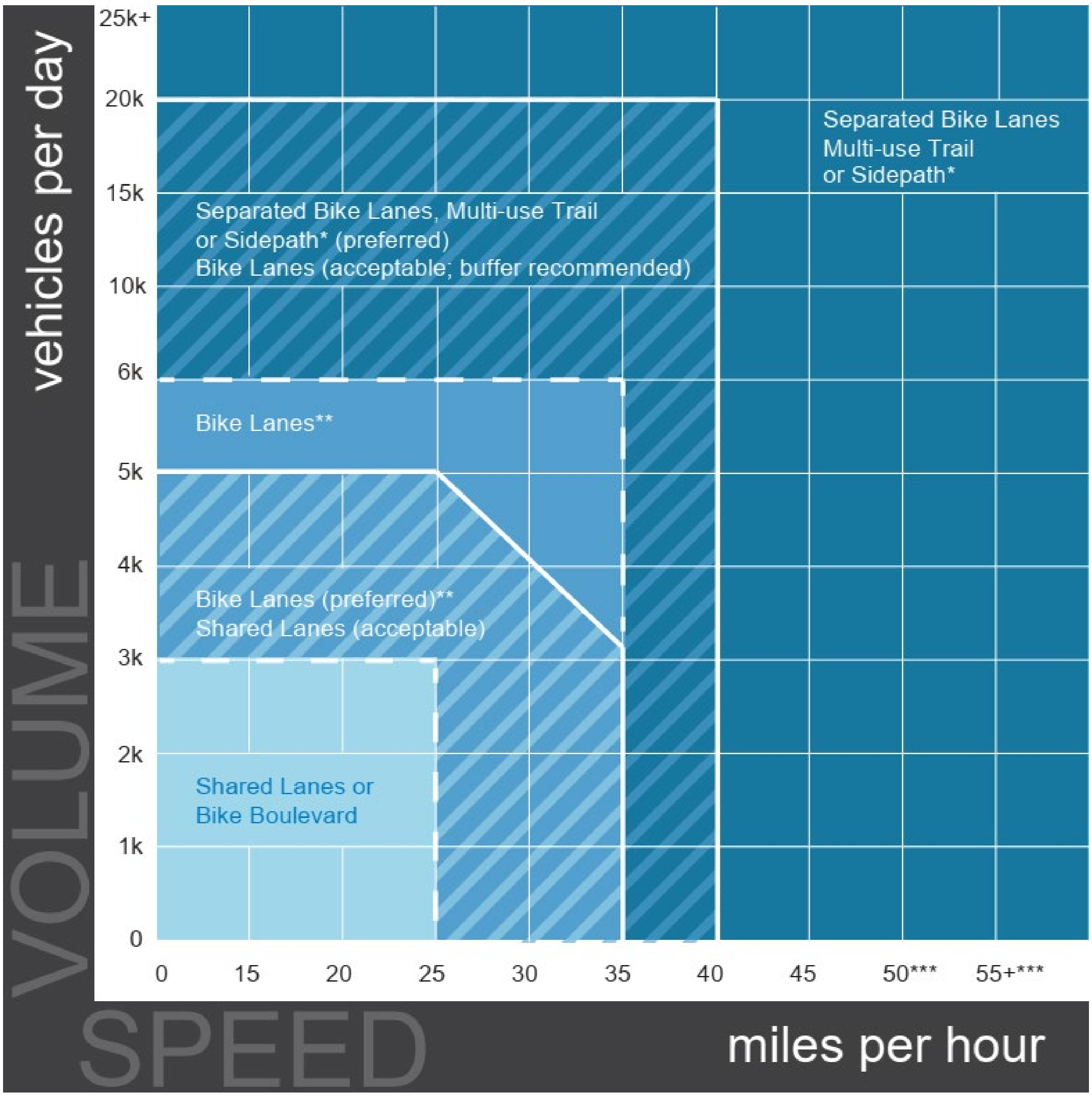


Figure 2-2 Urban and Suburban Facility Selection Matrix (FHWA, 2023a)

North Carolina Department of Transportation (NCDOT)

NCDOT's state traffic engineer, Bryan Mayhew, presented on the NCDOT approach. Their approach is arguably the most extensive of the three states that presented at the webinar. Some notable aspects of NCDOT approach include their deep dive into 600 crash reports by reviewing the crash narrative and location to search comprehensively for crash factors. Figure 2-3 is an example of a graphic summarizing the results from the crash factor analysis. They examined factors such as signalization, density, vehicle size, proximity to home, building set back distance, left-turns, struck from behind incidents, and commercial areas.

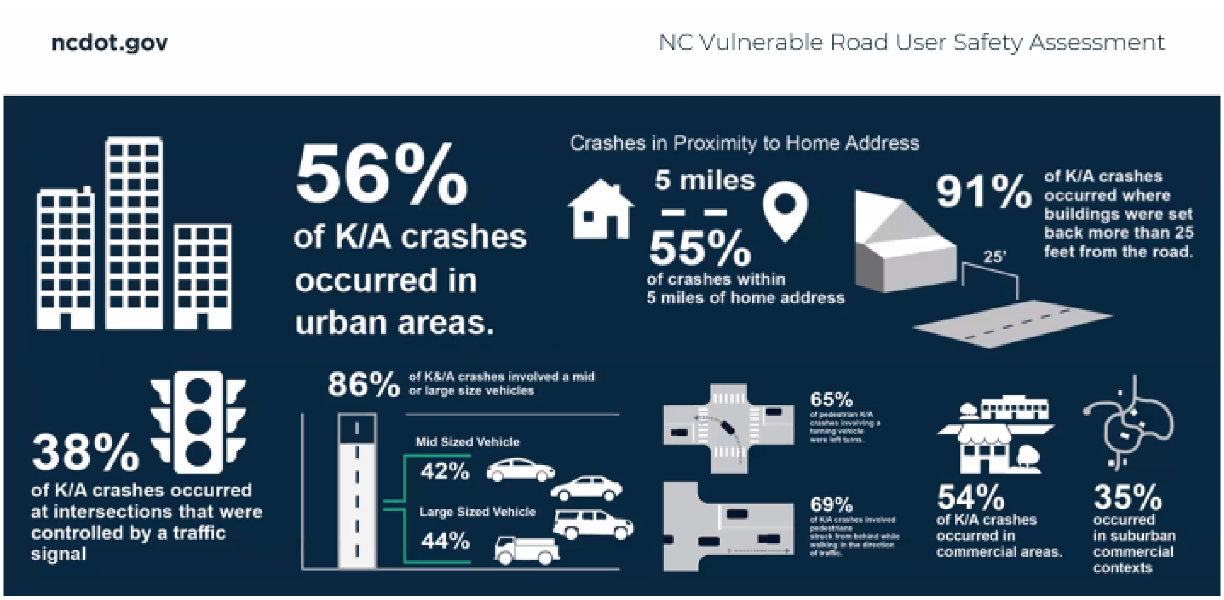


Figure 2-3 Example of NCDOT Summary Graphic on Crash Factors (FHWA, 2023)

NCDOT consulted with 19 metropolitan planning organizations (MPOs) and 18 regional planning organizations (RPOs). Figure 2-4 shows an example of a customized dashboard for each MPO or RPO where various statistics are presented such as annual pedestrian and bicycle crashes, the most common crash types by mode, and aggregated crash severity by mode.

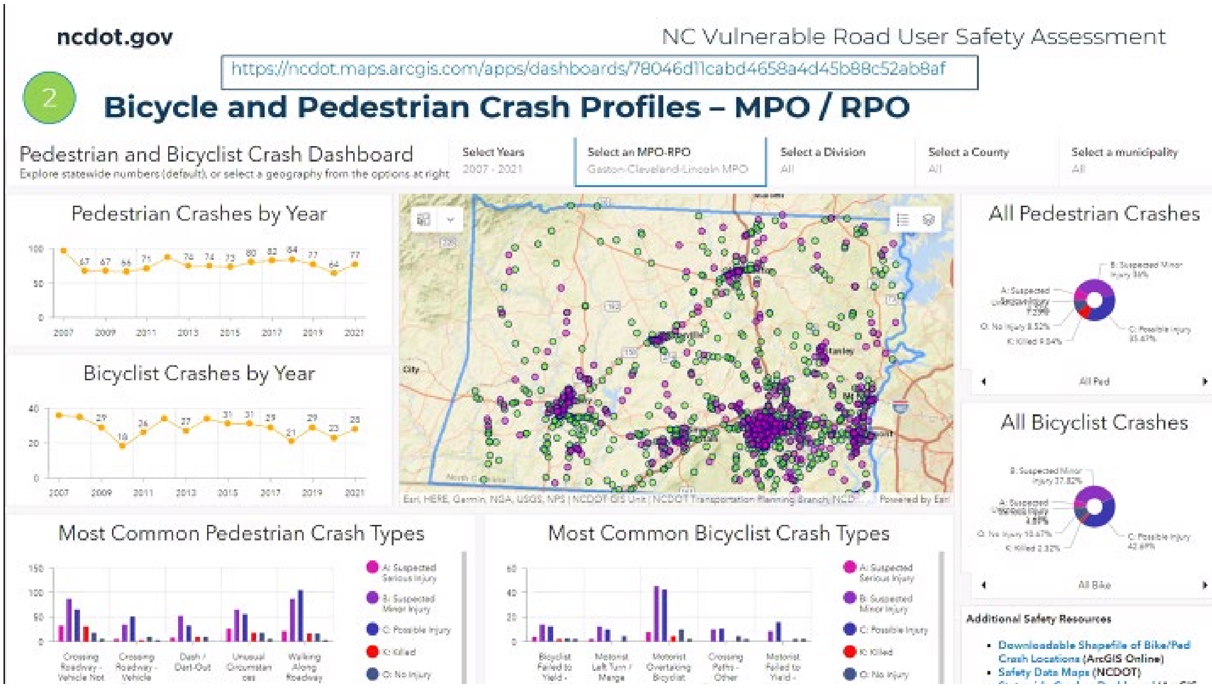


Figure 2-4 Example of a NCDOT Dashboard for Planning Organizations (FHWA, 2023)

The NCDOT pedestrian safety improvement program involves three types of analysis. The first is an area-based one and includes systemic, risk-based, corridor, and hot spot analysis. The second is focused on corridors and involves two focus areas: risk and crash, and multi-modal. The third is a responsive analysis based on crash data and is reactive. Figure 2-5 shows an example of a high-risk network screening produced for the Wilmington area. The top-down risk-based analysis progresses downward with the following steps: network screening/systemic analysis, historical crashes, pedestrian exposure/activity, and socioeconomic/equity factors.

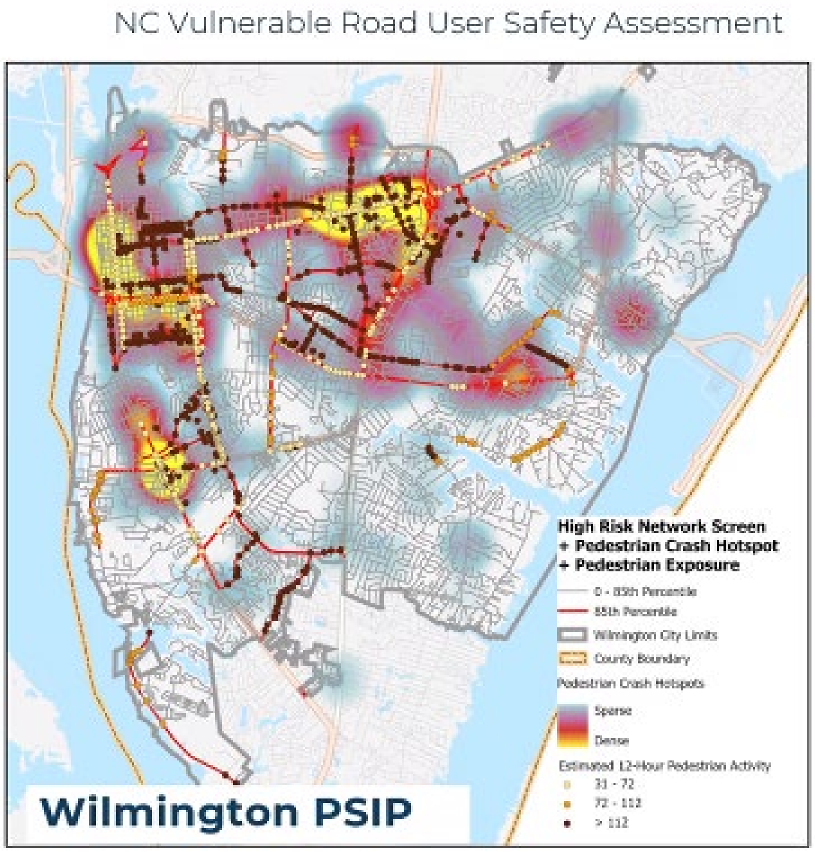


Figure 2-5 Example of Vulnerable Road User Safety Assessment for an Area (FHWA, 2023)

The following are some miscellaneous findings from NCDOT. Urban arterials always standout in terms of having higher risk. Good Samaritans or good neighbors involved in post-crash care account for 7% of the fatalities. There are mental-health-related incidents involving suicides such as when a person lays across a road. These miscellaneous findings are difficult to discover unless a deep dive is performed on the original crash reports.

The current report tracks closely with the aforementioned efforts from Texas, Iowa, and North Carolina. One reason for the close compatibility is because states are faced with the same federal due date of November 15, 2023. Therefore, there is only a small time window to develop a state VRU safety plan. Another is because of the challenges faced in planning for VRU safety. Unlike vehicular demand data, VRU demand data is much less available. Thus, one critical type of data is missing from performing statistical analysis. A fundamental independent variable in all HSM models is AADT, and the equivalent variable is not available for VRUs. Thus, all states are limited by the same data challenges which results in all states using similar methodologies. The consistent approach is to use the two-pronged approaches of systemic analysis and high-crash location analysis.

Other VRU Safety Literature

Literature on VRU crashes is also found to a large extent in research publications. The research literature includes journals, conference proceedings, and books. The audience is typically academics (i.e., students and faculty), although some journals (e.g., Transportation Research Record), also target professionals. Because of the emphasis on research, much of the literature is focused on futuristic technologies that might not see implementation in the near future. Despite the lack of immediate applicability, it is useful to anticipate future adoptions in order to coordinate with present efforts. Some future technologies, such as connected and autonomous vehicles, are expected to disrupt VRU safety by providing a large decrease in crash reduction. In presenting the state of research, the most relevant are presented first. The literature were organized by various categories to facilitate this review although some studies spanned multiple categories. The categories are risk, behavior, alcohol, facilities, countermeasures, information, medical, policy, and technology. It is the aim of this literature review to illustrate similarities and differences between the focus of research and the current priorities and countermeasure recommendations of policy makers like MoDOT and federal agencies. Note that some sources in this review consider motorcyclist to be a VRU whereas they are generally excluded in this report to be consistent with the FHWA definition of a VRU.

Risk Factor and Behavioral Studies

Several studies focused on the risk factors involved with VRU crashes or study the behavior of drivers and/or VRUs. In a broad overview of articles on behavior studies, Van Haperen et. al. (2019) reviewed previous behavioral studies involving 600 journal articles. They found the majority focused on car drivers (81%). VRUs were involved in 32% of articles. The most common types of VRUs addressed were pedestrians and bicyclists. In terms of the goal of the articles, 51% focused on monitoring behavior, 38% on safety improvement measures, and 10% on behavioral modeling. Other studies applied statistical techniques to identify factors that disproportionally affect VRUs. Cai et al. (2017) explored the use of various exogenous factors on non-motorist crashes. They used Florida data and performed joint negative binomial and logit modeling. They then used the method to identify three different hot zones: more dangerous driving environment, more hazardous walking and cycling environment, and both. Vilaca et al. (2017) performed statistical analysis on VRU data from Aveiro, Portugal, from 2012 to 2015. They found the variables that contributed to VRU crashes include meteorological conditions, proximity to crosswalk, and gender. They predicted that the crash risk increased by 2.7 times on urban street segments, by 10.6 times at pedestrian crosswalks, and by 3.5 times for females.

Expanding further, VRU injuries and fatalities may be shifting to an older demographic. The median age for VRU fatalities has increased from 26 in 1980 to 48 in 2019, while the median age in the US increased from 30 to 38. NHTSA finds that the pedestrian fatality rate from 1980 to 2019 is the highest in the 70+ age group for most of the years (NHTSA, 2021). However, the behavior of older drivers may still be worth considering. Ranachet et al. (2022) investigated the effect of aging on VRU detection. They found that VRU detection decreased with aging. The older-old adults, compensated for visual decline by doing more visual exploration. Further, helmet laws across the US are not consistent when it comes to age. While helmet usage can reduce risk of head injury by 60%, no state law requires adults to wear bicycle helmets.

However, in 21 states and Washington DC, young bike riders are required to wear a helmet (NSC, 2018). Between 1980 and 2019, nationwide bicyclist fatality rates decreased dramatically for ages less than 20 (NHTSA, 2021). Torfs and Meesmann (2019) examined the safety culture of VRUs via an E-survey of Road User Attitudes (ESRA). The data involved 25 European Union countries. They found that VRUs reported more crashes and felt less safe than car drivers. A pedestrian's feeling of safety is inversely correlated with headphone usage, while a cyclist's feeling of safety is inversely correlated with helmet use. NTSB recommends to all 50 states that it be required for bicyclists to wear an age-appropriate helmet while riding (NTSB, 2019).

Wang et al. (2022) investigated VRU crashes involving commercial trucks. They used North Carolina data from 2007 to 2019 and Tennessee data from 2009 to 2019. They examined the socio-demographics of both VRUs and truck drivers, temporal and weather effects, and environmental conditions. They found that crashes involving VRU and trucks occur most often on private property and parking areas, and they tend to be more severe than other crashes. They also found midblock crashes to result in more severe injuries. Schindler and Bianchi (2021) examined VRU crashes in Europe which amount to around 7600 fatalities annually. Crashes are especially severe when involving commercial trucks. The two most frequent crash scenarios are when (1) a truck turns right at an intersection and hits a cyclist riding parallel and going straight and (2) a pedestrian crosses in front of a truck in a perpendicular direction. The authors compare truck driving behavior on a test track and noted significantly different behavior with and without a pedestrian on the scene. On the topic of solutions, Charlebois et. al. (2019) investigated various technologies designed to warn truck drivers of nearby VRUs. The researchers tested ultrasonic technologies, radar, 360-degree video cameras, smart cameras, and a combination of these systems. They found that current VRU warning systems may not be sufficient to fully address the risks and no single system could warn the driver in time.

Komol et al. (2021) used various statistical and machine learning techniques to estimate VRU injury severity using data from Queensland, Australia, from 2013 to 2019. The study found that motorcyclists have the highest crash severity followed by pedestrians and then bicyclists. Yuan et al. (2022) considered risky VRU behaviors such as non-use of crosswalks, violation of traffic signals, riding against traffic, and stepping into highways. They performed statistical analysis of VRU crash data from China. Johnsson et al. (2018) examined surrogate safety indicators to complement crash data analysis. They approached each measure from various perspectives such as the initial conditions of an event, the magnitude of evasive action, and the injury risk. They found that no existing indicator captures all aspects of a traffic event. Sun et al. (2022) investigated how VRU crashes differed among the seasons. They used a hybrid random parameter logit with Bayesian network to associate injury severity and explanatory attributes. They found that there were significant differences across the seasons related to the factors of physical isolation, crash type, and motor vehicle type. Bassani et al. (2020) performed spatial analysis of VRU crash data from Turin, Italy, for 2006-2016. They used Geographical Information Systems and cluster analysis to find high concentrations of VRU crashes. They found large number of VRU crashes occurred at intersections especially along high traffic flow corridors. These risk studies painted a picture of VRU crashes such as the greater risk involved with pedestrians and the high occurrence of VRU crashes at intersections.

Another category of literature is focused on addressing specific facilities. This is intuitive since certain facilities have greater rates of VRU crashes. Muslim and Antona-Makoshi (2022) focused on VRU crashes on limited-access highways. Even though such facilities cater to high-speed vehicular movements and limit access, frequent VRU crashes still occur. The authors identified typical crash patterns involving occupants of crashed or disabled vehicles, people helping others, work zones, and law enforcement stops. Qian et al. (2022) tackled signalized intersections. The authors analyzed California crash data and discussed potential countermeasures. Specifically, they examined blind spot detection, VRU beacon systems, and ped/bike to vehicle communication. Lo and Huang (2015) also focused on signalized intersections. They studied the problem where pedestrians cannot cross safely within the allocated green time due to reduced mobility or a lack of awareness of the green light termination. They used data from Taipei, Taiwan, and VISSIM microsimulation. They also studied the use of bus preemption to minimize delay. Vu et al. (2021) focused on overtaking maneuvers on urban shoulders. They examined certain factors such as vehicle speed, lane width, VRU type, and location in the shoulder. They conducted a driving simulator experiment and identified two noticeable groups: overcautious drivers and aggressive drivers. The review illustrated the fact that different types of facilities result in different VRU risks with intersections being especially notable.

Using the knowledge or risk factors, behavioral factors, and facilities that see a greater rate of VRU crashes, MoDOT's Safety Action Plan recommends countermeasures that may be implemented to reduce pedestrian crash rates. As part of FHWA's Safe Transportation for Every Pedestrian (STEP) initiative, MoDOT has developed a Safety Action Plan to recommend actions to reduce pedestrian crashes and fatalities on Missouri highways and local roads. Nationally, uncontrolled pedestrian crossing locations often correspond to higher pedestrian crash rates compared to controlled locations. This is often due to a lack of pedestrian crossing accommodations (MoDOT, 2021). The Plan recommends a comprehensive analysis effort to identify locations with high pedestrian crash rates and great need for countermeasures. This includes both an individual location crash analysis to map pedestrian crashes and proactively identify hotspots, and a system-wide analysis using detailed data, demographics, and testing for drug and alcohol usage. Engineering studies that examine driver approach speeds, volumes, yielding, roadway configuration, and sight distances is also recommended. Effective street designs for pedestrian safety may be highly context-dependent, and NTSB (2018) recommends they be handled by local interests. However, these local planners may benefit from comprehensive and localized pedestrian data to support the process.

Countermeasures

The Safety Action Plan also lays out its recommended countermeasures that include upstream stop/yield signage and markings, additional overhead lighting, high-visibility markings, and restrictions to parking on the crosswalk approach. MoDOT also mentions investigating alternative crosswalk warning systems like the Rectangular Rapid Flashing Beacon (RRFB) and Pedestrian Hybrid Beacon (PHB). The STEP initiative is part of the greater Every Day Counts (EDC) model, developed by FHWA and AASHTO. The model facilitates greater efficiency at state and local levels by identifying and rapidly deploying proven but underutilized innovations. Innovations to improve the safety of VRUs are chosen based on safety benefits, ease of adoption, and market readiness (MoDOT, 2021). Both state and federal agencies involved in improving

VRU safety value solutions that may be implemented with relative ease and efficiency, which coincides with the previously mentioned examples of crosswalk improvements, changes to road design, and education programs.

Countermeasures that are explored in the academic literature range from the type that can be considered "ready-to-implement" to futuristic technologies, such as autonomous vehicles, vehicle-to-everything (V2X) communications, and machine learning. This section will focus on the countermeasures that are ready-to-implement. Roge et al. (2014) considered ways of improving truck driver situational awareness of VRUs. There is potential that the addition of aerodynamic front sections, addition of extra window apertures, and the lowering of the vehicle could help improve the detection of VRUs near trucks. The volume of space visible to drivers was analyzed using digital human modeling. Wu (2020) investigated the use of Driver Feedback Signs (DFS). Because these signs are deployed at a single point on the roadway, the location and the allocation of the signs throughout a city are important considerations. The authors proposed certain benchmarking criteria for a citywide DFS framework. Tasic et al. (2017) examined the concept of "Safety in Numbers," meaning that the number of crashes increases at a lower rate than the number of VRUs. In terms of countermeasures, this concept seems to promote multimodal transportation improvements involving the modes of walking, biking, and public transit. The authors showed the effect of "Safety in Numbers" using performance measures from Chicago. Inputs such as trip generation, multimodal infrastructure, network connectivity and completeness, and accessibility were used to model exposure in terms of number of trips, trip length, travel opportunities, and conflicts. Scholliers et al. (2016) studied ten different VRU countermeasures in the European Union. The authors produced quantitative estimates of safety, mobility, and comfort impacts. The resulting benefit cost ratios seem to favor countermeasures based on communications between VRUs and vehicles such as INS, PTW2V, VBS, and B2V. Table 2-1 and Table 2-2 summarize the various countermeasures and B/C ratios. As previously discussed, the vast majority of research countermeasure literature focus on emerging technologies that are the main focus of the present report. Information on these countermeasures may serve as an aid to state and federal agencies, including FHWA and AASHTO that developed EDC, to make an informed decision as to which technologies will be propelled in the future.

Table 2-1 Countermeasures Descriptions (Scholliers et al. 2016)

Countermeasure	Description
INS	Cooperative Intersection Safety – roadside unit detects VRUs and warns road users
PTW2V	PTW (powered two wheelers) oncoming vehicle information system – PTW and cars exchange messages
VBS	VRU Beacon System – VRU tag broadcasts to drivers
CAL	Crossing Adaptive Lighting
B2V	Bicycle to Car Communications – cyclists and cars exchange messages
GWC	Green Wave for Cyclists – system provides speed advice to cyclists
IVB	Information on Vacancy on Bicycle Racks
IPT	Intelligent Pedestrian Traffic Signal – signal detects pedestrians, predict trajectories, and requests priority green light
BSD	Blind Spot Detection
PCDS+EBR	Pedestrian & Cyclist Detection System + Emergency Braking

Table 2-2 B/C for Countermeasures (Scholliers et al. 2016)

	INS	PTW2V	VBS	CAL	B2V	GWC	IVB	IPT	BSD	PCDS+EBR
B/C	7.9	20	2.6	1.8	4.8	1.5	-0.1	0.5	0.2	0.3

As with the academic literature, countermeasures discussed in state and federal reports may pertain to infrastructure changes, education, or policy changes. Beyond the previously mentioned countermeasures regarding infrastructure (e.g. crosswalk lighting, high-visibility markings, alternative crosswalk signage, etc.), there are more countermeasures that pertain to bicycles specifically. 45% of all midblock fatalities were due to a motorist overtaking the bicycle. Bicycle crash severity is also higher in the midblock as travel speeds of vehicles tend to be higher than at intersections with traffic lights, stop signs, and turning vehicles. Separating bicyclists using bike lanes from the midblock may reduce the likelihood of serious or fatal injury. Further, a road diet can reduce speeds and provides space on a roadway for implementation of these bicycle facilities. Installation of separated bike lanes could also increase bicycle ridership and bicyclist compliance with intersection rules. Regarding intersections, infrastructure improvements such as a bicycle signal phase, bicycle box, or two-stage bicycle turn box may add additional safety at intersections for bicyclists (NTSB, 2019).

Education

Aside from countermeasures like improvements to infrastructure and vehicles, state and federal agencies also developed suggestions for education programs. MoDOT recommends that education be targeted in high pedestrian crash locations or corridors, and should employ a positive approach, not fear-based. Regarding its content, education should cover walking facing traffic when the sidewalk is not available and avoiding walking on the roadway when a sidewalk is available (Tobias et. al., 2022). Similarly, bicycling on the side facing traffic may also be worth emphasizing. NHTSA reports that about a third of bicyclists died in crashes involving a motor vehicle overtaking a bicycle, where the motorist reported not detecting the bicycle before the crash. In addition, wearing bright and reflective clothing or attaching lights or reflectors onto the bicycle may also be effective countermeasures, as 45% of bicyclist fatalities occur in dark conditions whereas fewer than 20% of bicycle trips take place at night (NTSB, 2019). As mentioned previously, there is a strong recommendation for helmet usage.

Policy

A robust public education program may be a step towards establishing a public safety culture. As described in a FHWA report, a public safety culture is a system in which states or communities have citizens who understand the risks associated with transportation and choose to make safe choices when using the transportation system. Road users with a strong safety culture use safety devices available to them, such as seat belts and helmets, obey traffic laws, limit distractions, and refrain from using roads when impaired. The public safety culture is explained in FHWA's Safe System approach (FHWA, 2022). The Safe System approach is founded on six major principles: deaths and serious injuries are unacceptable, humans make mistakes, humans are vulnerable, responsibility is shared, safety is proactive, and redundancy is crucial. The approach revolves around anticipating human mistakes by designing and managing road infrastructure to keep the risk of mistakes low. The Safe System approach is holistic, and the public safety culture aspect is coupled with an organizational safety culture in which every organization should value and pursue safety, keep safety in mind during planning, scoping, designing, and constructing infrastructure, and regularly communicating the importance of road safety. FHWA notes that the Safe System approach has reduced traffic fatalities by 68.5%, 57.6%, and 47.3% in Norway, France, and Sweden, respectively, from 2000 to 2019. Within this time, the United States has reduced its own fatalities by 5.6%.

NSC recommends setting speed limits using a Safe System approach, coupled with stronger speed limit enforcement and infrastructure measures like roundabouts and speed bumps. A report (NSC, 2018) notes that New York City was successful in reducing pedestrian fatalities through policy changes that included reducing the city's default speed limit and increasing enforcement of speeding laws. It has been shown that speed is usually the determining factor in the outcome of crashes involving pedestrians. Pedestrians struck at 20 mph have a 90% chance of survival whereas pedestrians struck at 40 mph have a 20% chance of survival (MoDOT, 2022). Additionally, an NTSB report notes that alternative means for setting speed limits are available, that incorporate crash history and the presence of VRUs, instead of using 85^{th} percentile speed limit. Lowering injury risk for VRUs by lowering speed limits is often difficult because state transportation department policies currently emphasize the use of the 85^{th} percentile speed limit (NTSB, 2017).

Additional studies on policy are present in the academic literature, which address general goals and directions that the public government should pursue to improve VRU safety. Klanjcic et al. (2022) analyzed the KSI indicator (killed or seriously injured) from 24 European Vision Zero cities in 5 countries. They found that cities with the most pedestrian and bicyclist mode shares are the safest. They also found that a large percentage of low-speed roads significantly reduces car-occupant injuries. Their policy recommendation is to increase pedestrian and bicyclist mode shares to improve safety for all. Chang et al. (2022) investigated VRU safety as part of transportation asset management (TAM). They propose a policy of incorporating VRU safety into TAM decision-making. Their method involves the use of a safety-weighted effectiveness ratio for TAM. Some factors considered were asset importance, location, pedestrian safety risk, costs, and remaining life in the budget allocation process. Ptak (2019) studied VRU statistics and legislations in Europe. They analyzed biomechanics and kinematics data. The authors advocate for the use of numerical method for making policy decisions especially with regards to reducing VRU head injuries. Gupta and Bandyopadhyay (2020) performed meta-analysis for 18 VRU safety studies for low-income countries. They found no evidence that road engineering interventions reduced fatal or injury crashes. But they did find that mandatory helmet law, automated enforcement systems, and pedestrian signal interventions were effective for increasing safety law compliance. The study found evidence that daytime running-headlights did reduce crash injuries. Hammond and Musselwhite (2013) researched the concept of attitudes and usability in urban shared space. Shared space refers to design that encourages pedestrians, bicyclists, and vehicles to use the same deregulated space. They used accessibility audits, focus groups, and surveys. They found very positive attitudes towards shared space but VRUs had concerns with design and usability. Khayesi (2020) focused on the effects of transportation planning on VRU safety. They found that, often, planning is more focused on motorized transportation instead of VRUs, including the elderly and disabled. They advocate for addressing the root cause of vulnerability in planning. Cabarkapa (2020) examined VRU safety in the European Union and in developing and underdeveloped countries. They advocate for the use of inclusive road infrastructure safety management policies at all stages of the infrastructure life cycle, including planning, design, and construction. The policy literature addressed various issues such as the effect of mode share on safety, TAM, and the inclusion of VRU safety into the entire project process. Many of these studies were from non-U.S. countries, so it is difficult to know how well they might translate to the U.S.

Medical

In examining trends in VRU crash data, it is important to acknowledge the medical aspect of VRU crashes. Where injuries and fatalities are involved, there are medical data that may be useful in supplementing the existing crash data. NTSB reports that current crash data likely underestimates that level of bicycling activity in the US and police crash report data likely underestimates the scope of bicyclist nonfatal injuries (NTSB, 2019). As mentioned previously, localized data can support the decision-making process for VRU safety related infrastructure projects. A statewide system of linking state police crash reports to hospital intake and emergency room medical records may facilitate the development of countermeasures to reduce VRU crash rates and crash severity (NTSB, 2018).

Various studies focus on medical aspects of VRU safety. Tee et al. (2021) analyzed the existence of the “cushion effect” in VRUs who are involved with serious blunt abdominal injuries. The effect comes from the fat distribution. The study examined 592 VRUs using computed tomography imaging and utilized the subcutaneous fat ratio measure to control for the total body area. The study found that the “cushion effect” does exist. Radjou and Kumar (2018) reviewed the global VRU motor vehicle crash statistics that up to 50% of global traffic fatalities involve VRUs and up to 80% of the developing country traffic fatalities involve VRUs. The authors reviewed 193 fatalities from Puducherry, India, and found that 80% of traffic fatalities involved VRUs, the elderly were overrepresented, head injury was the most common cause of death, and early death, those occurring within 24 hours of injury, occurred for 50% of the cases. Wang et al. (2021) probed the use of common head injury criteria (HIC) for predicting actual VRU head injuries in traffic crashes. The authors performed detailed reconstruction of 31 head injury cases using finite element multibody pedestrian modeling. They found that kinematics-based injury criteria can accurately predict head injury. Shi et al. (2020) assessed the effectiveness of using head injury criteria and other measures to predict VRU severe head injuries caused by ground impact in traffic crashes. The authors found that angular acceleration, linear acceleration, head injury criteria, coup pressure, countercoup pressure, maximum principal strain, and cumulative strain damage measure correctly predicted actual injuries. Wu et al. (2021) analyzed the greater risk of injury and death of elderly (> 60 years old) VRUs as compared to the young. They examined 30 cases using detailed injury records and video. They used kinematic predictors such as linear acceleration, angular velocity, angular acceleration, and head injury criteria. They showed that calculated thresholds for head injury for the kinematic criteria were lower than previously reported. Devlin et al. (2019) investigated the level of recovery of VRUs after a traffic crash. They used a dataset of 6186 VRU patients over 8 years. They analyzed the patient-reported outcomes at 6 and 12 months after injury. They found that pedestrians have poorer outcomes compared to cyclists. Kisitu et. al. (2016) studied musculoskeletal injuries due to traffic crashes. They used data from Ugandan district hospitals from October 2013 to January 2014. They found that VRUs comprised 92% of all the musculoskeletal patients. They also found that 49% were pedestrians, 41% motorcyclists, and 2% cyclists. The medical studies analyzed the cushion effect, use of the HIC, elderly VRUs, injury recovery, and musculoskeletal injuries. Some of these studies point to the long-term consequences of VRU crashes.

Technology

The largest category of research in VRU safety involves the investigation of emerging technologies. The potential benefits of such technologies are expected to be great; however, much of the academic literature in this area focuses on vehicular and personal technologies which are the domain of vehicle and equipment manufacturers. The public agency with the most influence over this area is the National Highway Traffic Safety Administration which can promulgate motor vehicle safety standards. State departments of transportation have much less influence over vehicle and equipment manufacturers. The involvement of government agencies may be more along the funding side, as in the past 20 years, USDOT has invested over $700 million in research and development of V2X technology through partnerships with industry and state/local governments (NHTSA, 2020). However, implementation of these emerging technologies may not be a current priority of policy makers. MoDOT's Show-Me Zero timeline places policy changes and education plans before smart technologies and autonomous vehicles (MoDOT, 2022). Thus, even though the majority of literature is on technology, only a sampling of literature will be reviewed here. Desanalyaka et al. (2020) reviewed Cooperative Intelligent Transportation System (C-ITS) technology over the period of 2007-2020. They found that the focus has been on unidirectional communication involving VRUs alerting their presence. They advocate for greater use of cellular-based Vehicle-to-VRU (V2VRU) communication systems. Dubey et al. (2021) investigated the use of 77 GHz automotive radar for scanning surroundings and to detect VRUs. They used an integrated Bayesian framework where they tracked VRU's micro-Doppler signatures. Deep learning techniques were used to detect, classify, and track VRUs. Han et al. (2022) examined the use of Advanced Driver Assistance Systems (ADAS) and focused on blind zone VRU detection during right turns. They used the YOLO (You Only Look Once) machine learning technique, monocular camera distance ranging, and an approach-speed related warning system. They were able to achieve an error rate of 4% using an ideal frame rate of 50 frames per second (FPS) at 1920x1080 resolution video. Teixeira et al. (2023) researched the use of the vehicular On-Board Unit (OBU) that integrates inputs from smart city, vehicular, and VRU sources such as cameras, radars, lidars, smartphones, and smartwatches. They investigated the use of various communications medium such as ITS-G5, C-V2X, LTE, and 5G. They demonstrated the potential for the system to predict potential VRU collisions with high accuracy and small delay. Bighashdel and Dubbelman (2019) focused on the complicated problem of predicting pedestrian movements. An element of automated pedestrian collision avoidance with computer vision involves the prediction of pedestrian patterns. The authors reviewed the approaches including pedestrian path prediction methods. As the review showed, much of the academic research addressed highly technical aspects of emerging technologies that were specific to manufacturers. They addressed ITS-related topics such as C-ITS, V2VRU, and ADAS, and the use of machine learning algorithms such as YOLO.

3. VRU ANALYSIS METHODOLOGY

The data-driven analysis methodology is presented in three sections. The section on data types discusses the data used for performing safety analysis. These data include police crash reports, both queried from databases and original forms, roadway data, and hospital data. The section on analysis methodology discusses why predictive methods were not used and the dual approach of systemic and high-crash filtering was used instead. The cross-tabulation statistical technique (also known as contingency table) was used for systemic analysis. The section on countermeasure methodology discusses the use of the Crash Modification Factor (CMF) Clearinghouse along with proven low-cost countermeasures to inform agencies of the effectiveness and suitability of various VRU countermeasures.

Data Types

One type of data used for VRU safety assessment is a police crash report. The Missouri Statewide Traffic Accident Records System (STARS) (2019) standardizes reporting by specifying the Missouri Uniform Crash Report (MUCR). Another type of data is roadway data that contains information on traffic volumes, geometrics, and some land-use information. VRU crash and roadway data was requested for the most recent five-years, 2017-2021, in compliance with federal guidance for amount of data (Walker, 2022). At the start of the project, the 2022 crash data was not yet stable enough to be used and was not used. This five-year period falls across two versions of the MUCR, i.e., pre and post 2019. There were no significant issues in data compatibility across these two versions of the MUCR. One semantic difference was the injury severity of "suspected serious injury" for 2019 versus the previous "disabling injury". For this report, this category of severity was termed "serious injury" across all data years.

The MUCR involves potentially six or more pages that document a particular crash. The information in the report includes general information, location, collision diagram, persons involved in the crash, vehicle descriptions, probable contributing circumstances, and narrative statements. These MUCR reports are completed by the police, submitted to the Missouri State Highway Patrol (MSHP), and stored in databases maintained by MoDOT. The data from individual fields in the report are digitized and stored, and the original report is also stored as an image or a document (pdf) file. Table 3-1 shows the VRU data that was requested from MoDOT.

Table 3-1 Data Queried

Item	Scope	Notes
Crash		
Time frame	Latest 5 years	2017-2021
Party	All VRUs	Nonmotorized crashes only
Details	Comprehensive	All MUCR fields from the crash such as general crash information, location, damage, pedestrian, and driver/vehicle.
Geometric		
Roadway	Crash location	Number of lanes, divided/undivided, population density, signalized/unsignalized.

Table 3-2 shows the data fields obtained from MoDOT's Transportation Management System (TMS) for analysis with a brief description. This table contains variables from both the crash database and the roadway database. Not all the fields were used due to the short time frame of the project. The scope of the project was defined by the Technical Advisory Committee (TAC). The TAC had raised the following topics of interest: intersections by population density, number of intersection legs, and signalization; road segments by population density, number of lanes, and divided/undivided; high-crash intersections; high-crash segments; high-crash corridors; equity/low-income; transit; bicycle trails; and light condition. Even though some of the fields in Table 3-2 appear to involve only vehicle, they are actually related to VRU crashes. For example, in a two-vehicle crash, debris could damage nearby pedestrians. especially in cases of secondary crashes where pedestrians are assisting with a primary incident.

Table 3-2 Data Query Fields

HP_ACC_IMAGE_NO	Unique identifier assigned by MSHP for each crash
ACCIDENT_YR	Year
ACCIDENT_DATE	Date
SEVERITY	Crash severity: fatal, serious, minor, Property Damage Only (PDO)
HP_PERSON_INVL_CD	Number of persons involved
MODOT_COUNTY_NM	County
CITY_NAME	City
LANDED_LATITUDE	Latitude
LANDED_LONGITUDE	Longitude
LIGHT_CONDITION	Light condition: daylight, dark-lighted, dark-unlighted, dark-unknown
TRAVELWAY_NAME	Name of travelway
DIRECTION	Direction of travel
Log	Log mile of location on travelway, linearly referenced
ACCIDENT_DAY	Day of the week
ACCIDENT_MONTH	Month
URBAN_RURAL_CLASS	Population density: rural, urban, urbanized
FUNC_CLASS_NAME	Functional classification: interstate, arterial, major collector, minor collector, local
INTERSECTION_NO	Unique intersection number
STATE_SYS_CLS_NAME	If located on the state system
TRAVELWAY_ID	Unique travelway number
WORK_ZONE	If located on a work zone
Alcohol	If alcohol was involved (one of the many contributory circumstances)
Intersection_LOC	Crash location with respect to intersection (before, after, N/A)
TWO_VEH_ANALYSIS	Type of two-vehicle crash: angle, front to rear, sideswipe
CRASH_TRAFFICWAY	Travelway characteristics such as two-way undivided, two-way divided, unprotected median, turn lane
ROAD_ALIGNMENT	Road alignment: straight, curved
WEATHER_COND_1	Weather condition: rain, cloudy, clear
NUMBER_OF_LANES	Number of lanes
DIVIDED_UNDIVIDED	Divided or undivided travelway
TOTAL_AADT	AADT
TW_SPEED_LIMIT_CD	Speed limit
LENGTH	Segment length
SIGNALIZED_FLAG	Signalized or unsignalized
NO_OF_APPRCH_LEGS	Number of approach legs at an intersection
ENTERING_VOLUME	Volume entering intersection

A new type of data being explored for VRU safety assessment is hospital/medical data. There are several reasons for exploring this type of data. First, some VRU crashes are not documented by the police. Hospital data can be used to supplement police reports and to acquire uncaptured events. Second, police reports do not contain information on wheelchairs or rolling modes such as e-scooters or e-skateboards. Third, hospital information could include data on physical impairment depending on the labs performed. Fourth, hospital data provides insights into the injuries sustained by the VRU instead of the very broad categories defined in the MUCR. For example, hospital data contains information on emergency department visits and whether there was a critical consultation undertaken. Such information could potentially assist in the selection of countermeasures.

Table 3-3 shows an example of hospital data from the University of Missouri Hospital which is the Level 1 trauma center in Mid-Missouri. The International Classification of Diseases, 10th Revision (ICD-10) (WHO, 2004) was used for the uniform coding of hospital care. ICD-10 includes detailed codes for transport accidents (V00-V99) and provides information on detailed injury, possible drug and alcohol screening, pre-existing condition, and diagnosis. The sample data covers approximately four years from 07/01/2019 - 04/30/2023. Table 3-3 shows the potential for the use of hospital data to supplement crash reports. The data contains information on various rolling modes uncaptured in crash reports such as skateboards, scooters, wheelchairs, and mobility scooters. Such data could involve other aspects of incidents beyond crashes. For example, there were 68 incidents of falling from a moving wheelchair involving an average age of 56.3. These incidents could involve design features specified in the Public Right-of-Way Accessibility Guidelines (88 FR 53604) such as cross slope and curb ramp dimensions. For wheelchair collisions, the average age was 70.1 which emphasizes safety for the elderly. This initial investigation shows that hospital data has the potential to complement traditional highway safety data sources such as police crash reports and roadway data.

Other health data from Emergency Medical Services or other sources may also provide further information about scenes of injuries which may not be captured in the hospital or crash record. For instance, 16.7% of pedestrian injuries sustained by collision from a vehicle involved alcohol or other intoxicative substances, and 8.6% of all injuries were sustained as a result of a pedestrian outside of a vehicle from a secondary crash or unexpected vehicle inoperability. Data from the medical community appears to have great potential to complement existing sources and to provide greater insights into contributory circumstances and the impact of certain injuries on the long-term health of VRU users. Due to the limitation in the scope of the current project, there was only an initial investigation performed on the feasibility and usefulness of medical data for assessing VRU safety. In the future, further investigations could lead to a pathway for integrating medical data as part of regular VRU safety assessment.

Table 3-3 Example of Hospital VRU Data

Diagnosis Code	Diagnosis Description	#	Ave Age	ICU	Emcy. Dept.	Freq. Injury
V00.131	Fall from skateboard, initial encounter-V00.131A	359	23.9	7	201	Radius (22.6%)
V00.141	Fall from scooter (nonmotorized), initial encounter-V00.141A	182	26.0	6	103	Radius (33.3%)
V00.181	Fall from other rolling-type pedestrian conveyance, init-V00.181A	68	24.2	3	23	Radius (38.2%)
V00.811	Fall from moving wheelchair (powered), initial encounter-V00.811A	68	56.3	0	54	Femur (3%)
V00.812	Wheelchair (powered) colliding w stationary object, init-V00.812A	9	70.1	0	6	Ulnar (33.3%)
V00.831	Fall from motorized mobility scooter, initial encounter-V00.831A	102	32.6	4	65	Radius (13.7%)
V00.832	Motorized mobility scooter colliding w statnry obj, init-V00.832A	7	22.3	1	3	Head/Face (42.9%)
V00.838	Other accident with motorized mobility scooter, init encntr-V00.838A	65	38.8	1	30	Head/Face (24.6%)
V03.10X	Ped on foot injured pick-up truck, pk-up/van in traf, init-V03.10XA	403	37.3	43	113	Intracranial Hemorrhage (28.1%)
V18.0XX	Pedl cyc driver injured in nonclsn trnsp acc nontraf, subs-V18.0XXD	473	33.2	12	240	Radius (18%)
V18.2XXD	Unsp pedl cyclst injured in nonclsn trnsp acc nontraf, init-V18.2XXD	65	25.2	0	0	Head/Face (21.5%)
V18.4XX	Pedl cyc driver injured in nonclsn trnsp acc in traf, init-V18.4XX	33	47.8	2	36	Tibia (21.2%)
V19.3XX	Pedl cyclst (driver) injured in unsp nontraf, subs-V19.3XXD	402	33.8	35	44	Radius (16.9%)
V19.9XX	Pedl cyclst (driver) (passenger) injured in unsp traf, subs-V19.9XXD	455	35.5	25	175	Head/Face (13.4%)

Analysis Methodology

Federal guidance on the identification of high-risk areas allows for several data-driven safety analysis procedures (Walker, 2022, p.9). These procedures include predictive safety analysis, systemic safety analysis, and high injury network analysis. Predictive safety analysis uses a Highway Safety Manual (AASHTO, 2010) approach of forecasting safety performance of VRU facilities. Statistical approaches like predictive modeling rely on a sufficiently large dataset from which an adequate sampling distribution can be developed of the relevant data. In this case, the data consists of the independent variable, VRU crash frequency, and various dependent variables such as VRU volumes, geometrics, and traffic control. Unlike the availability of vehicular data from detectors and third-party location-based data, VRU demand data is scarce. Due to this lack of VRU data, predictive safety analysis is difficult to perform and less reliable than other methods. The research team is not aware of any states who are using the predictive approach for completing the first round of VRU safety assessment. None of the three states who presented at the FHWA VRU Safety Assessment seminar utilized the predictive approach.

Because crashes are random events in the sense that they can occur at unpredictable locations and times, systemic analysis is a way to predict the facilities with the highest risk. Systemic safety analysis is performed by fusing crash with roadway data. The cross-tabulation technique or contingency table was used for performing systemic analysis. Cross tabulation is a general statistical technique that is used in all fields of science, engineering, and health. The goal of cross tabulation is to discover the associations or correlations of variables with each (Momeni et al., 2018). For example, what is the relationship between VRU crashes and population density, intersection type, number of lanes, income, transit, lighting, etc.? Cross tabulation is suitable for use when there are categorical variables. Categorical variables are those variables that have finite discrete values. For example, population density has three possible values of rural, urban, and urbanized. Continuous variables can be categorized. Using the same example, population density thresholds for urban and urbanized are over 5,000 and over 50,000. Categorical data is put into a table where each cell has the value of the frequency of the observations that fit the categories represented by the cell. For example, a specific cell can have the categories of VRU crashes from facilities from urban four-legged signalized intersections. In a contingency table, the relationship (or independence, if looked at negatively) between variables can be tested using a goodness of fit test such as the Chi-Squared test. For conciseness, the details of the statistical testing were not included in this report.

In contrast to systemic analysis, high injury network analysis involves discovering the corridors and locations where the most VRU fatalities and injuries have occurred. This approach is complementary to systemic analysis as it flags specific facilities where there is a high crash history. Because VRU demand data is not readily available, the high-crash history could be due to high VRU demand leading to high exposure, i.e., more opportunities for crashes to occur. Even though it is not certain that the facilities highlighted by the high-crash analysis are high risk, it could be useful for agencies to focus on such facilities due to the high number of crash counts.

Countermeasure Methodology

The state of VRU countermeasure research is much less compared to vehicular countermeasures. One reason is the lack of VRU-related data that is necessary for the development of adequate statistical models. As previously discussed in the context of predicting safety methods for VRU analysis, VRU demand data, such as VRU volumes, are not available either individually by pedestrian, bicycle, etc. modes or collectively. Another challenge is the lower crash frequency when compared with the number of vehicular crashes. The small sample size results in unreliable statistical models that are dominated by noise.

Due to the aforementioned challenges, the approach documented in this report is to summarize proven low-cost countermeasures that could be deployed widely and across different facilities. The CMF clearinghouse is a primary resource for obtaining quantitative assessments of countermeasures. In addition, the stakeholder engagement surveys provide information on current and future use of select countermeasures in Missouri. In contrast, the information from national sources might contain circumstances that are not applicable to Missouri.

4. SYSTEMIC VRU SAFETY

Preliminary Trends

Comparing VRU with Other Crashes

VRU crashes are compared to other crashes to obtain a preliminary picture of VRU crashes in the state. Table 4-1 shows the number of annual fatal and injury crashes for total and VRU crashes in Missouri. The number of VRU fatal crashes account for 12.4% of the total number of fatal crashes in the past five years in Missouri. Nationally, VRU fatal crashes account for around 19% of the total number of fatal crashes, so the percentage in Missouri is much lower (NHTSA, 2022). VRU crashes account for an average of around 3% of the injury crashes but 12.4% of fatal crashes, indicating that VRU crashes tend to be more severe compared to other types of crashes.

Table 4-1 Missouri Total Crashes vs. VRU Crashes

Year	Total		VRU			
	Fatal Crashes	Injury Crashes	Fatal Crashes	VRU %	Injury Crashes	VRU %
2017	865	39567	113	11.6	1847	3.1
2018	848	38350	103	10.8	1761	3.1
2019	819	37832	124	13.1	1768	3.1
2020	914	33269	144	13.6	1591	3.2
2021	935	36047	135	12.7	1518	2.8

Bicyclist Versus Pedestrian Crashes

Two major modes included in VRUs are bicyclists and pedestrians. The crash severities between these two modes show that pedestrian crashes tend to be more severe than bicycle crashes. Figure 4-1 shows that pedestrian crashes accounted for around 89% of the fatal VRU crashes and around 68% of the minor injury crashes. For less severe crashes, such as injury crashes, pedestrian crashes account for a smaller percentage as shown in Figure 4-2 and Figure 4-3. The number of crashes involving both bicyclist and pedestrian was insignificant but was included for completeness. Unfortunately, there is no comprehensive demand data to account for exposure and to compare crash rates instead of crash frequencies. Some possible reasons for the relative difference in severity between the two VRU modes include the use of bicycle helmets and the protection provided by the bicycle. In terms of crash frequencies, pedestrian crashes occur more frequently at a ratio of 5 pedestrian crashes to 2 bicyclist crashes. The total crashes were 6488 for pedestrians and 2605 for bicyclists in the five-year period.

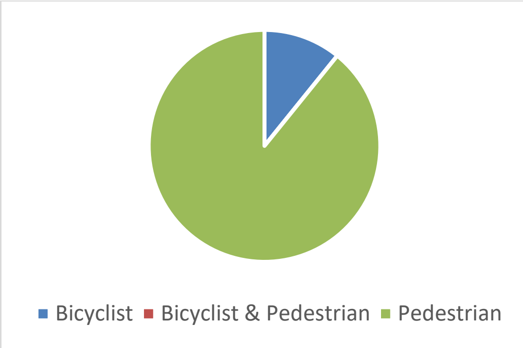


Figure 4-1 Missouri VRU Fatal Crashes

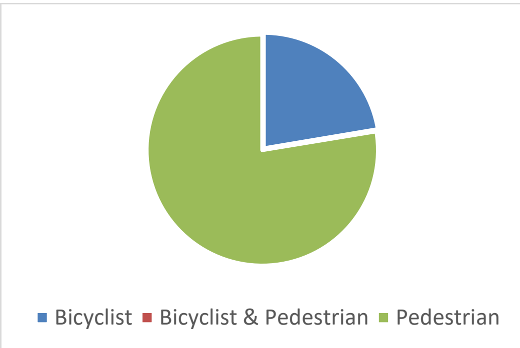


Figure 4-2 Missouri VRU Serious Injury Crashes

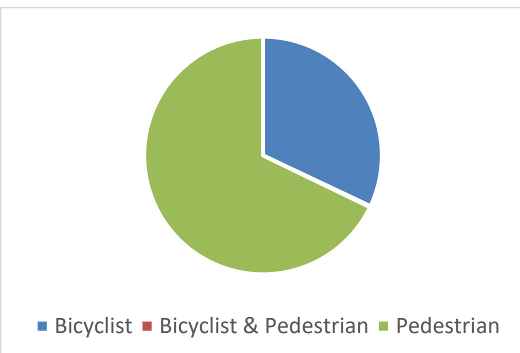


Figure 4-3 Missouri VRU Minor Injury Crashes

Metropolitan Areas

A significant number of VRU crashes occur in the major metropolitan areas in the state. Table 4-2 shows the number of VRU crashes by severity for the three largest metropolitan areas of St. Louis, Kansas City, and Springfield. These three metropolitan areas account for 70% of the fatal VRU crashes and over 75% of the total VRU crashes. The St. Louis region account for around 40% of the fatal VRU crashes and over 40% of the total VRU crashes. The counties included in the St. Louis metropolitan region include Franklin, Jefferson, Lincoln, St. Louis, St. Louis City, St. Charles, and Warren. The counties included in the Kansas City metropolitan region include Caldwell, Carroll, Cass, Clay, Clinton, Jackson, Johnson, Lafayette, Platte, and Ray. The counties included in the Springfield metropolitan region include Christian, Dallas, Greene, Polk, and Webster. Subsequent chapters of this report will contain details and regional maps that focus on the St. Louis and Kansas City regions.

Table 4-2 VRU Crashes in Major Missouri Metropolitan Areas

Severity	STL Metro	%	KC Metro	%	Spfld Metro	%	Metro %
Fatal	243	39.3	149	24.1	41.0	6.6	70.0
Serious Injury	786	42.5	397	21.5	150.0	8.1	72.1
Minor Injury	2907	43.8	1590	24.0	581.0	8.8	76.5
Total	3936	43.2	2136	23.5	772.0	8.5	75.2

Systemic Intersection Analysis

To be consistent with previous MoDOT studies, such as Tobias et al. (2022), intersections were classified according to three criteria: (1) population density, (2), number of intersection legs, and (3) signalization. For population density, rural is under 5,000, urban is between 5,000 and 50,000, and urbanized is over 50,000. For the number of legs in an intersection, a commercial driveway is not considered a leg. Thus, a 3-legged intersection could include a commercial driveway and act as a 4-legged intersection in terms of pedestrian navigation. From a VRU perspective, it would function quite differently than a T intersection. Signalization is classified as either signalized (Y) or unsignalized (N). The type of intersection control was not available in a centralized database, such as all-way stop control, minor leg stop control, roundabout, permissive left turns, protected left turns, and permissive/protected left turns.

Table 4-3 shows the crash frequencies by population density, number of intersection legs, and signalization. The shorthand for describing the intersection type involve three digits: one for density (**R**ural/**U**rban/urbani**Z**ed), one for the number of intersection legs, and one for signalization (**Y**es/**N**o). For example, U4N stands for urban 4-legged unsignalized intersection. There were a total of 6108 VRU crashes from 2017 to 2021. There were 282 fatal crashes and 1144 severe injury crashes. VRU intersection crashes accounted for only 0.6% of the serious injury crashes, but for 6.4% of the 4381 total fatal crashes in Missouri. Even though rural and urban intersections account for 9.2% and 10.3% of the fatal crashes, respectively, urbanized intersections accounted for over 80% of both the fatal and the serious injury crashes. Of note are the urbanized 3-legged unsignalized intersections that accounted for 34% of the fatal crashes and 29% of the serious injury crashes. Some of the 3-legged intersections were potentially 4-legged intersections that were miscoded. It is unclear why certain intersections were miscoded by the police. The prevalence of such an error is unknown since verification involves the manual review of aerial photographs. The four types of facilities with the highest frequency of fatal and serious crashes are urbanized 3-legged signalized (Z3Y) and unsignalized (Z3N) intersections and urbanized 4-legged signalized (Z4Y) and unsignalized (Z4N) intersections.

Table 4-3 Intersection Crashes by Density and Intersection Type

	Fatal		Serious Injury		Minor Injury		All Severity	
Facility Type	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Rural	26	9.2%	89	7.8%	215	4.6%	330	5.4%
R1N	1	0.4%		0.0%		0.0%	1	0.0%
R2N	1	0.4%	4	0.3%	3	0.1%	8	0.1%
R2Y	1	0.4%		0.0%		0.0%	1	0.0%
R3N	14	5.0%	52	4.5%	92	2.0%	158	2.6%
R3Y	1	0.4%	2	0.2%	5	0.1%	8	0.1%
R4N	8	2.8%	28	2.4%	110	2.3%	146	2.4%
R4Y		0.0%	3	0.3%	5	0.1%	8	0.1%
Urban	29	10.3%	137	12.0%	568	12.1%	734	12.0%
U1N	1	0.4%		0.0%		0.0%	1	0.0%
U2N	3	1.1%	5	0.4%	13	0.3%	21	0.3%
U2Y		0.0%		0.0%	1	0.0%	1	0.0%
U3N	11	3.9%	57	5.0%	204	4.4%	272	4.5%
U3Y	4	1.4%	6	0.5%	26	0.6%	36	0.6%
U4N	9	3.2%	58	5.1%	248	5.3%	315	5.2%
U4Y	1	0.4%	10	0.9%	70	1.5%	81	1.3%
U5N		0.0%	1	0.1%	3	0.1%	4	0.1%
Urban-ized	227	80.5%	918	80.2%	3899	83.3%	5044	82.6%
Z1N	8	2.8%	11	1.0%	24	0.5%	43	0.7%
Z1Y		0.0%		0.0%	1	0.0%	1	0.0%
Z2N	24	8.5%	40	3.5%	117	2.5%	181	3.0%
Z2Y	2	0.7%	11	1.0%	65	1.4%	78	1.3%
Z3N	96	34.0%	332	29.0%	1341	28.6%	1769	29.0%
Z3Y	29	10.3%	129	11.3%	521	11.1%	679	11.1%
Z4N	31	11.0%	186	16.3%	843	18.0%	1060	17.4%
Z4Y	35	12.4%	203	17.7%	960	20.5%	1198	19.6%
Z5N	1	0.4%	2	0.2%	4	0.1%	7	0.1%
Z5Y		0.0%	1	0.1%	11	0.2%	12	0.2%
Z6N	1	0.4%		0.0%		0.0%	1	0.0%
Z6Y		0.0%	2	0.2%	5	0.1%	7	0.1%
Grand Total	282	100.0%	1144	100.0%	4682	100.0%	6108	100.0%

As per the Preliminary Trends section, a significant number of crashes occur in the metropolitan regions of St. Louis and Kansas City. Figure 4-4, Figure 4-5, and Figure 4-6 show the frequency of crashes superimposed on the road network for St. Louis and Kansas City regions. The darkened, maroon-colored areas represent low-income tracts which will be discussed in more detail in the chapter on demographics. In St. Louis, the City of St. Louis appears to encompass many facilities with higher crash frequency. In Kansas City, certain corridors appear to encompass higher crash intersections, such as Prospect and Independence avenues. In Springfield, many higher-crash intersections are located in major corridors, such as Campbell and Glenstone avenues. These corridors will be discussed further in the chapter on high-crash analysis.

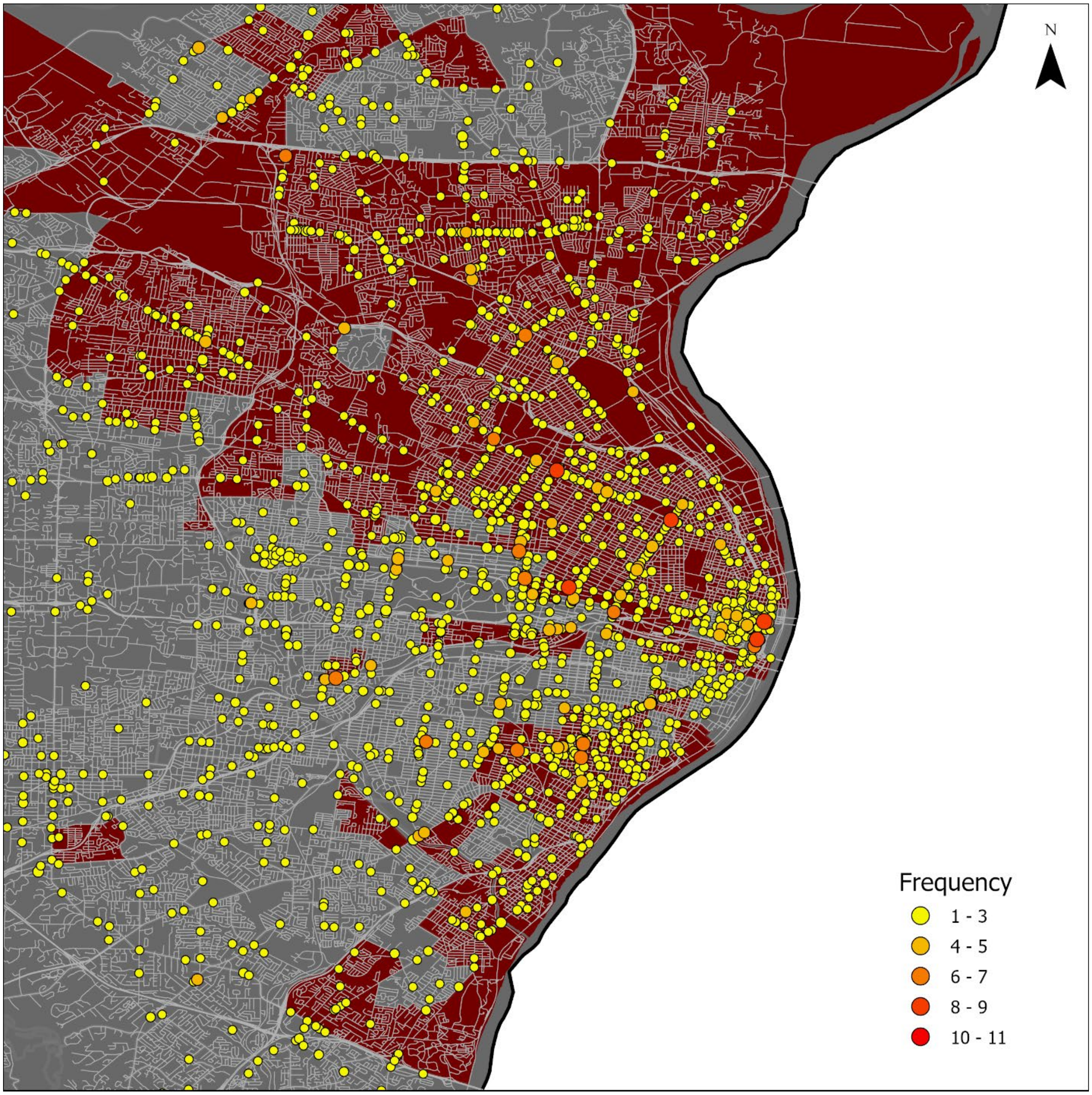


Figure 4-4 Intersection Crashes in St. Louis

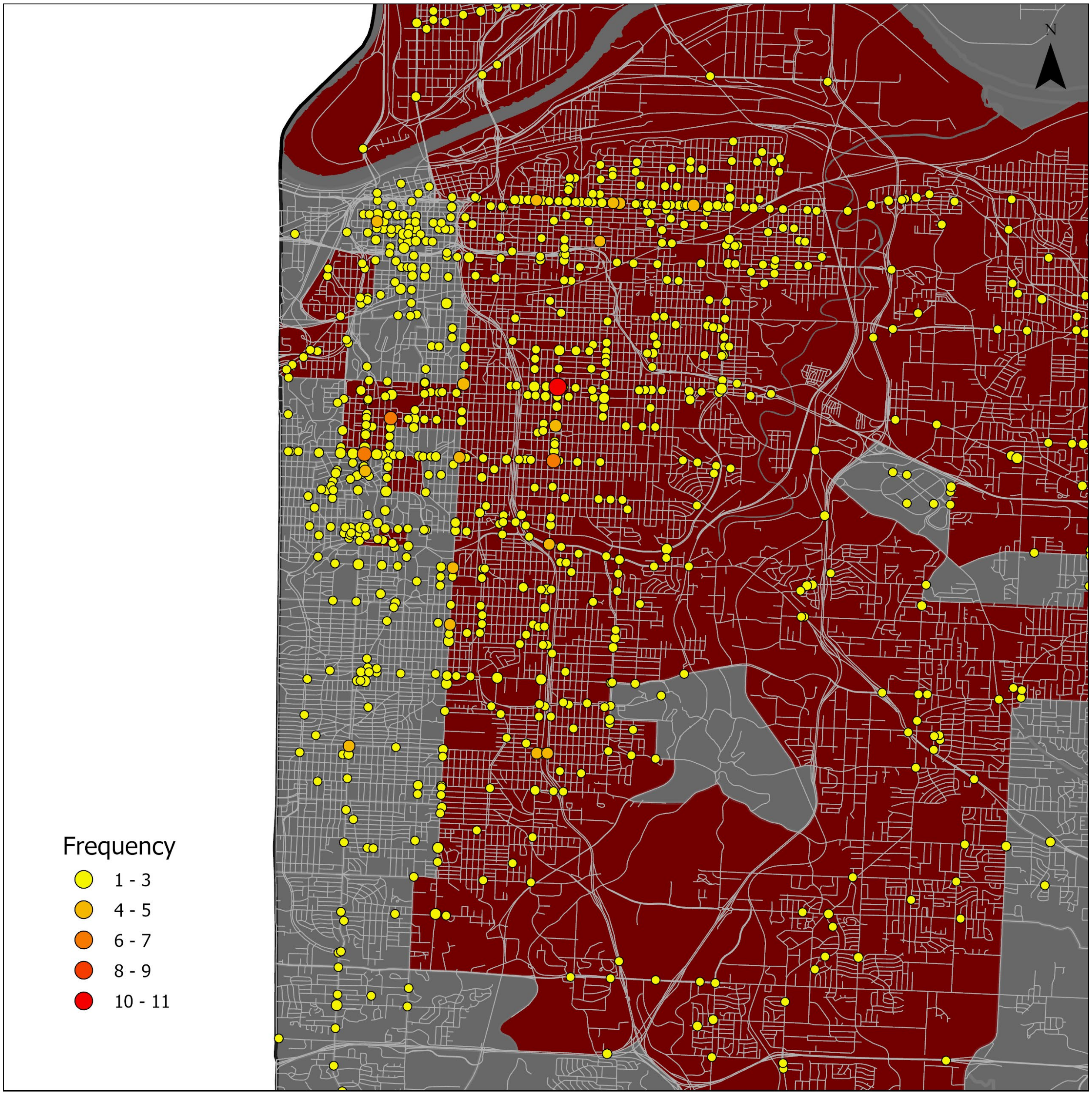


Figure 4-5 Intersection Crashes in Kansas City

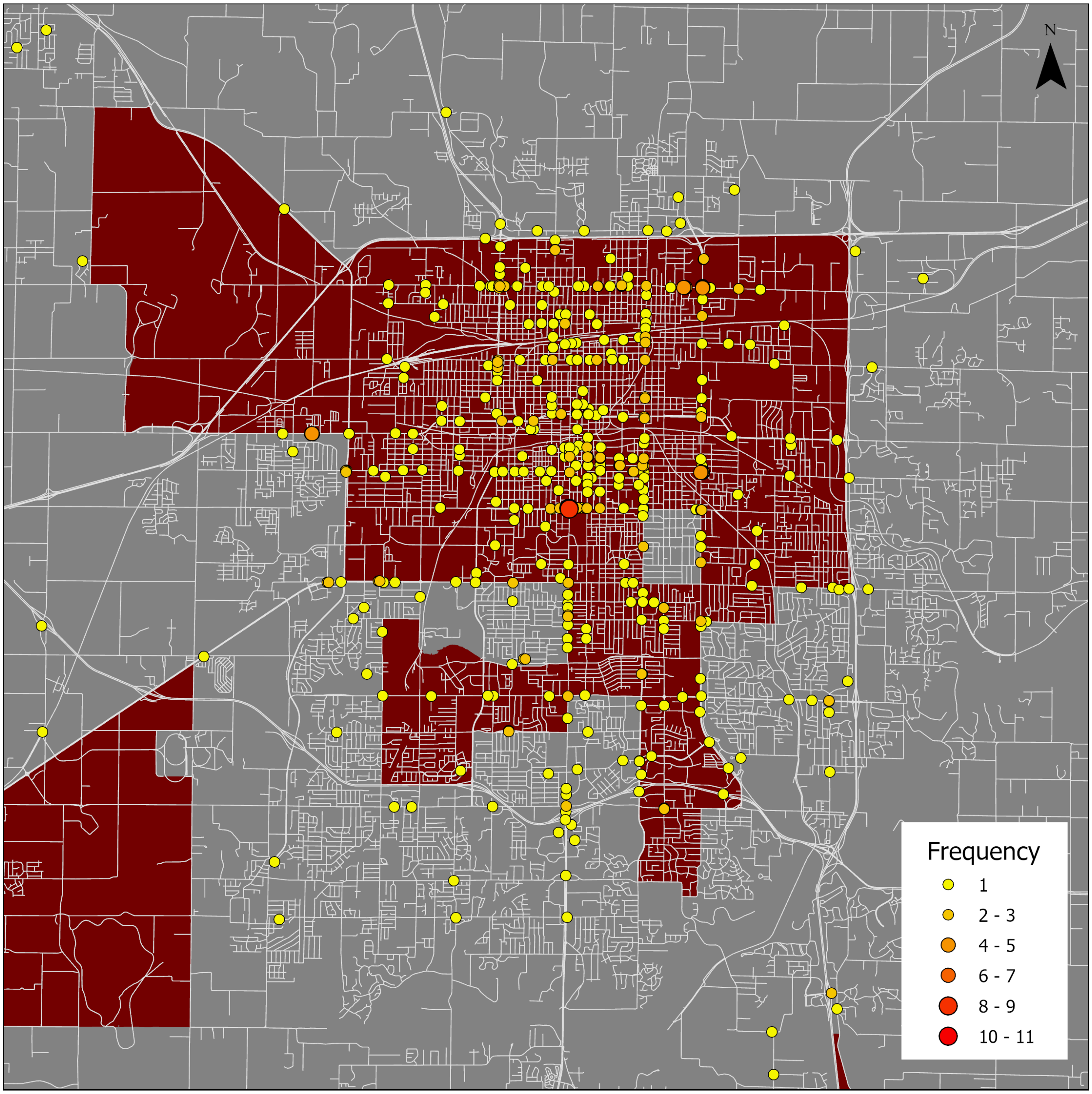


Figure 4-6 Intersection Crashes in Springfield

Systemic Segment Analysis

Similar to the intersection analysis, the segment analysis was also made to be consistent with previous MoDOT studies. Road segments were classified according to three criteria: (1) population density, (2) number of lanes, and (3) divided or undivided. The population density categories are the same as those used in the intersection analysis. For the number of lanes, an assumption was made that the opposite direction has the same number of lanes. This assumption was necessary since geometric data was only available for the direction of travel. An alternate way of classifying would be to use the number of lanes in only one direction. This approach is less preferable because it would be inconsistent with previous MoDOT studies, and it would be less informative since VRUs cross entire segments and not just one direction. Note that lanes imply that they are striped. So there could be bidirectional roads with no striped lanes such as in residential streets. Divided roadways are those that have some type of median.

Table 4-4 shows the crash frequencies on road segments by population density, number of lanes, and divided or undivided. Similar to intersections, a three-digit shorthand was also used for representing segment facilities: density (**R**ural/**U**rban/urbani**Z**ed), the number of lanes, and median type (**D**ivided/**U**ndivided). For example, R4D represents rural 4-lane divided roadways. There was a total of 2996 VRU crashes from 2017 to 2021. Of those, there were 337 fatal and 704 severe injury crashes. It is interesting to compare these numbers with the intersection numbers. Even though segments accounted for less than half of the VRU crashes, they accounted for more of the fatal crashes (337 versus 282). In contrast to intersections, segment crashes were more prevalent in rural facilities, accounting for 34.7% of the fatal VRU crashes. Of note for fatal crashes are the rural two-lane undivided (R2U) and the rural four-lane divided (R4D) facilities. Similar to intersections, many of the urbanized facilities also had significant numbers of fatal crashes. These facilities include two-lane undivided (Z2U), four-lane divided (Z4D), four-lane undivided (Z4U), six-lane divided (Z6D), six-lane undivided (Z6Y), and eight-lane divided (Z8D). Urbanized zero-lane undivided (Z0U) facilities also had 12.4% of the severe injury crashes. Some of the road segment types with the highest crash percentages were highlighted in yellow.

Table 4-4 Segment Crashes by Density and Divided/Undivided

Facility Type	Fatal		Serious Injury		Minor Injury		All Severity	
	Number	%	Number	%	Number	%	Number	%
Rural	117	34.7%	164	23.3%	329	16.8%	610	20.4%
R0D		0.0%		0.0%	1	0.1%	1	0.0%
R0U	10	3.0%	36	5.1%	106	5.4%	152	5.1%
R2D		0.0%		0.0%	1	0.1%	1	0.0%
R2U	59	17.5%	82	11.6%	169	8.6%	310	10.3%
R4D	33	9.8%	28	4.0%	31	1.6%	92	3.1%
R4U		0.0%	3	0.4%	5	0.3%	8	0.3%
R6D		0.0%	2	0.3%	3	0.2%	5	0.2%
R6U		0.0%	2	0.3%	2	0.1%	4	0.1%
R8D		0.0%		0.0%	1	0.1%	1	0.0%
Urban	26	7.7%	87	12.4%	216	11.0%	329	11.0%
U0U	3	0.9%	19	2.7%	63	3.2%	85	2.8%
U2U	7	2.1%	35	5.0%	86	4.4%	128	4.3%
U4D	3	0.9%	7	1.0%	6	0.3%	16	0.5%
U4U	3	0.9%	7	1.0%	21	1.1%	31	1.0%
U6D	3	0.9%		0.0%	2	0.1%	5	0.2%
U6U		0.0%	7	1.0%	10	0.5%	17	0.6%
U8D		0.0%		0.0%	1	0.1%	1	0.0%
U8U	1	0.3%		0.0%	2	0.1%	3	0.1%
Urbanized	194	57.6%	434	61.6%	1282	65.6%	1910	63.8%
Z0D	1	0.3%	2	0.3%	17	0.9%	20	0.7%
Z0U	10	3.0%	87	12.4%	415	21.2%	512	17.1%
Z2D	1	0.3%	10	1.4%	21	1.1%	32	1.1%
Z2U	29	8.6%	96	13.6%	345	17.6%	470	15.7%
Z4D	26	7.7%	31	4.4%	47	2.4%	104	3.5%
Z4U	19	5.6%	43	6.1%	125	6.4%	187	6.2%
Z6D	31	9.2%	27	3.8%	27	1.4%	85	2.8%
Z6U	16	4.7%	45	6.4%	115	5.9%	176	5.9%
Z8D	16	4.7%	14	2.0%	20	1.0%	50	1.7%
Z8U		0.0%	4	0.6%	18	0.9%	22	0.7%
Z10D	8	2.4%	6	0.9%	7	0.4%	21	0.7%
Z10U		0.0%	2	0.3%	3	0.2%	5	0.2%
Z12D	2	0.6%	2	0.3%		0.0%	4	0.1%
Grand Total	337	100.0%	704	100.0%	1955	100.0%	2996	100.0%

To summarize the systemic analysis, there were four types of intersection facilities and nine types of segment facilities that had higher frequencies of fatal or severe VRU crashes. They were Z3Y, Z3N, Z4Y, and Z4N for intersections, and R2U, R4D, Z0U, Z2U, Z4D, Z4U, Z6D, Z6Y, and Z8D for segments.

5. HIGH-CRASH ANALYSIS

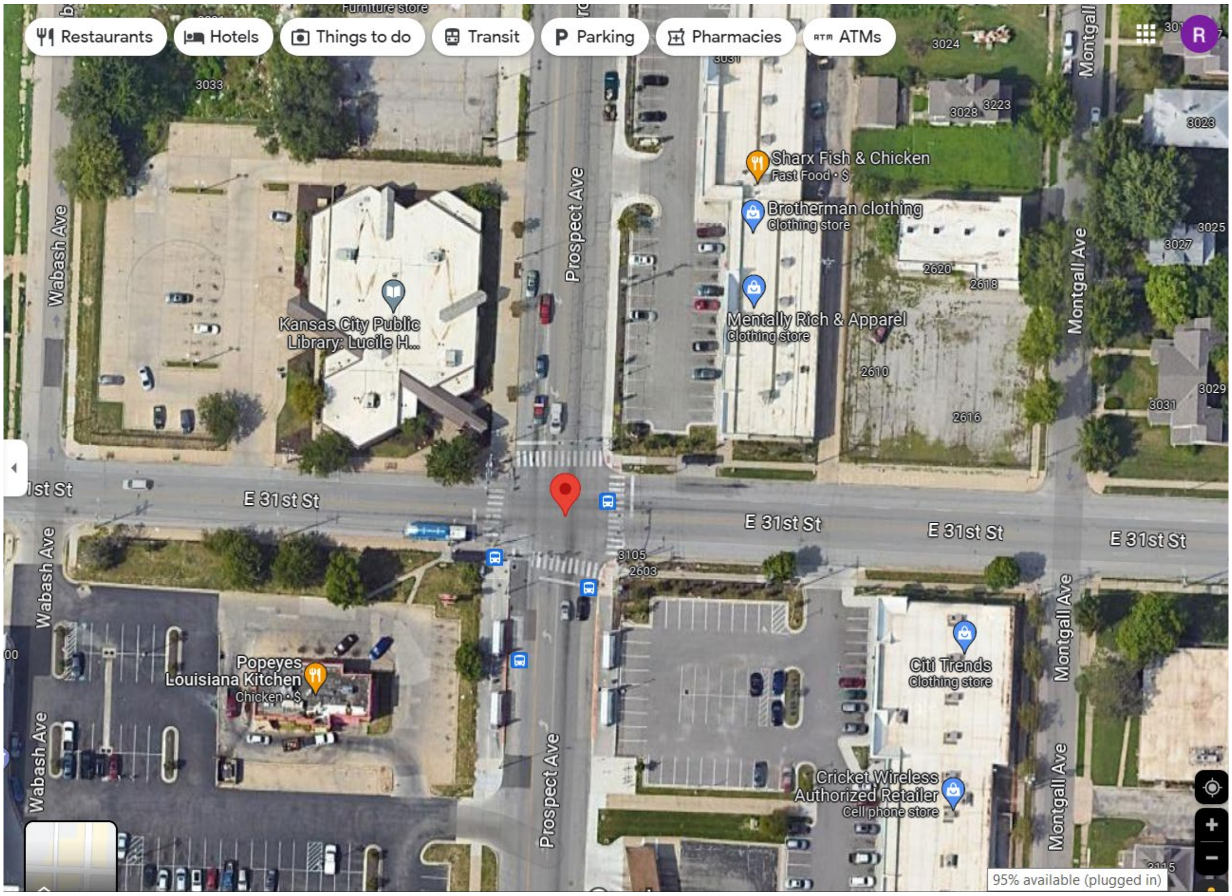
High-crash analysis involves identifying intersections, road segments, and corridors with the highest frequency of crashes. The particular locations identified through this analysis might not be due to systematic causes since crashes are random events. In other words, just because a crash occurred at a particular location, it does not mean that the characteristics of the location itself were primary risk factors. The implementation of countermeasures at such a particular location would not be the most efficient way of improving safety. On the other hand, certain locations, such as intersections and curves, could involve risk factors that are unique to those locations. In such instances, focusing on countermeasures specific to those locations could be appropriate. Therefore, high-crash analysis is complementary to systemic analysis. High-crash analysis focuses on certain unique sites while systemic analysis focuses on unique types of facilities.

In developing a list of high-crash intersections, an arbitrary threshold of 7 crashes/5 years was used. The reason for this value is to produce a manageable list of intersections for public agencies to examine. If the threshold were to be increased, then the list would be too few. Table 5-1 shows the list of high VRU crash intersections in Missouri. There were 16 intersections. Eleven of them are in the metropolitan St. Louis area with nine being in St. Louis City. These intersections accounted for 122 of the 5778 total intersections crashes. For a longer list of intersections, see APPENDIX D.

Table 5-1 List of VRU High-crash Intersections

	City	Intersection	Functional Class	# of Crashes	# Legs	Enter AADT
1	Kansas City	Prospect & E31st	Min Art / Min Art	11	4	17202
2	St. Louis	Washington & Bdwy	Art / Min Art	9	4	19849
3	Springfield	Campbell & W Grand	Min Art / Min Art	8	3?	23754
4	St. Louis	Bdwy & Walnut	Art / Coll	8	3?	27492
5	St. Louis	Lindell & Whittier	Min Art	8	3?	12741
6	St. Louis	Grand & 115	Art / Art	8	3?	19116
7	St. Louis	366 & Morganford	Min Art / Coll	7	4	25533
8	St. Louis	30 & Grand	Art / Min Art	7	4	35811
9	Maplewood	100 & Sutton	Art / Coll	7	4	17401
10	St. Louis	Lindell & Euclid	Min Art / Coll	7	4	17228
11	St. Louis	Kgshwy / Delmar	Art / Min Art	7	4	42168
12	St. Louis	Kgshwy / 115	Art / Min Art	7	3?	23084
13	Flordell Hills	W Florissant / Jennings	Min Art / Min Art	7	4	30430
14	Columbia	763 & University	Min Art / Coll	7	4	23489
15	Kansas City	E39th & Prospect	Min Art / Min Art	7	4	17979
16	Kansas City	Bwdy & W39th	Min Art / Min Art	7	4	28230

Government entities with jurisdiction over the intersections in this list could then investigate to see if any countermeasures would be appropriate for deploying at these locations. An example of a high VRU crash intersection is Prospect Avenue and 31st Street in Kansas City. Figure 5-1 shows the aerial view, while Figure 5-2 shows a street view facing southbound. This intersection has several generators of pedestrian and bicyclist traffic. These include a Kansas City public library, several restaurants, and several retail outlets. In addition, there are bus stops on both sides of Prospect Avenue just south of the intersection. The roads meeting at the intersection all involve multiple lanes with Prospect Avenue having five and E 31st having four. Multiple lanes results in greater VRU crossing distances as well as vehicles making different movements such as left turns lanes on Prospect Avenue.



(Imagery ©2023 Airbus, CNES / Airbus, Maxar Technologies, Map data © 2023 Google)

Figure 5-1 Example of Prospect Avenue and 31st Street, Aerial Photograph

Figure 5-2 Example of Prospect Avenue and 31st Street, Street View Photograph

In contrast to intersection crash analysis, road segments are examined over longer distances. Even though it is possible for particular points on a road segment to possess elevated risk, such as a sharp horizontal curve or a location with a sight obstruction, many types of segment crashes are not tied to a point on the roadway. And by examining longer distances, particular points on a roadway are also included. This type of analysis also results in more unified and consistent application of countermeasures that take into account how users, both VRUs and vehicles, travel over long distances. Intersection crashes are not considered while examining segments, so all crashes are “mid-block” crashes.

The VRU high-crash list for road segments involves roads that had a high-crash frequency from 2017 to 2022. Similar to the intersection list, a manageable number of roadways, i.e., ten, were included on the list. Table 5-2 shows the road segments with the highest frequency of VRU crashes. The high number of interstates and access-controlled facilities indicate that many of these VRU crashes consist of a pedestrian involved with a previous incident such as a disabled vehicle or a previous crash. These pedestrians had exited their vehicles after the primary incident. Figure 5-3 shows the collision diagram of such an example crash on I-44. The example involved a vehicle with a flat tire and a second vehicle parked behind this vehicle. A tractor-trailer veered on the shoulder striking the second vehicle and producing debris that injured three pedestrians near the tire changing operation. For a longer list of high-crash segments, see APPENDIX F.

Table 5-2 List of VRU High-crash Segments

Name	Frequency/Five Years
I-70 W	31
I-55 S	25
I-44 W	24
I-70 E	23
US 67 S	19
US 40 E	19
I-44 E	17
US 61 S	16
Grand Blvd.	16
West Florissant Ave.	16

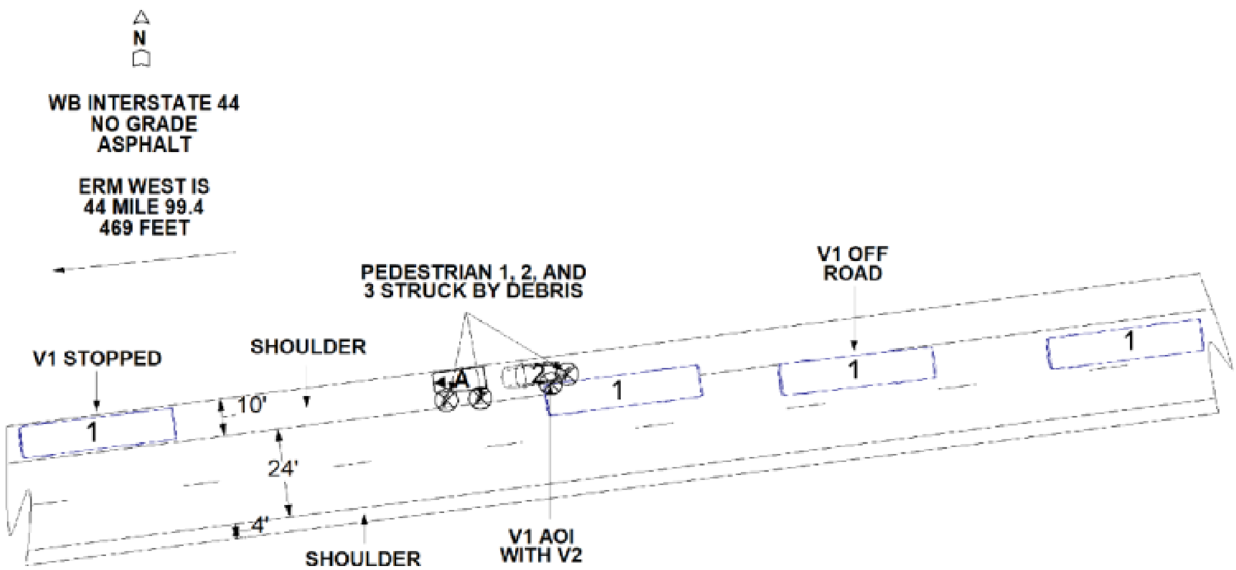


Figure 5-3 Example of a VRU Segment Crash on Interstate 44 (MO Crash Report 3210028032)

The VRU high-crash list for corridors involves roads that had a high-crash frequency from 2017 to 2022. Similar to the intersection and segment lists, a manageable number of roadways, i.e., ten, were included on the list. Table 5-3 shows the corridors with the highest frequency of VRU crashes. Eight of the ten roads are in the metropolitan St. Louis area. Figure 5-4 shows the high-crash corridors in metropolitan St. Louis. Many of these corridors are in or near the City of St. Louis. For a longer list of high-crash corridors, see APPENDIX E.

Table 5-3 List of VRU High-crash Corridors

Name	Area	Frequency/Five Years
Grand Blvd.	St. Louis	103
Kingshighway Blvd.	St. Louis	74
Independence Ave.	Kansas City	55
West Florissant	St. Louis	54
MO 30	St. Louis	52
Chambers Rd.	St. Louis	44
Prospect Ave.	Kansas City	43
US 67	St. Louis	42
MO 180	St. Louis	41
MO 100	St. Louis	40

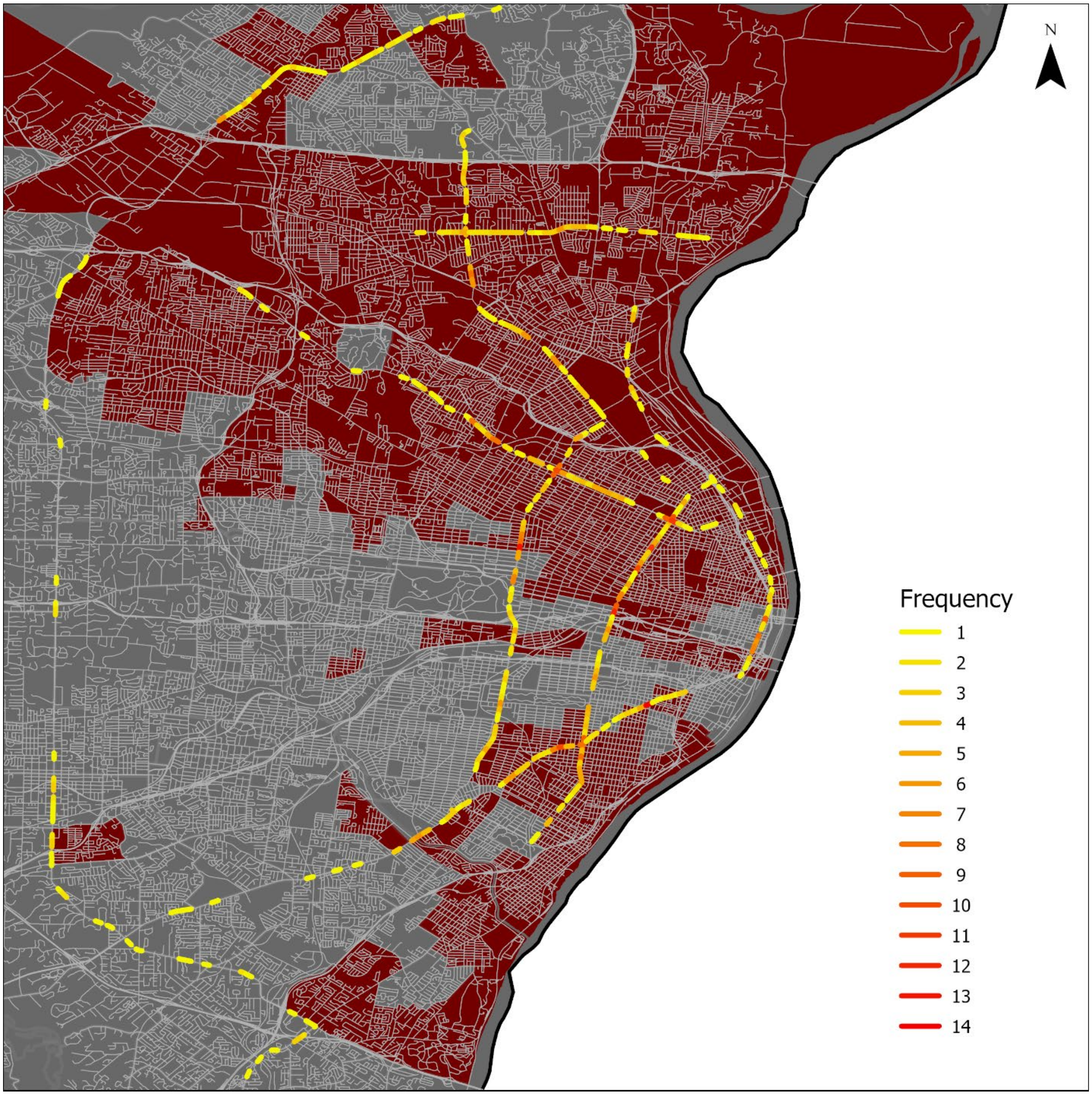


Figure 5-4 High-crash Corridors in the St. Louis Region

Figure 5-5 shows an example of a portion of a high-crash corridor, Grand Blvd. The portion shown is near the Grand MetroLink Park-n-Ride lot and includes bus stops on both sides of Grand Blvd. This incremental examination is a way of dividing a corridor into manageable sections for deploying countermeasures.

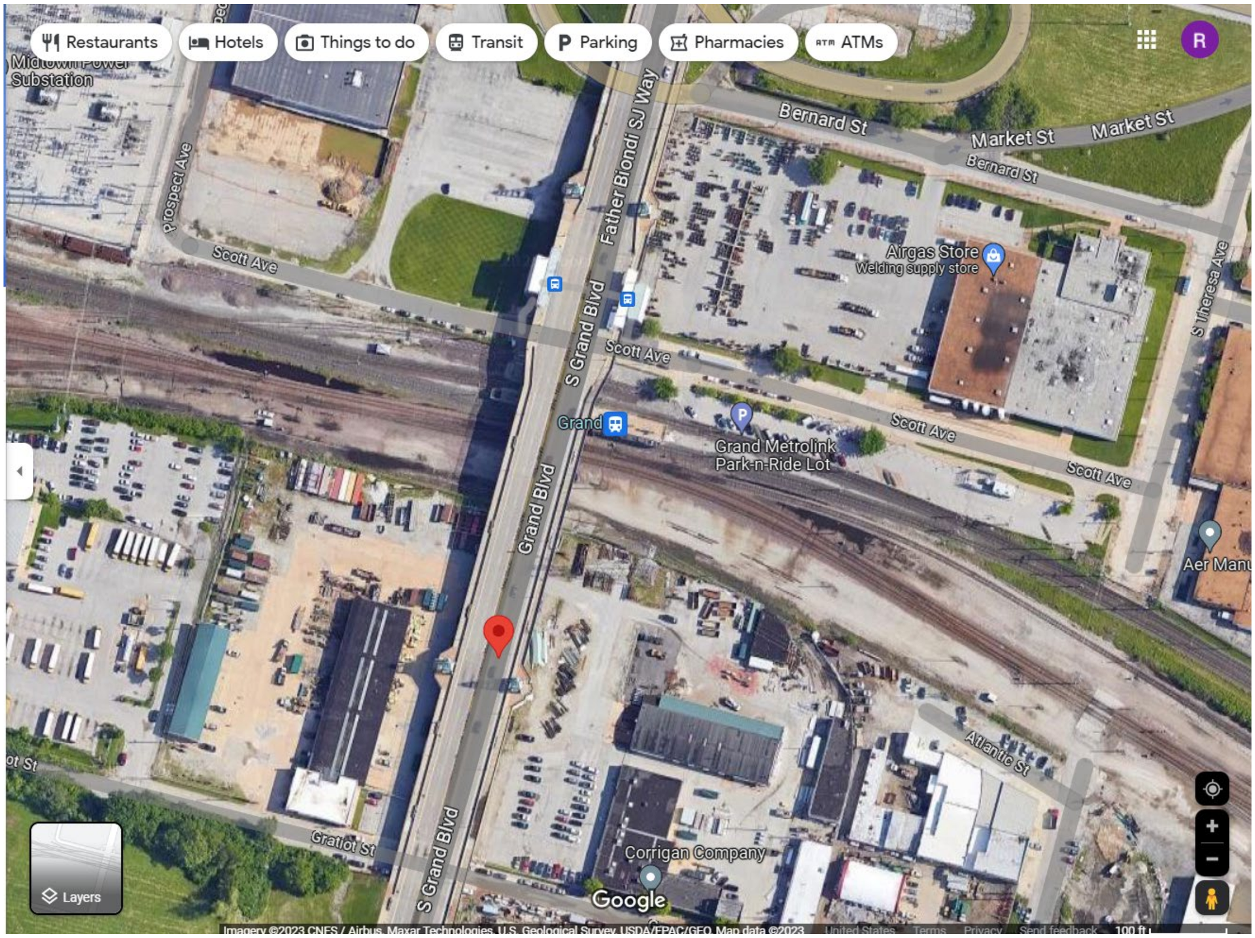


Figure 5-5 Example of a VRU Corridor Crash on Grand Blvd.

6. DEMOGRAPHICS AND CONTRIBUTING FACTORS ANALYSIS

Demographics Analysis

Federal guidance on VRU safety assessment (Walker, 2022) highlights the importance of equity considerations in investigating VRU safety as VRU crashes could affect poorer neighborhoods disproportionately. As per the discussions in the chapter discussing literature and state of practice, the American Community Survey (ACS) performed by the Census Bureau is one source of data for assessing level of poverty. ACS uses the definition of low-income community in the Federal tax code, 26 U.S.C. §45D(e). A tract qualifies as low income when the poverty rate is at least 20%.

A spatial analysis was performed on the VRU crash data of 8957 VRU crashes. These points were plotted alongside poverty data for the state of Missouri using Esri's ArcGIS software. Poverty data came from the 2016-2020 ACS 5-year estimates to determine if a census tract is considered a low-income community. Table 6-1 compares the number of VRU crashes by severity between qualified and non-qualified census tracts. Table 6-1 shows that a high percentage of the crashes occur in low-income tracts for all crash severities. There are several potential reasons for this result. There could be higher demand for walking and bicycling due to lower vehicle ownership. There could be differences in facility design in those tracts. And pedestrian and bicyclist behavior could differ. Some literature discusses the higher prevalence of VRU crashes in lower income countries (e.g., Manisha and Bandyopadhyay, 2020; McIlroy et al., 2019), but no research is available on the impact of income on VRU crashes in Missouri. For example, low-income communities were not addressed specifically in the recent MoDOT report on pedestrian safety (Tobias, 2022).

Table 6-1 Proportion of Qualified Low Income VRU Crashes

Severity	Qualified	Not Qualified	Total
Minor Injury	3671 (56.4%)	2837 (43.6%)	6508 (100%)
Severe/Disabling Injury	1113 (61.0%)	711 (39.0%)	1824 (100%)
Fatal	363 (58.8%)	254 (41.2%)	617 (100%)
Total	5147 (57.5%)	3802 (42.5%)	8949 (100%)

Figure 6-1 shows a map of the low-income tracts in Missouri in pink. VRU crashes are shown as dots and colored according to severity: red for fatal, yellow for serious injury, and green for minor injury. Figure 6-1 gives a sense of the overall concentration of crashes and the distribution of low-income tracts in Missouri, but is, otherwise, at too large of a scale. More informative are the regional crash maps. Figure 6-2 displays fatal and severe injury crashes in St. Louis. The visual inspection shows more VRU crashes located in the low-income tracts, especially in the city of St. Louis. Figure 6-3 displays fatal and severe injury crashes in Kansas City. Figure 6-4 shows the fatal and severe crashes in Springfield. In the St. Louis, Kansas City, and Springfield maps, the corridors identified in the high-crash analysis are visible and are located in many low-income tracts.

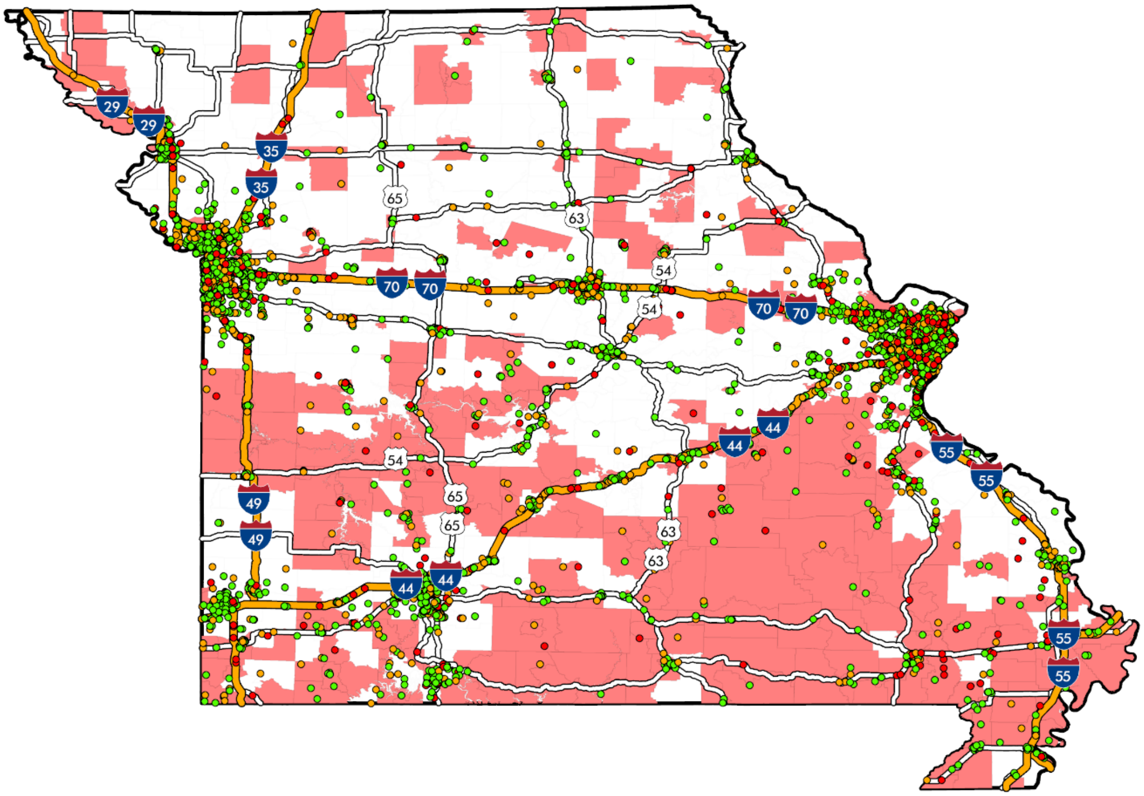


Figure 6-1 VRU Crashes and Low-Income Tracts in Missouri

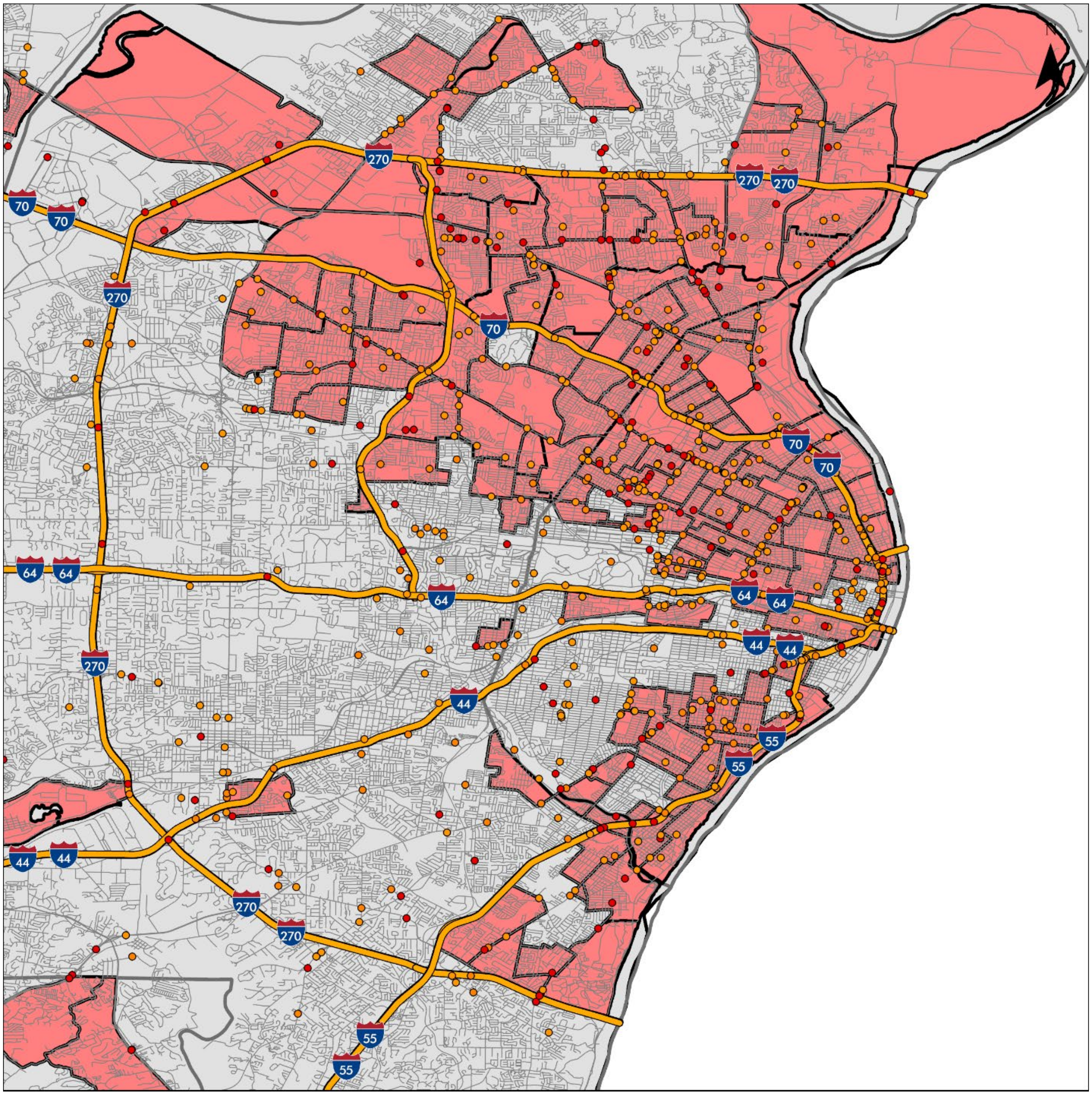


Figure 6-2 VRU Crashes and Low-Income Tracts in St. Louis

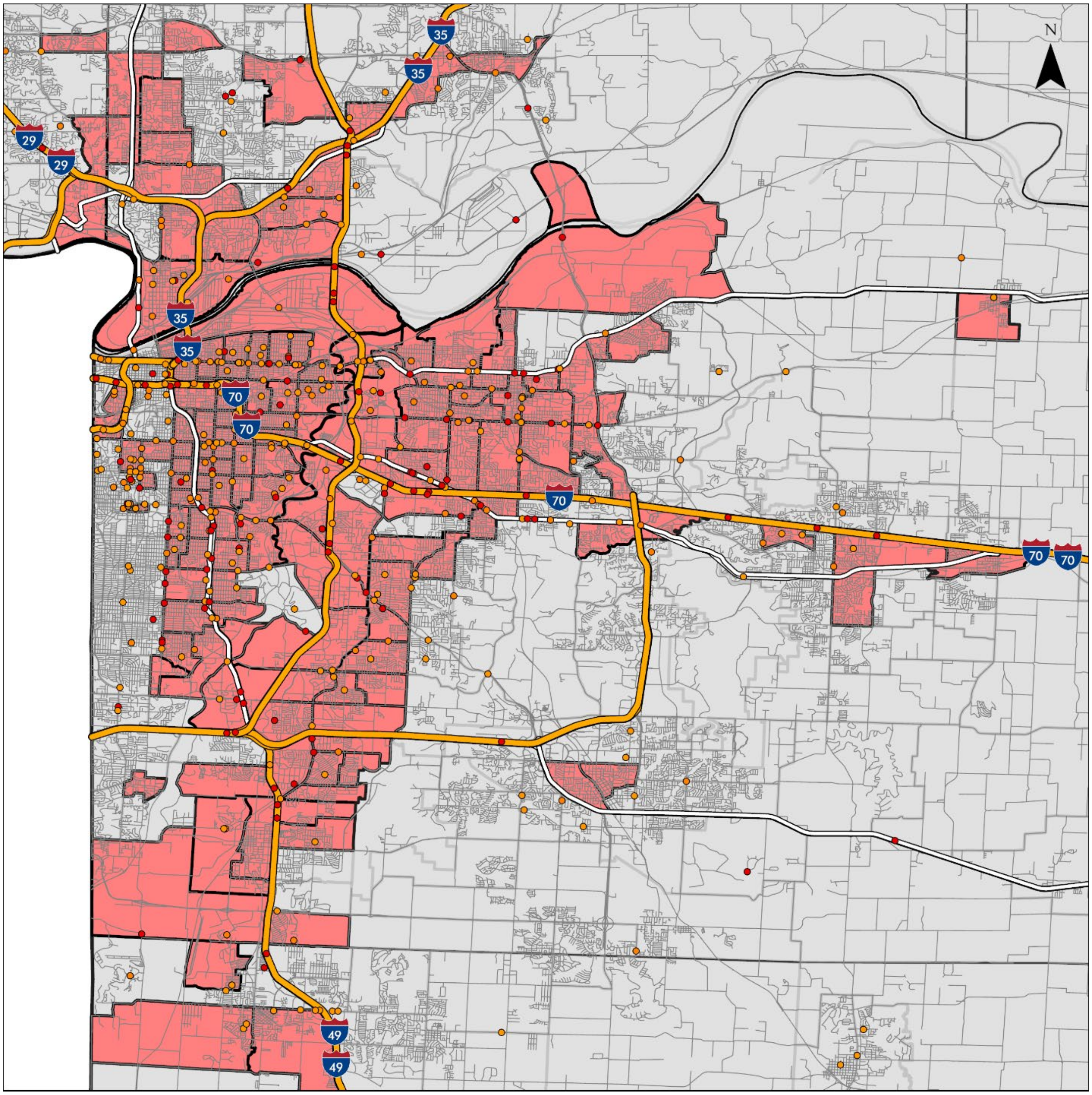


Figure 6-3 VRU Crashes and Low-Income Tracts in Kansas City

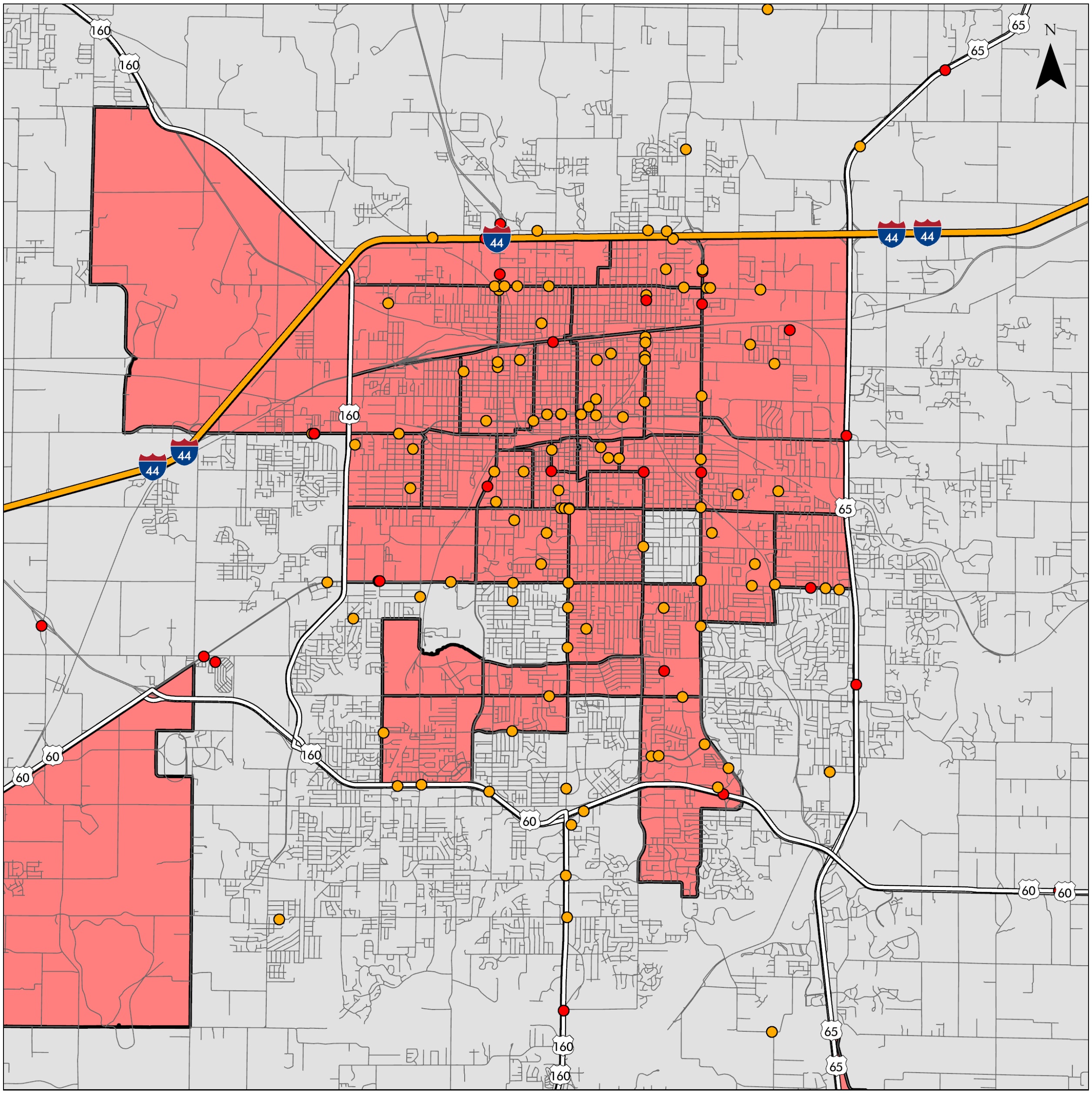


Figure 6-4 VRU Crashes in Low-Income Tracts in Springfield

A related and specific issue related to poverty concerns unhoused encampments and VRU safety. People who are unhoused could interact with the transportation system in various ways. They could live in encampments that are in close proximity to transportation facilities or live on transportation facilities such as under freeway overpasses. They may live in shelters for periods of time and have an address for collecting mail. Thus an address that is listed on a police crash report does not necessarily mean that an individual is housed. There are several challenges to understanding such users and to provide countermeasures for improving their safety. There are challenges to obtaining reliable data to better understand the scope and needs of that population. Police crash reports do not indicate an unhoused individual, nor do the narrative statements typically reveal any such information. Medical or hospital data could potentially contain such information. For example, an investigation from Clark County, Nevada (Hickox et al., 2014), used coroner's data to analyze fatalities from the housed population. That study found that the unhoused had approximately 22 times the pedestrian death rate of other residents, the greatest proportion of fatal crashes occurring from 6 pm to 12 am, and significantly greater proportion of alcohol impaired pedestrians. There is a need to discover ways for obtaining data related to the unhoused VRU population in order to understand their behavior and safety needs.

Transit Analysis

One type of land-use that generates VRU trips is transit/bus stops. FHWA and FTA are both interested in improving VRU safety in these land-use areas to preserve and promote transit access (Walker, 2022, p. 13). Crash data analysis was performed to analyze the relationship between VRU crashes and transit/bus stops. This analysis was performed for the portions of the St. Louis and Kansas City regions as these areas contain a majority of VRU crashes. There is no statewide database for the location of transit/bus stops. This data was obtained from the relevant regional transit agencies. In St. Louis, the Metropolitan Saint Louis Transit Agency (Metro St. Louis) is the bi-state agency that operates the MetroBus and the MetroLink light rail systems. In Kansas City, the Kansas City Area Transportation Authority (KCATA) is the bi-state agency that operates scheduled transit services in addition to demand-responsive and paratransit services. Transit stop locations were obtained from these agencies.

The analysis of VRU crashes near transit/bus stops involved the following procedure. The locations of the transit and bus stops for Metro St. Louis and KCATA were imported into GIS, and these locations were overlayed on top of the regional maps in conjunction with the crash locations. The proximity of the VRU crashes to transit/bus stops was analyzed. A proximity threshold was used to determine if a crash was within the area of influence of a transit/bus stop. This is only a surrogate way of finding transit-related VRU crashes as that information is not available in crash reports, even if crash narratives were to be parsed individually. The HSM (AASHTO, 2010) uses the 1,000 ft threshold for the presence of bus stops, school, and alcohol establishments (e.g., Section 12.7.3). However, this large threshold is for aggregating the total number of bus stops or establishments and is too large for an influence area that reflects the specific circumstances surrounding a crash. Pulugurtha and Vanapalli (2008) geocoded vehicle-pedestrian crashes and investigated the spatial distributions of crashes near bus stops. They determined that a proximity threshold of 100 ft or 200 ft are appropriate for a transit influence area for safety analysis purposes.

Relevant portions of St. Louis and Kansas City were analyzed to describe the relationship between transit stops and VRU crashes. There were 3315 crashes in St. Louis County and St. Louis City. Of those, 1149 (~35%%) occurred within 200ft of MetroBus stops and MetroLink stations and 569 (17.2%) occurred within 100 ft of MetroBus stops. In Platte, Clay, and Jackson counties in Kansas City, there were a total of 1897 VRU crashes. Of those, 650 (34.3%) occurred within 200 ft of KCATA stops and 510 (26.9%) occurred within 100 ft of KCATA stops. Using the 200 ft threshold results in around 35% of VRU crashes being transit-stop-related in both St. Louis and Kansas City.

Further spatial analysis was performed considering the service area of the public transit systems, which includes the area where riders would walk to and from stations. FHWA suggests that riders of public transit are only willing to walk between a quarter- and half-mile to and from a station (FHWA, 2013), which equates to about five to ten minutes of walking. Using spatial data of MoDOT road system, a travel network of St. Louis and Kansas City was created and the service areas of the cities' public transit system were plotted. Figure 6-4 shows the service area of the St. Louis MetroBus system assuming a 10-minute walk time from bus stations. VRU crashes are also shown. The service area was calculated using a 100ft buffer area from streets. 2886 (87.1%) of the 3315 VRU crashes in the St. Louis area are within a 10-minute walk-time service area of the MetroBus system. The same service area analysis was performed for the Kansas City KCATA public transit system.

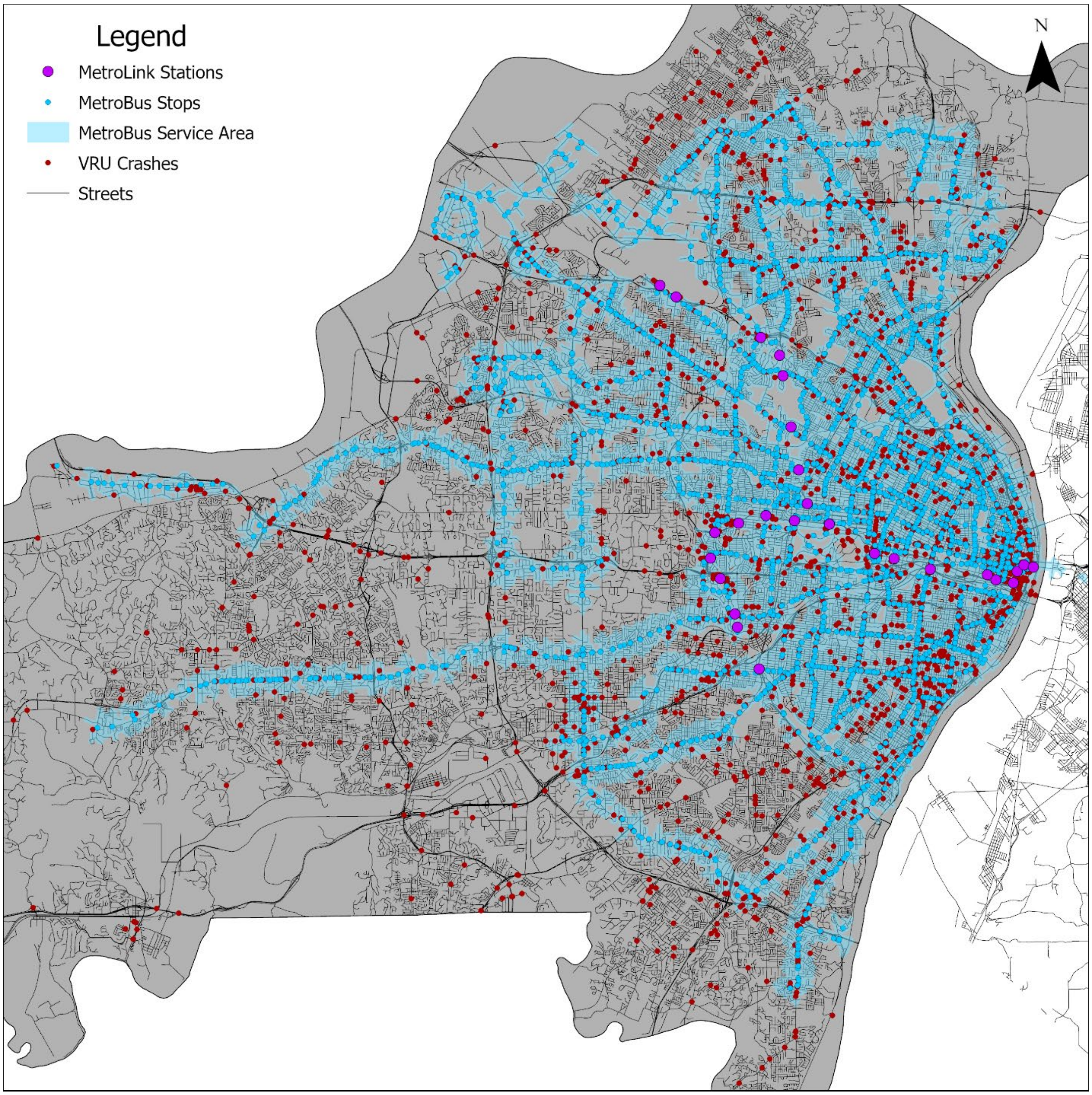


Figure 6-5 VRU Intersection Crashes Overlayed on Top of Transit Service Area in St. Louis

For Kansas City, Missouri, 1483 (78.2%) of the 1897 VRU crashes in Platte, Clay, and Jackson County are within a 10-minute walk-time service area of the KCATA bus system. Figure 6-5 depicts this service area.

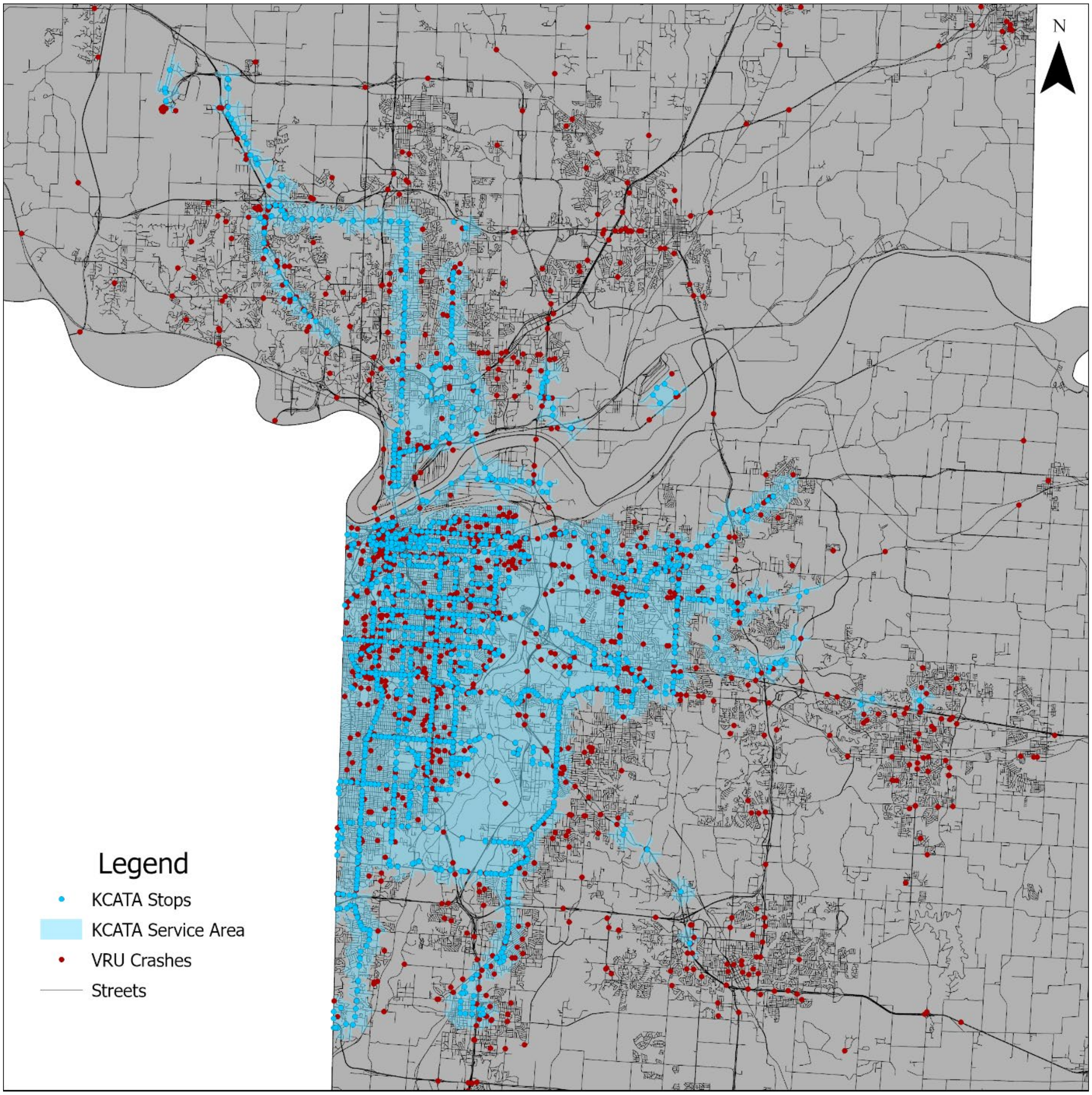


Figure 6-6 VRU Intersection Crashes Overlayed on Top of Transit Service Area in Kansas City

Bicycle Trails

Crashes occurring near bicycle trails in Missouri were analyzed. VRU crashes often occurred on the street nearest to a trail and are marked as such within police crash reports. Therefore, a spatial analysis using ArcGIS was performed using MoDOT road data and the VRU crash data to find all crashes occurring within 100ft of a listed bicycle trail. The crash counts for each trail are tabulated and the locations of these bicycle trails are shown in Figure 6-6 and Table 6-2..

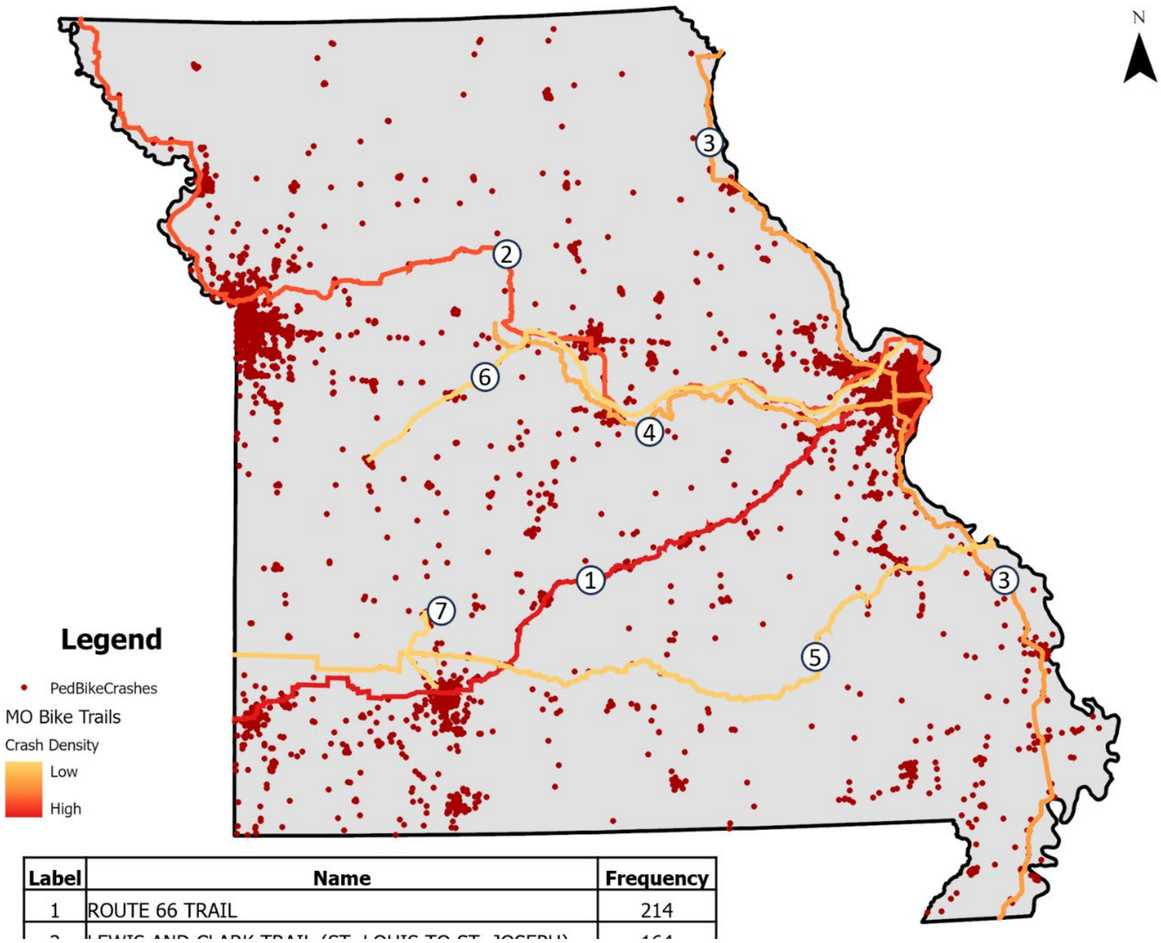


Figure 6-7 VRU Crashes Showing Proximity to State Bicycle Trails

Table 6-2 VRU High Crash List Near Trails

Label	Name	Frequency/Five Years
1	Route 66 Trail	214
2	Lewis and Clark Trail (St. Louis to St. Joseph)	164
3	Great River Road Trail	86
4	Lewis and Clark Trail (St. Louis to Boonville)	62
5	Transamerica	17
6	Katy Trail	6
7	Frisco Highline Trail	4

The bicycle trail with the highest number of VRU crashes within 100 ft was the Route 66 Trail with 214 crashes. This trail runs between St. Louis and Joplin, through Springfield. The second highest number of VRU crashes was observed on the Lewis and Clark Trail, at 164 crashes. This trail runs primarily on the north side of the Missouri River, through St. Louis, Jefferson City, Columbia, Kansas City, and St. Joseph. All seven bicycle trails that were analyzed span a portion of the state and traverse both inside and outside city limits. For portions of their lengths, these bicycle trails run parallel to a vehicle road. Bicyclists involved in these crashes may have been using the nearby trail and exited onto the road using a trail entrance before the crash occurred. Therefore, while the crash report associates the crash with a road, the presence of a nearby bicycle trail may influence the number of VRU crashes observed on the road.

Light Condition

There are six possible light conditions in a crash report: daylight, dark-lighted, dark-unlighted, dark-unknown lighting, other, and unknown (STARS, 2019). Daylight is defined as 30 minutes before sunrise to 30 minutes after sunset or “natural” light. Dark-lighted involves no natural light but man-made light on the roadway and not other roadside sources. Dark-unlighted involves no natural or man-made light on the roadway. Dark-unknown lighting involves no natural light but the presence of man-made light is undetermined at the time of the crash. Other and unknown includes other unique circumstances that are explained in the narrative/statements section of the police crash reports.

Intersections

The effect of the light condition on intersection crashes is examined by looking at each severity individually. Table 6-2 shows the intersection crashes under various light conditions by severity. Looking at fatal crashes, there are a large percentage of fatal crashes (68.1%) that occur under dark conditions. However, a significant portion of those (46.5% for fatal and 34.8% for serious injury) already involve man-made lighting. Other non-lighting countermeasures could be considered for night-time. The percentage of daylight crashes decreases as the severity decreases. For serious injury crashes, again, a significant percentage of dark condition crashes involve man-made lighting. In summary, many fatal and serious injury intersection crashes involve dark conditions, but a high percentage of those already occur under man-made lighting.

Table 6-3 Light Conditions and VRU Injury Severity on Intersections

Sev-erity	Dark - Lighted		Dark – Unkn. Light.		Dark - Unlit		Daylight		Other		Unkn.		Total
	#	%	#	%	#	%	#	%	#	%	#	%	#
Fatal	131	46.5	2	0.7	59	20.9	89	31.6	1	0.4	0	0.00	282
Serious Injury	398	34.8%	9	0.80	122	10.7	614	53.7	1	0.1	0	0.00	1144
Minor Injury	1130	24.1	27	0.6	272	5.8	3242	69.2	3	0.1	8	0.17	4682
Grand Total	1659	27.2	38	0.6	453	7.4	3945	64.6	5	0.1	8	0.13	6108

Segments

The effect of the light condition on segment crashes is also examined by looking at each severity individually. Table 6-3 shows the segment crashes under various light conditions by severity. Looking at fatal crashes, there are a large percentage of crashes (76%) that occur under dark conditions. In contrast to intersections, a majority of fatal crashes (54%) and serious injury crashes (27.8%) that are dark involve dark-unlighted conditions. The two cells are highlighted. Therefore man-made lighting could be explored as a countermeasure for segment VRU crashes. Similar to intersection crashes, the percentage of daylight crashes decreases as the severity decreases. For serious injury crashes under dark conditions, there was a higher percentage of unlighted versus lighted crashes. In summary, fatal and serious segment crashes involve dark conditions, and a high percentage of those occur under unlighted conditions.

Table 6-4 Light Conditions and VRU Injury Severity on Segments

Sever-ity	**Dark - Lighted**		**Dark – Unkn. Light.**		**Dark - Unlit**		**Daylight**		**Other**		**Unkn.**		**Total**
	#	%	#	%	#	%	#	%	#	%	#	%	#
Fatal	73	21.7	1	0.3	182	54.0%	80	23.7	0	0.0	1	0.3	337
Serious Injury	175	24.9	1	0.1	196	27.8%	330	46.9	2	0.3	0	0.0	704
Minor Injury	354	18.1	21	1.1	321	16.4	1255	64.2	1	0.1	3	0.2	1955
Grand Total	602	20.1	23	0.8	699	23.3	1665	55.6	3	0.1	4	0.1	2996

7. COUNTERMEASURES

Major VRU Countermeasure Sources

The following are descriptions of various major sources for VRU countermeasures. They include NCHRP reports, FHWA websites, and other published guides and manuals. The order of presentation consists of national manuals, NCHRP report, and other resources.

Highway Safety Manual

The Highway Safety Manual (HSM) (AASHTO, 2010) is the national manual that promotes a quantitative safety analysis approach. The strength of the HSM is in the procedures for performing safety prediction via the use of safety performance functions and related steps. Thus, the number of crashes can be predicted on a facility that has various countermeasures implemented. As explained previously in the introduction, the predictive approach was not undertaken due to unavailability of required VRU data. Nevertheless, the HSM contains default distributions for bicycle and pedestrian crashes for different types of facilities. These distributions are also reported by severity. For example, for rural two-lane, two-way road segments in Chapter 10, the percentages of FI crashes are 0.4 and 0.7 for bicycle and pedestrian, respectively. For urban and suburban arterial segments in Chapter 12, the VRU crash proportion is differentiated between facilities under or equal to 30 mph and those above 30 mph. For urban and suburban intersections, there are SPFs predicting vehicle-pedestrian collisions given the type of intersection, AADT, number of lanes crossed by a pedestrian and pedestrian volumes. Three CMFs are listed for pedestrian collisions: bus stops, schools, and alcohol sale establishments. The CMF for the presence of bus stops within 1,000 ft of an intersection is 2.78 for 1 or 2 and 4.15 for 3 or more. The CMF for the presence of schools within 1,000 ft of an intersection is 1.35. The CMF for the presence of alcohol sales establishments within 1,000 of an intersection is 1.12 for 1-8 and 1.56 for 9 or more. Chapter 14 of HSM also provides pedestrian CMF values for converting minor-road stop control to all-way stop (0.57), removal of an unwarranted signal (0.82), providing intersection illumination (0.58), permitting right-turn-on-red (1.57, 1.80 for bicyclist), and modifying change plus clearance interval to ITE 1985 practice (0.63). HSM discusses many other types of treatments such as providing bicycle lanes, widening curb lanes at intersections, narrowing roadway at pedestrian crossings, installing raised pedestrian or bicycle crosswalks/crossings, marking crosswalks at uncontrolled locations, providing raised median or refuge islands, installing pedestrian heads, installing pedestrian countdown timers, installing automated pedestrian detectors, installing stop line and other crosswalk enhancements, providing exclusive pedestrian timing, providing leading pedestrian interval, and placing “slalom” profiled pavement markings on bicycle lanes. However, HSM does not provide CMF values for them. In summary, the soon to be updated edition of the HSM has very limited information on bicycle and pedestrian countermeasure performance.

Manual on Uniform Traffic Control Devices (MUTCD)

The MUTCD (FHWA, 2009) sets the minimum standards on traffic signs, markings, and signals. All fifty states are in substantial conformance with these standards. Even though this manual does not provide performance data on countermeasures, it provides the specifications for the countermeasures that relate to traffic control devices.

CMF for Uncontrolled Pedestrian Crossing Treatments

NCHRP Report 841 (NAS, 2017) presents CMFs for uncontrolled pedestrian crossing treatments. The report discussed the following three general types of treatments: signing and markings, beacons and warning lights, and curb and raised pavements. Signing and markings include crosswalk signs and markings, such as high-visibility crosswalk marking patterns, and advanced YIELD and STOP markings and signs. Beacons and warning lights include pedestrian hybrid beacons, rectangular rapid flashing beacons, and in-pavement warning lights. Curb and raised pavement treatments include pedestrian refuge islands, curb extensions, and raised pedestrian crossings. The CMFs of this report were incorporated into other sources such as the CMF Clearinghouse, HSM, and the MUTCD.

Guidance to Improve Pedestrian and Bicyclist Safety at Intersections

NCHRP Report 926 (NAS 2020) provides guidance to improve pedestrian and bicyclist safety at intersections. It provides a process for selecting intersection design and operational treatments. It recommends nine guiding principles when selecting countermeasures. These are:

- Assume pedestrians and bicyclists will be present
- Minimize and manage conflict points
- Minimize travel time and delay for pedestrians and bicyclists
- Minimize exposure to conflicts
- Control speeds and minimize speed differentials
- Prioritize comfort
- Provide and convey a predictable, reasonable path
- Manage sight lines and visibility
- Ensure accessibility

This report contains an informative table (Table 29, Design Tradeoffs of Safety Countermeasures) that summarizes 35 countermeasures and the various tradeoffs such as safety impact, cost (deployment and maintenance), public process, motorist operations/comfort/safety, pedestrian operations/comfort/safety, and bicyclist operations/comfort/safety.

Application of Pedestrian Crossing Treatments for Streets and Highways

NCHRP Synthesis 498 (NAS, 2016) is a synthesis of practice on the application of pedestrian crossing treatments for streets and highways. The synthesis was derived from surveying transportation agencies, analyzing current practice and policy, and performing literature review. The survey involved 40 states and D.C. and 19 counties and municipalities. The current practice relies greatly on locally tailored design and guides, AASHTO and NACTO guides, and CMFs, either from the Clearinghouse or locally developed. Countermeasures were generally classified into either roadway design features or traffic control devices.

The report presented the following list of resources that were the top resources utilized for countermeasure selection. The reported frequency of usage is noted in parenthesis.

- ADA guidelines (80.6%)
- Solicit public input (52.8%)
- Internal design resource (41.7%)
- Cost-benefit analysis (38.9%)
- CMF Clearinghouse (36.1%)
- FHWA's Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations (27.8%)
- External design resources (22.2%)
- FHWA Toolbox of Countermeasures (22.2%)
- Internal countermeasure resources (19.4%)
- NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings (19.4%)
- Consult other original research (19.4%)
- Other methods (19.4%)
- PEDSAFE (13.9%)

CMF Clearinghouse

The Crash Modification Factor (CMF) Clearinghouse (FHWA, 2023b) is an online database of highway safety countermeasures that is sponsored by FHWA. A CMF specifies the proportion of crashes expected after the deployment of a safety countermeasure. It is a measure of the effectiveness of a countermeasure. CMFs could be employed to produce an estimate of the expected benefits as part of a cost-benefit analysis. The Clearinghouse also provides a quality rating for a particular CMF. CMF quality is dependent on various factors such as the study design, size and quality of data, methodology, and statistical confidence. Many VRU-related countermeasures are available in the Clearinghouse. Appendix B includes a summary of the information from the Clearinghouse for some of the proven low-cost VRU countermeasures. In general, the existing CMF values for VRU countermeasures are somewhat complicated to use due to several reasons. First, there are often contradictory values for the same countermeasure presented in the same research journal. For example, a single report on the installation of bike lanes presented disparate CMF values of 1.69 (2 stars), 0.86 (2 stars), and 2.24 (3 stars). In other words, the countermeasures could have produced a large increase or decrease in crashes. The existence of seemingly contradictory CMF values is not unusual. Sometimes researchers use various equation forms to model the same dataset. Data from different locations could reflect local conditions and produce different values. And different statistical modeling methodologies could produce different values. Gross et al. (2010) lists six common methods of generating CMFs, including Empirical Bayes Before-After study, before-after with comparison group study, cross-sectional study, case-control study, and cohort study. The use of a different CMF methodology could yield very different values. Second, HSM (AASHTO, 2010) guidance allows CMFs to be multiplied with each other, thus assuming that they are independent. However, many VRU countermeasures are highly dependent and are often deployed in conjunction with each other. The independence assumption potentially overinflates the effects of multiple CMFs. Third, it is sometimes difficult to know if the CMF value derived using data from other states will translate well in a local jurisdiction. Having laid out some of the difficulties associated with the use of CMFs, they are nonetheless some of the best sources of information on the quantitative benefits of countermeasures. The reader is encouraged to use them in prioritizing their deployment of countermeasures, albeit with caution.

Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations

Zegeer et al. (2005) produced a report on crosswalks that is dated but is referenced by many agencies. This report not only discussed the performance of marked crosswalks but also provided recommendations for improving pedestrian safety at crossings. The report concluded that marked crosswalks at an uncontrolled location resulted in no difference in pedestrian crash rate. The report determined that raised medians decreased significantly pedestrian crash rates. Other recommendations include the use of traffic signals with pedestrian signals when warranted, installing traffic-calming devices (e.g., raised crossings, street narrowing, diverters), providing nighttime lighting, using access management, and implementing different types of warnings (e.g., flashers, signs), and eliminating parking.

Pedestrian and Bicycle Crash Analysis Tool

FHWA's Pedestrian and Bicycle Crash Analysis Tool (PBCAT) (Thomas et al., 2022) is a web-based program that assists in crash typing specific crashes. Crash typing is a way of analyzing precrash circumstances in order to determine preventative strategies. Crash typing is a precursor to analysis of possible countermeasures. The program asks a set of questions with preselected responses to generate the crash type. For example, it asks the user to describe the location of the incident, the motorist's behavior, and the non-motorist's behavior. Even though crash typing could be useful, the information needed requires that a user read the witness narratives and study the collision diagram. PBCAT is therefore somewhat labor intensive.

Evaluation of Bicycle-Related Roadway Measures

Mead et al. (2014) produced a summary of bicycle-related roadway measures for the FHWA-supported pedestrian and bicycle information center. They classified countermeasures into eight categories of shared roadway, on-road, intersection, maintenance, traffic calming, trail/shared-use path, markings/signs/signals, and other miscellaneous. The shared roadway treatments include road surface, bridge/tunnel/overpass/underpass access, lighting, parking, median, driveway, and lane reduction and narrowing. On-road facilities include various types of bike lanes, paved shoulders, and contraflow bike lanes. Intersection improvements include curb radii change, roundabout, markings, sight distance improvement, turning restriction, and merge/weave areas. Traffic calming include mini traffic circles, chicanes, speed tables/humps, diversion, bike boulevards, and visual narrowing. Trail/shared-use path improvements include separation, path treatments, and intersection treatments. Markings/signs/signals include bicycle pavement markings, signs, rectangular rapid flashing beacon (RRFB), High-Intensity Activated crossWalK (HAWK) beacon or hybrid beacon, signal detection, optimized signal timing, and bicycle signal head. Other miscellaneous treatments include enforcement, education, wayfinding, and other bicycle-friendly policies. This report was an outgrowth of the unpublished HSM Knowledge Document and is consistent with the focus of FHWA's Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE).

VRU Countermeasures

In order to be consistent with previous MoDOT efforts, the discussion of countermeasures will be organized in a similar fashion as the research report on pedestrian countermeasures (Tobias et al. 2022). The countermeasures presented here are all low-cost, and most of them have benefits documented through research and case studies. Some are promoted by the FHWA as a Proven Safety Countermeasure related to VRU safety (e.g., crosswalk visibility enhancements, rectangular rapid flashing beacons). The countermeasures were categorized according to roadway segment or intersection only for ease of organization. Many countermeasures could apply to multiple types of locations. For example, crosswalk treatments could apply to either a mid-block crosswalk or an intersection crosswalk.

Roadway Segment Countermeasures

Rectangular Rapid Flashing Beacon

The rectangular rapid flashing beacon (RRFB) has two rectangular-shaped yellow LED lights that flash in an irregular pattern after being actuated by a VRU, either automatically or manually. The deployment of the RRFB in non-actuated mode is discouraged. The beacon is placed below the VRU crossing sign and above the diagonal downward arrow pointing at the crossing. The RRFB can raise driver awareness of crossing locations and alert of crossing VRUs. The potential safety benefits include a 47% reduction in pedestrian crashes and a yield rate of up to 98% (Zegeer et al., 2017). FHWA (n.d.) recommends RRFB deployment in multilane crossing with speed limits of less than 40 mph. Figure 7-1 shows an example of RRFB deployed at a crosswalk along with signage.

Figure 7-1 Example of RRFB (Source: FHWA-SA-21-053)

Pedestrian Hybrid Beacon

Pedestrian Hybrid Beacon (PHB) is also known as the high-intensity activated crosswalk (HAWK) beacon. The PHB is suitable for deployment at an unsignalized location. The PHB signal head has two red lenses over a single yellow lens. The lenses are dark until activated by a VRU. The PHB then flashes yellow to alert drivers and changes to solid yellow and then solid red. NCHRP (Zegeer et al., 2017) reports the potential to reduce 69% of pedestrian crashes. NCHRP (NAS, 2016) reports the usage of PHBs in 75% of the states and 65% of municipalities. Figure 7-2 shows an example of a PHB near a university in Columbia, Missouri.

Figure 7-2 Example of PHB Signal (Source: Columbia Daily Tribune, 2015)

Narrowing Travel Lanes

The narrowing of travel lanes, also known as lane diets, involves reducing lane widths from 12 ft down to 11, 10, or 9 ft. One caveat is the impact on large vehicles such as buses and trucks. A lane diet has several potential benefits. First, there is a reduction in pedestrian crossing distances thus reducing exposure. Second, the reduction has the potential to provide space for other countermeasures such as widening sidewalks, buffer spaces, and bike lanes. Because lane diet implementations and purposes (e.g., to increase the number of lanes instead of safety) can vary, the safety effects of lane reductions have been mixed. For example, Harwood (1990) reported a total crash reduction of between 24% and 55% when narrowing occurred in conjunction with the installation of a center two-way left-turn lane. NCHRP (NAS, 2016) reports 67% of states and 78% of municipalities surveyed have used narrower lanes to improve pedestrian safety.

Road Diets (e.g. 4 to 3)

Road diets, also known as road conversions, is the reduction in the number of traffic lanes, often the through lanes. For example, a four-lane road with two through lanes in each direction is converted into three lanes with a center two-way left-turn lane (TWLTL) and expanded buffer space to bicycle and pedestrian facilities. The potential safety improvements can result from traffic speed reduction, access management, and greater separation from bicyclists and pedestrians. Beyond safety, there could also be additional benefits such as improved parking and land use. NCHRP (NAS, 2016) recommends limiting this countermeasure to an ADT of 25,000. NCHRP reports 78% of states and 72% of municipalities surveyed have used road diets. Harkey et al. (2008) reported a CMF of 0.71. Figure 7-3 shows an example of a conceptual drawing of a roadway that was converted into a three lane with a TWLTL.

Figure 7-3 Example of a Drawing of a Road Diet (Source: BikeWalkKC)

Raised Medians and Median Islands

Raised medians and median islands, also known as center islands, refuge islands, or pedestrian islands, protect VRUs by providing a raised area. These areas provide separation from vehicles, thus refuge, and allows VRUs to focus on one direction of traffic at a time in looking for gaps. Zegeer et al. (2002) reported CMF values for raised medians of 0.54 and 0.61 for marked and unmarked crosswalks, respectively. In terms of raised medians, NCHRP (NAS, 2016) reports 89% of states and 67% of municipalities surveyed have used them. The most frequent reason cited for the use of raised medians is to manage access by reducing the number of conflict points in the VRU’s path of travel. They are commonly employed at higher-speed and higher-volume facilities such as multilane highways.

In terms of median islands, 97% of states and 94% of municipalities surveyed have used them. NCHRP (NAS, 2016) discussed two general reasonings for deploying them. The majority approach is to deploy for high-speed and high-volume facilities with characteristics such as multiple lanes. Some use an opportunistic approach where the median islands fit into an existing situation such as TWLTL and sufficient right-of-way.

Raised Crosswalks

Crosswalk treatments such as raised crosswalks and high visibility crosswalks apply to any situation where crosswalks are implemented. Thus they involve many intersection scenarios but could also apply to mid-block locations. Raised crosswalks have a dual effect of both calming vehicular traffic and enhancing VRU visibility by elevating the crosswalk with respect to the travel lanes. There is evidence that there is improved VRU scanning by drivers (NAS, 2016). The crosswalk can be considered as an extension of a sidewalk since it is elevated to the height of the sidewalk. The raised crosswalk performs similar to a speed table typically used on residential facilities to manage speeds. Bahar et al. (2007) reported a CMF value of 0.70 for all crashes. Potential issues with raised crosswalks include discomfort for vehicles (e.g. emergency vehicles), noise, and drainage. NCHRP (NAS, 2016) reports a CMF of 0.70 for all crashes and 0.64 for fatal injury crashes. NCHRP reports that only 17% of states used them, while 72% of the municipalities surveyed used them. The reason for the low state usage is due to them being more applicable for use in residential facilities.

Figure 7-4 Example of a Raised Crosswalk Installation in Springfield (Source: CivicEngage, 2022)

High Visibility Crosswalks

The MUTCD (FHWA, 2009) describes marked crosswalks as defining and delineating paths for pedestrians. High visibility refers to types of markings such as ladder, continental, bar pairs, and triple four markings. These markings improve visibility via wider lines or additional lines (Zegeer et al., 2017). One benefit of this type of a crosswalk is the increased visibility to drivers and the resulting increase in yielding to VRUs. NCHRP (NAS, 2016) reports that high visibility crosswalks have a CMF value of 0.52, generally, and 0.63 in school zones. NCHRP notes that almost all jurisdictions surveyed have used them and 25% use them at all marked crosswalks. Some use them for certain conditions such as school zones, high VRU demand, wide roads, and high-speed facilities. Figure 7-5 shows a conceptual diagram of a high visibility mid-block crosswalk along with other enhancements.

Figure 7-5 Diagram of a High Visibility Crosswalk (Source: FHWA-SA-21-049)

Enhanced Illumination at Crossings

Not to be confused with general roadway lighting for vehicles, illumination at crossing is targeted specifically for VRUs. The lighting is typically deployed on both approaches to a crosswalk and the crosswalk itself. The CMF values include 0.73 for injury crashes and 0.79 for all crashes (Harkey et al. 2008). NCHRP (NAS, 2016) reported that 72% of the states and 78%

of the municipalities have used such a treatment. Often, illumination is deployed in conjunction with beacons.

Automated VRU Detection

Automated VRU detection (e.g., Pedestrian User-Friendly Intelligent (PUFFIN)) eliminates the need for a VRU to manually push a button, and it could also extend the walk phase for slower VRUs. Reliability and maintenance were two noted issues that prevented greater use in the U.S. compared to Europe and Australia (NAS, 2016). Because this technology is relatively new in the U.S., there is only limited information available and no reported statistical findings on its effectiveness. Figure 7-6 shows examples of the PUFFIN signal with the VRU detector circled in red.

Figure 7-6 Examples of Automated VRU Detection (Source: PEDSAFE)

Intersection Countermeasures

VRU Refuge Islands

Refuge islands are also known as center islands or pedestrian islands. They are deployed at mid-block locations in addition to intersections. The island allows VRUs to focus on one direction of traffic at a time. When combined with curb extensions, they shorten the distance and exposure at which VRUs are at the same vertical level as traffic. The reported safety benefits varied, but one study showed reductions of pedestrian crashes by 23% and 33% when replacing painted medians (Zegeer et al., 2017).

Advance Stop/Yield Bar and Signs

Advance markings and signs are placed upstream (e.g., 30 ft) from crosswalks to provide advanced warning to drivers and allow for a buffer space in case subsequent vehicles were unable to see a VRU in the crosswalk. The markings can be supplemented with the MUTCD R1-5 ("Stop Here for Pedestrians") or R1-5a signs. Parking is restricted between the advanced markings and the crosswalk. Some have reported that vehicle stopping distance increases with such treatments even though the marginal increase in vehicles stopping or yielding is small (e.g., Van Houten et al., 2002). NCHRP reports that nearly 90% of the state and municipalities surveyed use such treatments.

In-Roadway "Yield to Pedestrian" Signs

The MUTCD R1-6 "Yield to Pedestrian" signs are placed in the middle of an uncontrolled crosswalk or median island. NCHRP (NAS, 2016) reports that there is only limited knowledge about the safety effects of such signs. Some note that the signs could be easily damaged since they are in the middle of the roadway. NCHRP (NAS, 2016) reports that 70% of the states and municipalities use such signs. Figure 7-7 shows an in-roadway crossing sign on Broadway in Cape Girardeau.

Figure 7-7 Example of an In-Roadway Pedestrian Crossing Sign (Source: Southeast Missourian)

Pedestrian Warning Signs

The MUTCD W11-2 pedestrian crossing warning sign can be deployed in locations where pedestrians are not expected. Evidence for the effectiveness of such signs alone is lacking. This may be due to the fact that the sign is often deployed in conjunction with other treatments. NCHRP (NAS, 2016) reports that 100% of the states and 88% of the municipalities surveyed have used such warning signs. Some agencies note that they use such signs under certain circumstances such as near schools and bus stops or when there are sign distance issues.

Parking Restrictions

Vehicles parked too close to intersections and crosswalks can affect the mutual visibility of both VRUs and vehicles. Parking restrictions reduce the potential for VRUs darting out. Such restrictions can be used in conjunction with physical barriers such as bulb outs or bicycle parking to prevent illegal parking. NCHRP (NAS, 2016) recommends a restriction of at least 20 ft. NCHRP presents a CMF of 0.7 for pedestrian crashes (Gan et al., 2005). NCHRP reports 75% of states and 88% of municipalities surveyed have used parking restrictions.

Reduced Curb Radii

A reduction in the curb radius results in a sharper turn and a decrease in vehicle turning speeds. A smaller curb also results in more curb area for VRUs to use. A potential issue with this treatment is more difficulty for large vehicles, such as emergency vehicles or buses, to navigate the smaller radius. Another issue is vehicles encroaching upon the curb. Thomas et al. (2015) developed an equation to estimate the CMF value based on the skew angle as skew can lead to a wide curb radius. NCHRP (NAS, 2016) reports that 64% of the states and 78% of municipalities surveyed used curb radius reduction. Some agencies have a policy of using the minimum curb radius for a given design vehicle. Figure 7-8 illustrates how a smaller curb radius changes a vehicle's right turning path for both trucks and passenger vehicles.

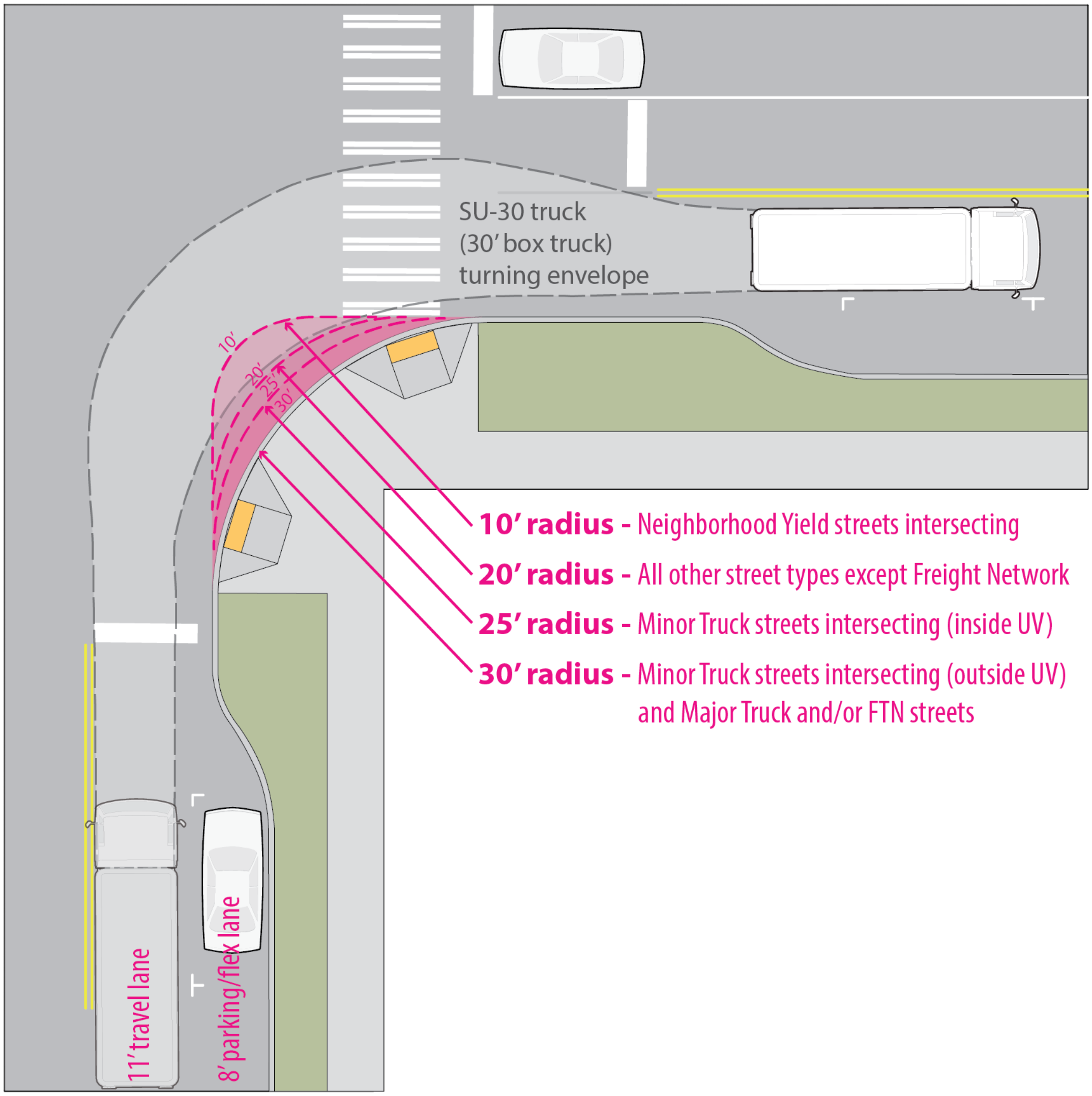


Figure 7-8 Curb-Radius Design Guide Example (Source: City of Seattle ROW Manual)

Curb Extensions/Bulb-Out

Curb extensions, also known as bulb-outs and neck-downs, extend the curb into the street and shorten the distance that VRUs have to travel while crossing the street. The potential benefits include increasing VRU visibility due to the elevation on the curb, reducing crossing distances, deterring vehicles from parking near intersections and occluding, and reducing curb radii and slowing turning vehicles. There is some evidence that such treatments slow turning traffic leading to crash reductions (King, 1999). NCHRP (NAS, 2016) reports that 94% of the states and municipalities surveyed use them for specific situations. Factors for using this treatment include downtown settings, high VRU traffic, and improving VRU safety. They are often used in conjunction with marked crosswalks, high-visibility crosswalks, pedestrian signals, pedestrian beacons, and leading pedestrian intervals. Figure 7-9 shows an example of bulb-out being implemented in an existing intersection in the Volker neighborhood in Kansas City.

Figure 7-9 Example of Bulbouts in Kansas City (Source: volkerkcmo.org)

Leading Pedestrian Interval (LPI)

A leading pedestrian interval (LPI) is the green time given to VRUs only before the onset of the parallel vehicular green time. This leading interval varies between 3 and 7 seconds. Since VRUs are released before vehicular traffic, they have already established their presence in front of motorists. Reported CMF values vary but a recent study presented a value of 0.41 for pedestrian-vehicle crashes (Fayish and Gross, 2010). NCHRP (NAS, 2016) reports that 61% of states and 77% of municipalities surveys used LPIs. Applicable conditions for LPI deployment include situations involving aggressive drivers and relatively low VRU volumes insufficient to command driver attention, heavy turning volumes, multiple turn lanes, and high elderly VRU demand.

Pedestrian Countdown Timers

Pedestrian countdown timers are signals that show the remaining pedestrian time. The counting starts at the beginning of the flashing “DON’T WALK” and ends at the display of the solid “DON’T WALK.” The timers help VRUs to judge whether there is sufficient time to cross. This is especially helpful to the mobility-challenged, the elderly, and adults with small children. The CMF value for the most successful study is 0.75 (Markowitz et al., 2006). There does not appear to be any negative effects on motorist behavior with countdown timers. The MUTCD (FHWA,

2009) requires any new pedestrian signals to implement countdown timers. Figure 7-10 shows an example of a VRU countdown signal head.

Figure 7-10 Example of a VRU Countdown Timer (Source: Chicago Metropolitan Agency for Planning)

No Right Turn on Red

In jurisdictions that do not prohibit right turn on red (RTOR), such as a turn could be made after a full stop and yielding to any VRUs. The RTOR prohibition helps to reduce situations where motorists fail to yield to VRUs. One reason for the failure to yield is a driver's attention on the vehicles to their left. No RTOR also helps to reduce the likelihood of vehicles moving into the crosswalk as they wait for a gap in traffic to make the right turn. NCHRP (NAS, 2016) recommends the treatment for locations with high VRU volumes. Harkey et al., 2008 reports a CMF value of 0.97, a small crash reduction, possibly reflecting the small percentage of RTOR crashes at intersections. NCHRP reports 86% of states and 94% of municipalities surveyed have used no RTOR at select locations. Figure 7-11 shows an example of a RTOR restriction in St. Charles County.

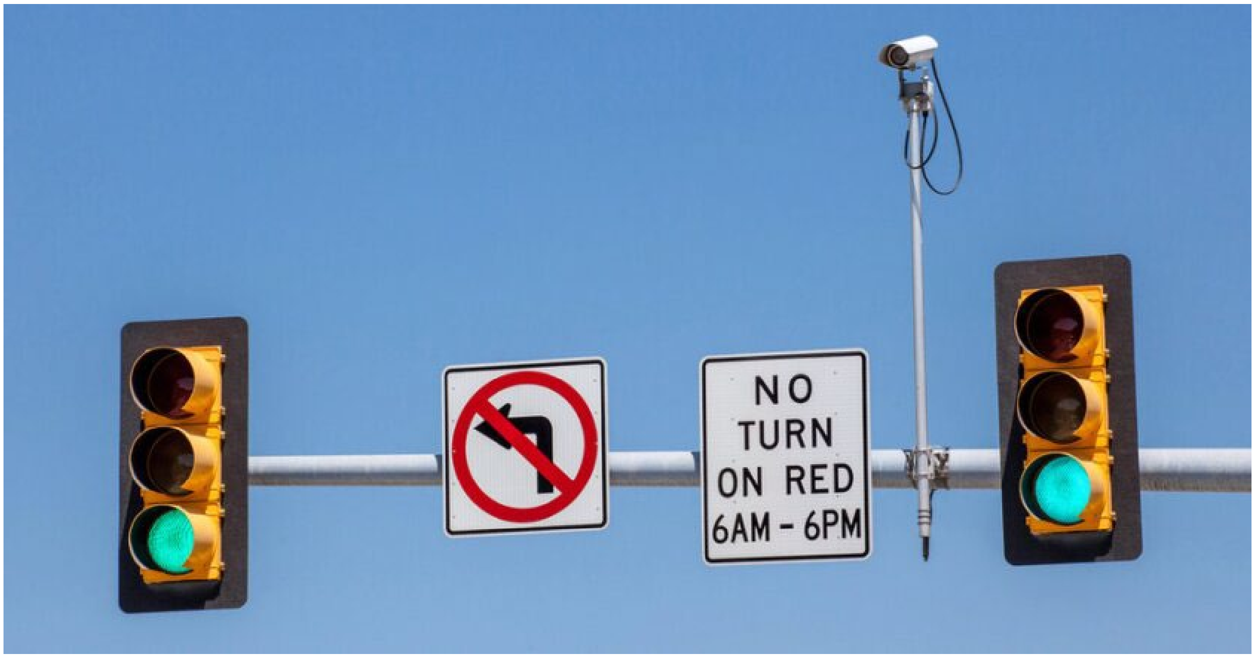


Figure 7-11 Example of No RTOR (Source: St. Louis Post-Dispatch, 2022)

Crosswalk Lighting

Crosswalk lighting makes VRUs more visible during nighttime and low-visibility conditions. Commercial areas, streets and building lights could provide ambient lighting that enhances VRU visibility. Harkey et al., 2008 presents a CMF value of 0.73 for injury crashes and 0.79 for all crashes at intersections. For road segments, the CMF is 0.77 for injury crashes and 0.80 for all crashes. NCHRP (NAS, 2016) reports that 72% of states and 78% of municipalities surveyed used lighting at crossings under certain circumstances.

8. STAKEHOLDER ENGAGEMENT

As per federal requirements (Walker, 2022), relevant stakeholder agencies were consulted on the desirability and feasibility of various priorities and strategies. Various types of agencies were involved including metropolitan planning organizations (MPOs), regional planning commissions (RPCs), MoDOT districts, counties, cities, and VRU advocacy groups. Feedback from stakeholders were obtained from an electronic survey, two stakeholder engagement meetings, and a video conference targeting the St. Louis area. There were more than 90 stakeholders engaged throughout the project. The stakeholders represented the entire state of Missouri and were from all seven MoDOT districts in the state. This chapter is divided between a discussion of the stakeholder surveys and a summary of the hybrid stakeholder meetings.

Stakeholder Surveys

An electronic survey was sent to the main agencies and organizations that are involved with VRU safety. The survey started at the end of July, 2023, and was active for two weeks. The survey questions and possible answers are presented in Appendix A. There was a total of 39 respondents. There were three initial questions that involve describing the respondents. Figure 8-1 shows the distribution of respondents across various agencies. The two largest types of agencies were MoDOT (33.3%) and MPO (23.1%). There were county representatives that participated in the stakeholder engagement meetings; however, there were no county respondents for the survey.

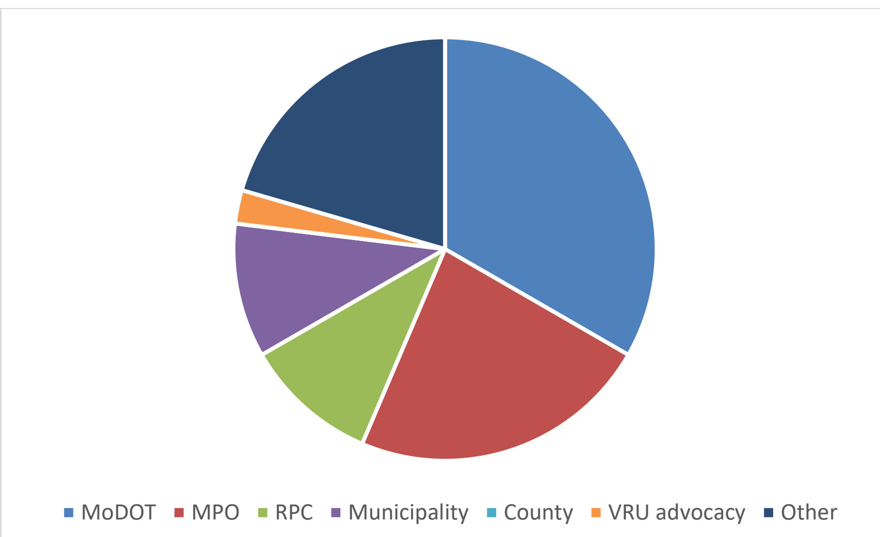


Figure 8-1 Responding Agencies

Table 8-1 shows the distribution of the survey respondents by MoDOT district. All seven MoDOT districts were represented in the survey, but there were large contingencies from the Southwest and St. Louis districts. These two districts contain the large metropolitan areas of St. Louis and Springfield. These two districts encompassed 12 out of 16 of the high-crash intersections in Missouri. St. Louis also has 8 out of 10 high-crash corridors in Missouri.

Table 8-1 Distribution of Respondents by MoDOT District

District #	District Name	Percent Response
1	Northwest	5.1%
2	Northeast	5.1%
3	Central	2.6%
4	St. Louis	33.3%
5	Southwest	48.7%
6	Southeast	2.6%
7	Kansas City	2.6%

Table 8-2 shows the years of experience with VRU safety for each respondent. A high proportion of the respondents (41%) had three or fewer years of experience. In addition to countermeasures, this result points to a need to train and mentor new staff involved in VRU safety. Providing personnel mentoring and development opportunities could be part of a comprehensive safety plan.

Table 8-2 Years of Involvement with VRU Safety

# of Years	%
0-3 years	41.03%
4-6 years	7.69%
7-10 years	17.95%
11-15 years	10.26%
16-20 years	10.26%
> 20 years	12.82%

Subsequent questions addressed systemic safety, contributing factors, and countermeasures. Respondents were asked to select the highest priority intersections that they intend to focus on for VRU safety. Multiple selections were allowed. The same classification scheme used in systemic analysis was used in the survey. In other words, intersections were classified according to population density (rural/urban/urbanized), number of legs, and signalization (yes/no). Figure 8-2 shows U4N (15.8%) and U4Y (19.3%) being the highest types of intersections selected. There appears to be an overwhelming interest in urban and urbanized intersections as U3N (8.8%), U3Y (8.8%), Z4N (10.5%), and Z4Y (8.8%) also received high interest. The preferences revealed by the survey differ from the systemic analysis results. Table 4-3 shows that the highest crash frequencies are dominated by the urbanized facilities of Z3N (34%), Z3Y (10.3%), Z4N (11%), and Z4Y (12.4%). Perhaps, many respondents did not have jurisdiction over urbanized facilities even though they work in MoDOT districts that encompass major metropolitan areas.

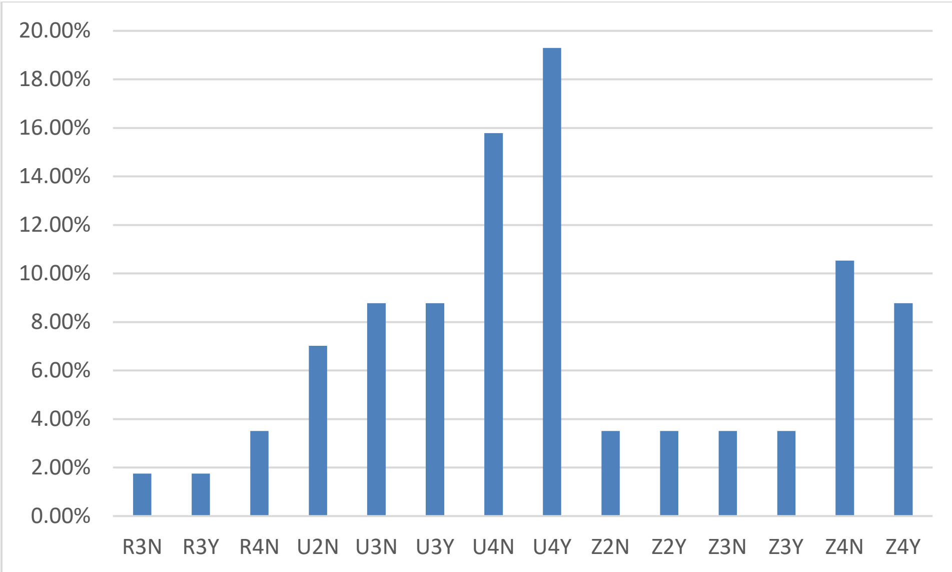


Figure 8-2 Highest Priority Intersection Type

Figure 8-3 shows the U2U, U4D, U4U, U6U, and Z4U as the highest priority segments that stakeholders intend to focus on. Except for one type, they are all undivided facilities. Also, except for one urbanized facility, they are all urban facilities. The facilities selected in the survey differ from the facilities highlighted via the systemic analysis. The facilities with the highest crash frequencies shown in Table 4-4 are R2U, R4D, Z2U, Z4D, Z4U, Z6D, Z6U, and Z8D. In other words, the survey results focus on urban facilities, while the systemic analysis results focus on some rural and many urbanized facilities.

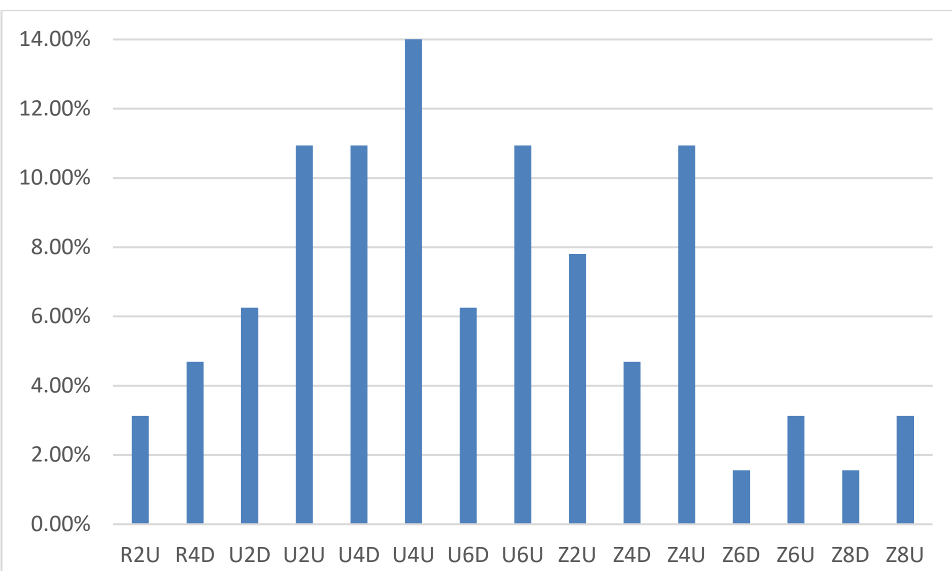


Figure 8-3 Highest Priority Segment Types

Figure 8-4 shows the top contributing factors that stakeholders intend to focus on. Vehicular speeding, distracted driving/walking/rolling, and human behavior are the ones mentioned the most often in the survey. This emphasis is consistent with the high priorities listed in Missouri's strategic highway safety plan, Show-Me Zero (MoDOT, 2022). This is also consistent with a deep dive of VRU crash reports. When the witness narratives, police summaries, and collision diagrams were consulted, there is an overwhelming sense that human factors are frequent and controlling. In other words, aggressive and distracted behaviors are some of the most dominating contributory factors in VRU crash scenarios. Other contributing factors noted as important in the survey, i.e., transit stops, equity, and lighting, are also noted in the federal guidance (Walker, 2022) as important factors to consider in VRU safety planning. The crash results point to the same concerns documented in the survey. Table 6-1 shows that severe crashes occur more often in qualified low-income areas (58.8% for fatal and 61% for severe injury). The crash analysis of transit areas shows that around 35% of VRU crashes occurred within 200 feet of bus stops in metropolitan St. Louis and Kansas City areas. For lighting, the crash results showed differences between intersections and segments, as a significant proportion of artificially lit intersections still experience VRU crashes.

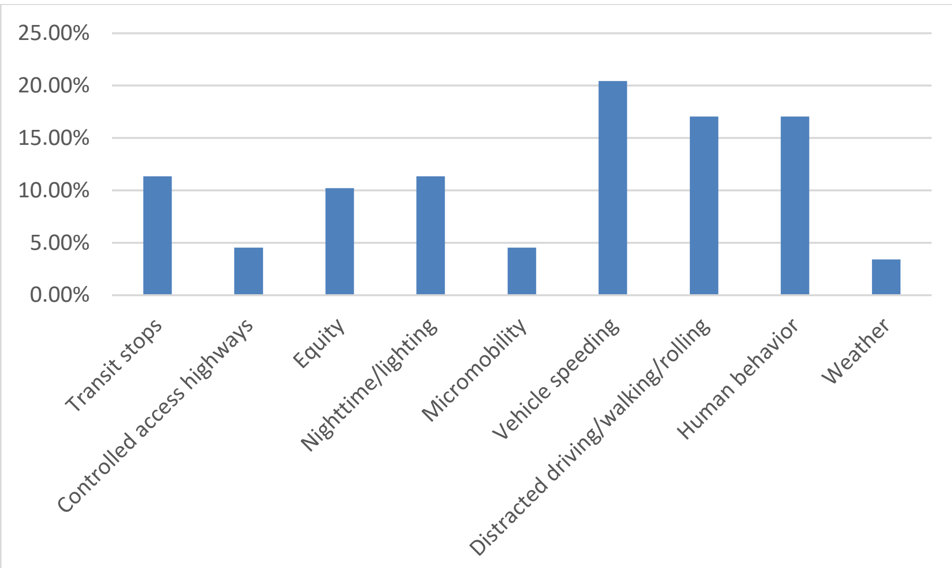


Figure 8-4 Top Contributing Factors from Stakeholder Survey

There were several questions that concerned countermeasures for improving VRU safety. Because there is only limited guidance concerning countermeasure deployment, such as the limited availability of CMFs and the lack of understanding between the interaction effects among multiple countermeasures, the experience of local agencies in Missouri captured by the survey provides a valuable source of guidance. There are a few points to note about how the countermeasure survey questions were developed. First, most of the countermeasures listed are proven low-cost countermeasures. Many of these countermeasures were part of the FHWA Every Day Counts initiatives and have a documented history of state deployments and case studies. Second, some previous deployments and/or research have only focused on one mode of VRU such as walking or biking. The current integrated VRU approach would necessitate the consideration of all VRU modes and potentially different tradeoffs among different VRU modes. Even terminology is sometimes tied to one mode, e.g., pedestrian signal, when in reality a countermeasure could serve multiple VRU modes.

Figure 8-5 shows the segment countermeasures that are commonly implemented for stakeholders. All of the countermeasures were utilized by the stakeholders with the ones used most being speed reduction measures such as signs and speed feedback trailers, sidewalks, road narrowing, road diets, raised medians, high-visibility sidewalks, and flashers/beacons. Figure 8-6 shows the intersection countermeasures that are commonly implemented for the surveyed stakeholders. The most frequently utilized countermeasures are advanced stop/yield bars, curb extensions, and conversions to roundabout. The least used countermeasures are automated VRU detection, probably due to newness and cost, and the removal of channelized right turns.

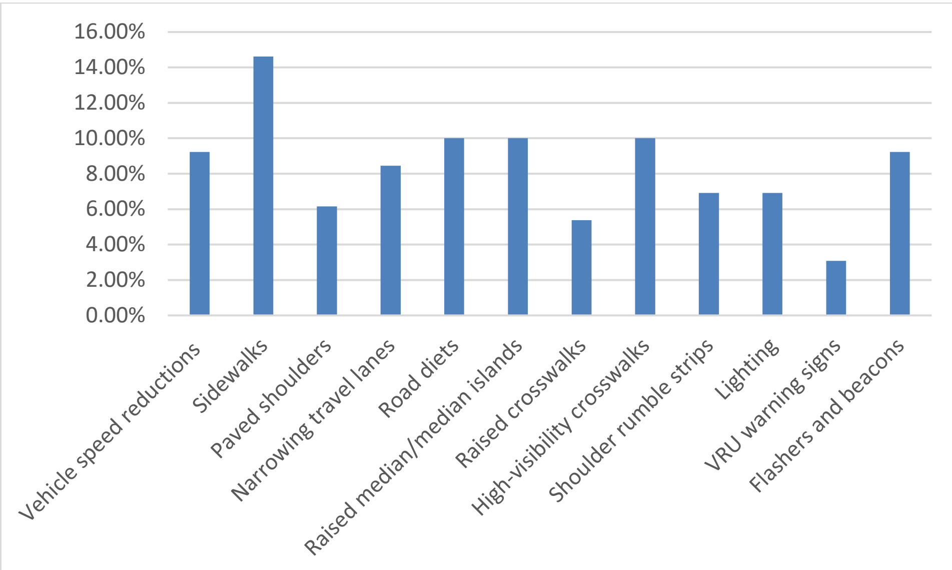


Figure 8-5 Top Segment Countermeasures from Stakeholder Survey

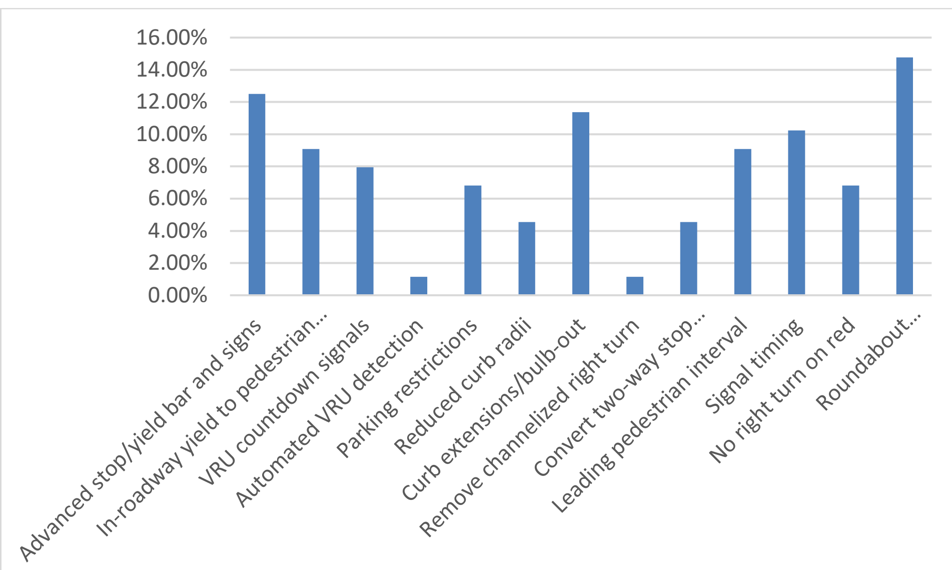


Figure 8-6 Top Intersection Countermeasures from Stakeholder Survey

There were two follow up questions related to countermeasures that asked if there were countermeasures that an agency is interested in exploring in the future. This contrasts with the previous two questions that focused on what has been done before. Figure 8-7 and Figure 8-8 present the results for what stakeholders would like to deploy in the future. For segments, the answer differs only slightly from what is deployed currently. Raised crosswalks and lighting were the two countermeasures that could result in greater deployment in the future. For intersections, agencies expressed an interest in exploring some countermeasures that are currently not deployed as frequently such as automated VRU detection and removing channelized right turns.

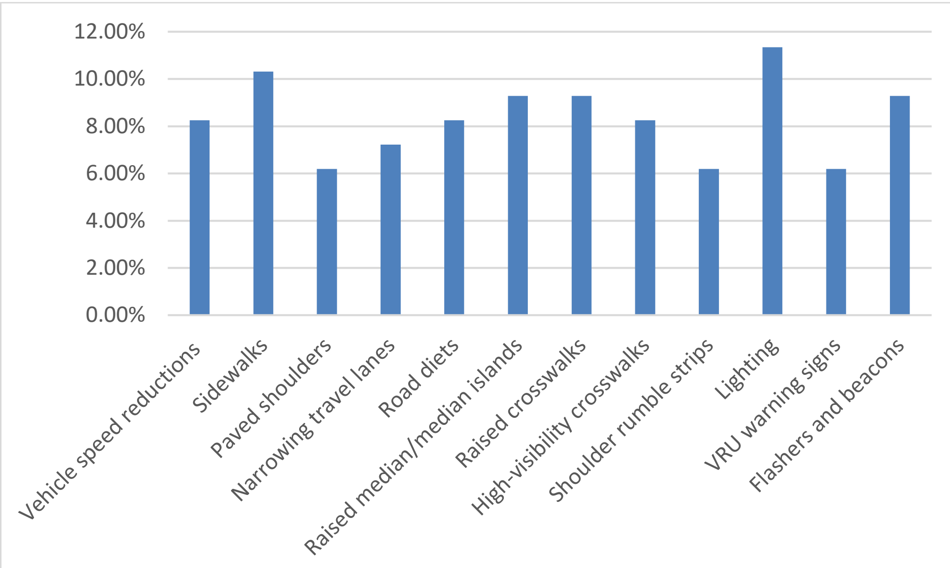


Figure 8-7 Future Segment Countermeasures from Stakeholder Survey

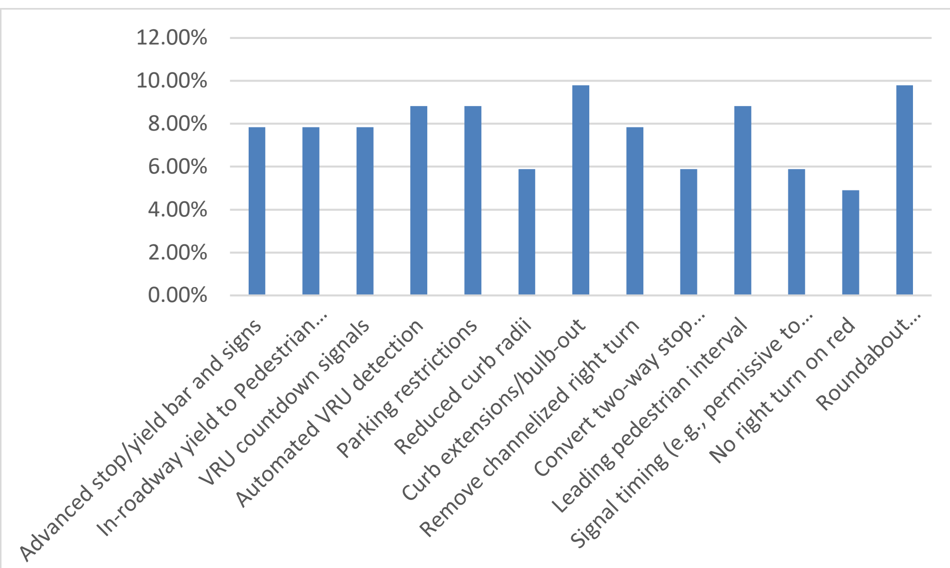


Figure 8-8 Future Intersection Countermeasures from Stakeholder Survey

The survey also allowed respondents to leave written comments. One comment was about the use of VRU fencing which was a countermeasure not listed on the survey. Another comment concerned the safety of baggage/luggage carried by unhoused transit riders and the resulting increased loading time and capacity of buses. One person expressed the concern over some transit-related countermeasures that might improve pedestrian safety while deteriorating transit service. For example, decreasing turning radius, narrowing lanes, and implementing bulb outs could affect the maneuverability of large transit vehicles and even emergency vehicles.

Stakeholder Engagement Meetings

Two separate stakeholder engagement meetings were conducted on two different days: July 17 and August 17, 2023. The meetings were held after the bulk of the crash data analysis was completed so that systemic and high-crash analyses results could be presented to stakeholders. The meetings were hybrid meetings with both in-person and remote options. The attendance at the first meeting was 38 which included 8 TAC and research team members. The attendance at the second meeting was 23 which included 5 TAC and research team members. The list of attendees along with the contact information is presented in Appendix C: Stakeholder Contact Information. This list could be used for future engagements such as when the VRU safety assessment plan is to be revised.

Table 8-3 provides details of the participating stakeholders. The stakeholder meetings captured agencies that were representative of the entire state geographically and population-wise. Column 2 shows that there was representation from various MoDOT districts. Column 3 shows that the organization ranged from large metropolitan organizations of close to three million people to small cities and RPCs that served rural communities. In terms of organization type, there was participation from MPOs, RPCs, counties, cities, and advocacy organizations.

Table 8-3 Stakeholder Characteristics

Agency Name	MoDOT District	Population	Organization Type
BikeWalkKC	KC	-	Advocacy Organization
East-West Gateway Council of Governments	SL	2,820,253	MPO
Harry S Truman Coordinating Council	SW	217,000	RPC - Barton, Jasper, McDonald, and Newton counties
Jefferson City	CD	43,228	City
Kansas City	KC	508,394	City
Kaysinger Basin Regional Planning Commission	SW	111,297	RPC - Bates, Benton, Cedar, Henry, Hickory, St Clair, and Vernon counties
Lake St. Louis	SL	17,311	City
Mark Twain Regional Council of Governments	NE	121,872	RPC - Audrain, Macon, Marion, Monroe, Pike, Ralls, Randolph, and Shelby counties
Mid-America Regional Council	KC	2,806,615	MPO
Southwest Missouri Council of Governments	SW	657,287	RPC - Barry, Christian, Dade, Dallas, Greene, Lawrence, Polk, Stone, Taney, and Webster counties
Mo-Kan Regional Council	NW	133,578	RPC - Andrew, Buchanan, Clinton, and Dekalb counties MO
Northwest Arkansas Regional Planning Commission	SW	558,507	MPO - McDonald County (MO)
O'Fallon	SL	93,644	City
Ozark Foothills Regional Planning Commission	SE	74,048	RPC - Butler, Carter, Reynolds, Ripley, and Wayne counties
Ozarks Transportation Organization	SW	475,432	MPO - Greene and Christian counties
Springfield	SW	169,724	City
St. Charles County	SL	409,981	County
St. Charles	SL	70,493	City
St. Joseph	NW	70,656	City
St. Louis County	SL	997,187	County
St. Peters	SL	58,523	City
Pioneer Trails Regional Planning Commission	KC	153,689	RPC - Johnson, Lafayette, Pettis, and Saline counties

For each stakeholder meeting, the results of the VRU safety assessment were presented. Specifically, the crash data analysis results presented included systemic facilities, high-crash locations (intersections, segments, and corridors), and select contributing factors such as transit, poverty, and nighttime. Throughout the meeting, feedback was solicited and obtained from the stakeholders.

The following are highlights from the stakeholder discussions.

- Jefferson City suggested more exploration of education and outreach as long-term countermeasures. The Missouri Coalition has centralized programs for that purpose.
- Mo-Kan mentioned the difficulty in implementing improvements in low volume roads in rural areas. They also mentioned the lack of shoulders as a factor in safety.
- FHWA recommended comparing the safety of pedestrian intersection lighting versus generic intersection lighting. Lighting information in crash reports is very basic.
- There was interest from various stakeholders about the intelligent VRU signals such as Puffin and Toucan which can detect and extend VRU signal times.
- St. Charles County will be deploying Signal Performance Measures systems which can collect pedestrian and bicyclist demand data.
- There were some discussions on the correlation between trail access points and crashes.
- Several stakeholders were interested in exploring roundabout conversions even in rural areas.
- East-West Gateway expressed difficulty in obtaining funding for implementing VRU safety improvements on high crash corridors in St. Louis.
- Stakeholders mentioned the importance of ADA issues and that sidewalks have deteriorated.
- Some expressed that there was stronger opposition to Complete Streets in rural areas compared to urban.
- There was much interest in the use of LPI in the metro areas of St. Louis and Kansas City.
- Some had interest in looking into VRU safety for special events.
- Bike Walk KC suggested the use of traffic ticket data and to investigate equity issues with enforcement. Overenforcement could potentially be less effective than other methods.
- Several suggested investigating the effect of different sized vehicles on VRU safety beyond just commercial vehicles.
- Many were interested in controlling vehicle speed, including the use of automated speed governors.
- MoDOT mentioned that the new distracted driving law will go into effect in August, 2023.
- There were some discussions on future vehicular technologies such as automated VRU detection, VRU active hood crumble zones, and electric autonomous vehicle fleets.
- Springfield raised the issue of underreported crashes. The use of hospital data could be one source of complementary data.
- Some raised the issue of Complete Streets policy. MoDOT is investigating updating policies.
- BikeWalkKC recommended the importance of raising public consciousness and the need to change public perceptions of the built-in environment.

- Springfield suggested the use of compliance data as a surrogate for safety. Compliance data could be another way measuring the effectiveness of countermeasures.

The following are some concluding thoughts on the stakeholder engagement efforts. As shown by the high number of participants, there is great interest from various agencies on VRU safety. There were dynamic discussions at the meetings on various aspects of VRU safety, including countermeasures. However, the difficulty in funding VRU safety improvements was expressed by several attendees. Some have pointed out potential conflicts in the deployment of VRU countermeasures such as the potential to decrease transit service. The survey demographics show that there are many agency staff that are relatively new to the area of VRU safety. A high proportion of the respondents (41%) had three or fewer years of experience. Training and networking opportunities would serve these staff well. The lack of VRU demand data is an impediment to the application of more advanced statistical methods. The dual process of using surveys and engagement meetings worked well to obtain substantial feedback within a short time frame.

Targeted Video Conference

A special meeting was scheduled to engage with the city and county of St. Louis. This meeting was held because staff from St. Louis city and county were not able to attend the two group stakeholder engagement meetings. As discussed in the high crash analysis of this report, there are many facilities in the city and county of St. Louis that had a large number of VRU crashes. For example, nine of the high-crash intersections and eight of the high-crash corridors were in St. Louis City or County. The TAC felt it was important to obtain feedback from staff having jurisdiction over those locations. The special meeting was held on August 23, 2023, with the acting deputy director of St. Louis County Department of Transportation and Public Works and his assistant division manager. The same information presented at the group stakeholders meetings was discussed at this special meeting. However, the discussion centered around issues in the St. Louis region.

Similar to other agencies, a main issue discussed is how to maximize the limited county budget for the various needs, including maintenance of existing facilities, new construction, and safety improvements. Unlike other agencies, the County is not eligible for many types of federal grants and has to rely on local funding. A particular challenge is to find funding for deploying systemic improvements across long segments of roadways. For example, the cost for deploying street lighting, both the capital cost and the long-term maintenance and recurrent electricity costs, is very high. An added challenge is the recent steep increase in construction costs along with problems in supply chain and labor. The purchasing power of pre-COVID planned funds has been eroded significantly. St. Louis county, like many other agencies, have significant challenges in funding safety improvements.

A few specific contributory factors were discussed. The County does have certain policies that address safety related to transit stops. These policies include a landing pad for bus stops, separating stops from adjacent signals, and coordinating closely with Metro St. Louis. The County also focuses on crosswalks and has developed policies for the deployment of rectangular flashing beacons. The County did explore the use of hybrid beacons but did not find them to be a good fit in the locations that had crossing issues. The equity issues presented in the contributory factors section of this report is relevant to St. Louis County. Tracts that have lower income have more zero car households. These households who rely on transit do experience a larger number of VRU crashes.

The County was aware of the intersection of West Florissant and Jennings that is on the high crash list. They have a task force addressing that location as well as the West Florissant corridor. One issue with the location is poor access management with many commercial entrances. The County is partnering with neighboring cities to improve zoning in those areas. The local MPO, East-West Gateway Council of Governments, and MoDOT are working on developing guidance for such arterial facilities.

The County provided feedback on various countermeasures that are often touted as low-cost and proven. The County has not seen improvements in the narrowing of travel lanes. For example, they striped a 13-foot lane down to 10 foot. They did not observe a statistically significant decrease in average travel speeds. The County suspects that there needs to be something beyond just restriping to make drivers naturally reduce their speeds. In terms of signalization, the County has utilized leading pedestrian intervals (LPIs). They appear to be effective and the County is evaluating the treatment. They have not received much pushback from the public for the deployment of LPIs. In terms of intersection conversions, their constituents do not have a favorable view towards roundabouts. In addition, conversions would require significant costs in acquiring right-of-way since the land is already commercially developed. The County will continue to work with MoDOT to slowly introduce roundabouts when appropriate. In regard to curb radii reduction and bulb outs, there is the challenge of balancing VRU safety with access for larger vehicles such as transit buses and emergency vehicles. The county is looking into the deployment of traversal aprons as a possible solution to balance tradeoffs.

The County would like to see more evidence for the effectiveness of some of the suggested countermeasures. One difficulty with reports of successful case studies is that several countermeasures are deployed simultaneously. It is difficult to isolate the benefit from a single countermeasure. For example, high visibility crosswalks are often deployed with other treatments such as advanced warnings, signage, and even beacons. The CMF values reported in the CMF Clearinghouse are sometimes contradictory and often lacking for VRU countermeasures. Similar to the opinion of other agencies, the County would like to see more specific guidance and statistically significant evidence for several of the countermeasures.

9. CONCLUSION

Recently, there has been a more concerted effort to examine all VRUs modes together and to coordinate safety efforts across VRU modes. Traditionally, the focus has been on pedestrians and bicyclists. Unfortunately, data challenges inhibit efforts to improve VRU safety. Vehicular safety assessment is at a more advanced stage compared to VRU. One reason is that the funding and focus has been historically on driving. VRU safety is playing catch up in several ways. Average Daily Traffic is a widely available variable for measuring vehicular travel demand and exposure. VRU demand, on the other hand, is yet to be measured consistently. Because research has been historically focused on vehicles, there is a wealth of available CMFs with high quality ratings. CMFs associated with VRU countermeasures are comparatively rarer. Police crash reports, the staple of vehicular traffic safety analysis, lack the fields to capture VRU modes such as wheelchairs and e-scooters. But even with the multiplicity of challenges, the current VRU safety assessment can lead to various steps that can be taken to improve VRU safety.

This report documented several results of VRU safety assessment for Missouri. There is a high percentage of crashes that occur in urbanized intersections, with the three-legged unsignalized urbanized intersections being the highest, accounting for 34% of the total fatal VRU crashes. In terms of segments, rural segments account for around 35% of the total fatal crashes while urbanized segments account for nearly 60% of the total fatal crashes. There were several intersections in the metropolitan St. Louis area that saw a higher number of annual VRU crashes. Kansas City and Springfield also have a few high-crash intersections. VRU crashes on controlled access highways are often surprising because these facilities are not meant for normal VRU use. However, there are a high number of VRU crashes that occur on these facilities due to VRUs remaining from primary incidents.

This initial VRU safety assessment provides a base for continued assessment for the future. This report documents an efficient methodology for producing systemic and high-crash safety assessments. Due to the tight schedule, only a few contributory factors were investigated. In the future, more factors such as special events, weather, age, and impairment could be researched. Some stakeholders suggested data fusion of the crash data with police computer-aided dispatch data to examine the correlation between enforcement and VRU safety. The initial investigation into the use of hospital data could be greatly expanded by collecting data from all areas of the state. Medical researchers can be engaged to investigate if certain types of countermeasures could be more effective for reducing injury and improving long term recovery.

10. REFERENCES

AASHTO (2010). *Highway Safety Manual*. American Association of State Highway and Transportation Officials, Washington, D.C.

Bahar, G., Parkhill, M., Hauer, E., Council, F., Persaud, B., Zegeer, C., Elvik, R., Smiley, A., and Scott, B. (2007). “Prepare Parts I and II of a Highway Safety Manual: Knowledge Base for Part II.” Unpublished material from NCHRP Project 17-27, May.

Bassani, M., Rossetti, L., and Catani, L. (2020). “Spatial Analysis of Road Crashes Involving Vulnerable Road Users in Support of Road Safety Management Strategies.” Transportation Research Procedia, 45, 394-401. https://doi.org/10.1016/j.trpro.2020.03.031.

Bighashdel, A. and Dubbelman, G. (2019). “A Survey on Path Prediction Techniques for Vulnerable Road Users: From Traditional to Deep-Learning Approaches.” 2019 IEEE Intelligent Transportation Systems Conference (ITSC). https://doi.org/10.1109/ITSC.2019.8917053.

Cabarkapa, M. (2018). “A Problem of the Safety of Vulnerable Road Users in Montenegro.” International Journal of Injury Control and Safety Promotion, 25(4), 352-364. https://doi.org/10.1080/17457300.2018.1431936.

Cai, Q., Abdel-Aty, M., and Lee, J. (2017). “Macro-Level Vulnerable Road User Crash Analysis: A Bayesian Joint Modeling Approach of Frequency and Proportion.” Accident Analysis & Prevention, 107, 11-19. https://doi.org/10.1016/j.aap.2017.07.020.

Chang, C. M., Vavrova, M., and Mahnaz, S. L. (2022). “Integrating Vulnerable Road User Safety Criteria into Transportation Asset Management to Prioritize Budget Allocation at the Network Level.” Sustainability, 14(8317). https://doi.org/10.3390/su14148317.

Charlebois, D., Meloche, E., and Burns, P. (2019). “Detection of Cyclist and Pedestrians Around Heavy Commercial Vehicles.” 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV): Technology: Enabling a Safer Tomorrow, Eindhoven, Netherlands.

Dasanayaka, N., Hasan, K. F., Wang, C., and Feng, Y. (2020). “Enhancing Vulnerable Road User Safety: A Survey of Existing Practices and Considerations for Using Mobile Devices for V2X Connections.” arXiv – CS – Networking and Internet Architecture. https://doi.org/10.48550/arXiv.2010.15502.

Devlin, A., Beck, B., Simpson, P. M., Ekegren, C. L., Giummarra, M. J., Edwards, E. R., Cameron, P. A., Liew, S., Oppy, A., Richardson, M., Page, R., and Gabbe, B. J. (2019). “The Road to Recovery for Vulnerable Road Users Hospitalized for Orthopaedic Injury Following an On-Road Crash.” Accident Analysis and Prevention, 132, 105279. https://doi.org/10.1016/j.aap.2019.105279.

Dubey, A., Fuchs, J., Lubke, M., Weigel, R., Santra, A., and Lurz, F. (2021). "A Bayesian Framework for Integrated Deep Metric Learning and Tracking of Vulnerable Road Users Using Automotive Radars." IEEE Access, 9, 68758-68777. https://doi.org/10.1109/ACCESS.2021.3077690.

Fayish, A.C. and F. Gross, (2010). "Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before-After Study with Comparison Group," Journal of the Transportation Research Board, No. 2198, National Academies, Washington, D.C., pp. 15–22.

FHWA. (n.d.). Rectangular Rapid Flashing Beacons (RRFB). FHWA-SA-21-053. Federal Highway Administration, Office of Safety.

FHWA. (1998). "Safety Evaluation of Vulnerable Road Users." IRRD No. 895623.

FHWA (2009). *Manual on Uniform Traffic Control Devices*. Federal Highway Administration.

FHWA. (2013). "Actions to Increase the Safety of Pedestrians Accessing Transit." https://safety.fhwa.dot.gov/ped_bike/ped_transit/ped_transguide/ch4.cfm.

FHWA. (2022). "Zero Deaths and Safe System." https://highways.dot.gov/safety/zero-deaths.

FHWA. (2023a). *Vulnerable Road User Safety Assessment Webinar*. Division of Highway Safety, Pedestrian & Bicycle Safety.

FHWA (2023b). *Crash Modification Factor Clearinghouse*. Federal Highway Administration. <https://www.cmfclearinghouse.org/index.php> (Accessed 7/4/23).

Gan, A., Shen, J., and Rodriguez, A. (2005). *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects*. Final Report. Florida DOT.

Gross, F., Persaud, B., and Lyon, C. (2010). *A Guide to Developing Quality Crash Modification Factors*. Federal Highway Administration. FHWA-SA-10-032. December.

Gupta, M. and Bandyopadhyay, S. (2020). "Regulatory and Road Engineering Interventions for Preventing Road Traffic Injuries and Fatalities Among Vulnerable Road Users in Low- and Middle-Income Countries: A Systematic Review." Frontiers in Sustainable Cities, 2. https://doi.org/10.3389/frsc.2020.00010.

Hammond, V. and Musselwhite, C. (2013). "The Attitudes, Perceptions and Concerns of Pedestrians and Vulnerable Road Users to Shared Space: A Case Study from the UK." Journal of Urban Design, 18(1), 78-97.

Han, L., Li, H., Chen, J., Zheng, P., Zhang, Z., and Hua, Z. (2022). "A Novel Early Warning Strategy for Right-Turning Blind Zone Based on Vulnerable Road Users Detection." Neural Computing and Applications, 34(8), 6187-6206. https://doi.org/10.1007/s00521-021-06800-2.

Harkey, D., Srinivasan, R. Baek, J., Council, F. Eccles, K., Lefler, N., Gross, F., Persaud, B., Lyon, C., Hauer, E., and Bonneson, J. (2008). *NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements*. Transportation Research Board of the National Academies, Washington, D.C.

Harwood, D. (1990). *NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials*, Transportation Research Board, National Research Council, Washington, D.C.

Hickox, K., Williams, N., Beck, L., Coleman, T., Fudenberg, J., Robinson, B., and Middaugh, J. (2014). "Pedestrian Traffic Deaths Among Residents, Visitors, and Homeless Persons - Clark County, Nevada, 2008–2011." *CDC Morbidity and Mortality Weekly Report*, July 18, 63(28).

Johnsson, C., Laureshyn, A., and De Ceunynck, T. (2018). "In Search of Surrogate Safety Indicators for Vulnerable Road Users: A Review of Surrogate Safety Indicators." Transport Reviews, 38(6), 765-785.

Khayesi, M. (2020). "Vulnerable Road Users or Vulnerable Transport Planning." Frontiers in Sustainable Cities, 2, https://doi.org/10.3389/frsc.2020.00025.

King, M. (1999). "Calming New York City Intersections," *Transportation Research Circular E-C019: Urban Street Symposium Conference Proceedings*, Dallas, Texas, June 28–30, pp. 1–15.

Kisitu, D. K., Eyler, L. E., Feldhaus, I., Juillard, C., Dicker, R. A., Kajja, I., Waiswa, G., Beyeza, T., Ragland, D. R. (2016). "The Role of Ugandan District Hospital Orthopedic Units in the Care of Vulnerable Road Users: A Cross-Sectional Study." Injury Epidemiology, 3(1), https://doi.org/10.1186/s40621-016-0092-5.

Klanjcic, M., Gauvin, L., Tizzoni, M., and Szell, M. (2022). "Identifying Urban Features for Vulnerable Road User Safety in Europe." EPJ Data Science, 11(1), https://doi.org/10.1140/epjds/s13688-022-00339-5.

Komol, M. M. R., Hasan, M. M., Elhenawy, M., Yasmin, S., Masoud, M., and Rakotonirainy, A. (2021). "Crash Severity Analysis of Vulnerable Road Users Using Machine Learning." PLoS ONE, 16. https://doi.org/10.1371/journal.pone.0255828.

Lo, S. C. and Huang, H. C. (2015). "Traffic Signal Design and Simulation for Vulnerable Road Users Safety and Bus Preemption." AIP Conference Proceedings, 1642, 120-129. https://doi.org/10.1063/1.4906638.

Manisha, G. and Bandyopadhyay, S. (2020). "Regulatory and Road Engineering Interventions for Preventing Road Traffic Injuries and Fatalities Among Vulnerable Road Users in Low- and Middle-Income Countries: A Systematic Review." *Front. Sustain. Cities*, Vol. 2, May 19. https://doi.org/10.3389/frsc.2020.00010.

Markowitz, F., Sciortino, S., Fleck, J. and Yee, B. (2006). "Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation," *ITE Journal*, Vol. 76, No. 1, pp. 43–47.

McIlroy, C., Plant, K., Jikyong, U., Nam, V, Bunyasi, B., Kokwaro, G., Wu, J., Hoque, M., Preston, J., and Stanton, N. (2019). "Vulnerable Road Users in Low-, Middle-, and High-Income Countries: Validation of a Pedestrian Behaviour Questionnaire." *Accid. Anal. Prev.*, Oct. doi: 10.1016/j.aap.2019.05.027.

Mead, J., McGrane, A., Zegeer, C., and Thomas, L. (2014). *Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research*. Pedestrian and Bicycle Information Center.

MoDOT. (2021). *Safety Action Plan for Implementing Pedestrian Crossing Countermeasures*. Missouri Department of Transportation.

MoDOT. (2022). *Show-Me Zero: Driving Missouri Toward Safer Roads.* Missouri Coalition for Roadway Safety. https://www.savemolives.com/mcrs/show-me-zero.

Momeni, A., Pincus, M., Libien, J. (2018). "Cross Tabulation and Categorical Data Analysis." *Introduction to Statistical Methods in Pathology*. Springer, Cham. https://doi.org/10.1007/978-3-319-60543-2_5.

Muslim, H. and Antonia-Makoshi, J. (2022). "A Review of Vehicle-to-Vulnerable Road User Collisions on Limited Access Highways to Support the Development of Automated Vehicle Safety Assessments. Safety, 8(2). https://doi.org/10.3390/safety8020026.

NAS (2016). *Application of Pedestrian Crossing Treatments for Streets and Highways*. NCHRP Research Report 498. The National Academy of Sciences, Washington, D.C. https://doi.org/10.17226/24634.

NAS (2017). *Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments*. NCHRP Research Report 841. The National Academy of Sciences, Washington, D.C. https://doi.org/10.17226/24627.

NAS (2020). *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections.* The National Academy of Sciences, Washington, D.C. https://doi.org/10.17226/25808.

NAS (2021). *Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26072.

NHTSA. (2020). "NHTSA NTSB Response on NCAP, V2X, Bicycle Helmets and VRUs." U.S. Department of Transportation. https://www.nhtsa.gov/sites/nhtsa.gov/files/2021-12/NHTSA-NTSB-Response-07-16-2020-NCAP-V2X-Bicycle-Helmets-VRUs-tag.pdf.

NHTSA. (2021). "Comparing Demographic Trends in Vulnerable Road User Fatalities and the U.S. Population, 1980-2019." Traffic Safety Facts Research Note No. DOT HS 813 178.

NHTSA. (2022). *Early Estimates of Motor Vehicle Traffic Fatalities and Fatality Rate by Sub-Categories*. National Highway Traffic Safety Administration, Washington, D.C.

NSC. (2018). “Position/Policy Statement, Vulnerable Road Users.” National Safety Council. https://www.nsc.org/getattachment/d5babee6-582d-4e66-804f-8d06f9b021a4/t-vulnerable-road-users-147.

NTSB. (2019). “Bicyclist Safety on US Roadways: Crash Risks and Countermeasures.” National Transportation Safety Board Report No. NTSB/SS-19/01 PB2019-101397. https://www.ntsb.gov/safety/safety-studies/Documents/SS1901.pdf.

NTSB. (2018). “Pedestrian Safety.” National Transportation Safety Board Report No. NTSB/SIR-18/03 PB2018-101632. https://www.ntsb.gov/safety/safety-studies/Documents/SIR1803.pdf.

NTSB. (2017). “Reducing Speed-Related Crashes Involving Passenger Vehicles.” NTSB/SS-17/01 PB2017-102341. https://www.ntsb.gov/safety/safety-studies/Documents/SS1701.pdf.

Ptak, M. (2019). “Method to Assess and Enhance Vulnerable Road User Safety During Impact Loading.” Applied Sciences (Switzerland), 9(5), https://doi.org/10.3390/app9051000.

Pulugurtha, S. and Vanapalli, V. (2008). “Hazardous Bus Stops Identification: An Illustration Using GIS.” *Journal of Public Transportation*, Vol. 11, No. 2.

Qian, X., Jaller, M., Xiao, R., and Chen, S. (2022). “Analysis of Intelligent Vehicle Technologies to Improve Vulnerable Road Users Safety at Signalized Intersections.” National Center for Sustainable Transportation.

Radjou, A. N. and Kumar, S. M. (2018). “Epidemiological and Clinical Profile ff Fatality in Vulnerable Road Users at a High Volume Trauma Center.” Journal of Emergencies, Trauma and Shock, 11(4), 282-287. https://doi.org/10.4103/JETS.JETS_55_17.

Ranchet, M., Bremond, R., Pala, P., Columb, M., and Cavallo, V. (2022). “The Detection of Vulnerable Road Users by Younger and Older Drivers.” Transportation Research Part F: Psychology and Behaviour, 91, 357-367.

Roge, J., El Zufari, V., Vienne, F., and Ndiaye, D. (2015). “Safety Messages and Visibility of Vulnerable Road Users for Drivers.” Safety Science, 79, 29-38.

Schindler, R. and Bianchi Piccinini, G. (2021). “Truck Drivers’ Behavior in Encounters with Vulnerable Road Users at Intersections: Results from a Truck-Track Experiment.” Accident Analysis and Prevention, 159, https://doi.org/10.1016/j.aap.2021.106289.

Scholliers, J., van Noort, M., Johansson, C., Mans, D., Silla, A., Bell, D., Hancox, G., Leden, L., Giannelos, I., Bax, B., and Malone, K. (2016). “Impact Assessment of Its Applications for Vulnerable Road Users.” Transportation Research Procedia, 14, 4515-4524.

Shi, L., Huang, H., Han, Y., Davidsson, J., and Thomson, R. (2020). “Evaluation of Injury Thresholds for Predicting Severe Head Injuries in Vulnerable Road Users Resulting From Ground Impact Via Detailed Accident Reconstructions.” Biomechanics and Modeling in Mechanobiology, 19(5), 1845-1863. https://doi.org/10.1007/s10237-020-01312-9.

STARS. (2019). *Missouri Uniform Crash Report Preparation Manual*. Statewide Traffic Accident Records System (STARS) Committee.

Sun, Z., Xing, Y., Gu, X., Chen, Y., Wang, J., and Lu, H. (2022). "Exploring injury severity of vulnerable road user involved crashes across seasons: A hybrid method integrating random parameter logit model and Bayesian network." Safety Science, 150. https://doi.org/10.1016/j.ssci.2022.105682.

Tasic, I., Elvik, R., Brewer, S. (2017). "Exploring the Safety in Numbers Effect for Vulnerable Road Users on a Macroscopic Scale." Accident Analysis and Prevention, 109, 36-46. https://doi.org/10.1016/j.aap.2017.07.029.

Tee. Y. S., Cheng, C. T., Hsieh, C. H., Kang, S. C., Fu, C. Y., Derstine, B. A., Su, G. L., and Wang, S. C. (2021). "Does a 'Cushion Effect' Really Exist? A morphomic analysis of vulnerable road users with serious blunt abdominal injury." Healthcare (Switzerland), 9(8), https://doi.org/10.3390/healthcare9081006.

Teixeira, P., Sargento, S., Rito, P., Luis, M., and Castro, F. (2023). "A Sensing, Communication and Computing Approach for Vulnerable Road Users Safety." IEEE Access, 11, 4914-4930. https://doi.org/10.1109/ACCESS.2023.3235863.

Thomas, L., Srinivasan, R., Worth, M., Parker, M. and Miller, R. (2015). *Jurisdiction Speed Management Action Plan Development Package*. FHWA-SA-15-017, Federal Highway Administration, Washington, D.C.

Thomas, L., Levitt, D., Vann, M., Blank, K., Nordback, K., and West, A. (2022). *PBCAT Pedestrian and Bicycle Crash Analysis Tool Version 3.0 User Guide*. FHWA-HRT-22-071, McLean, VA.

Tobias, P., Szwedo, T., and Nye, B. (2022). "Missouri Systemic Countermeasures to Improve Pedestrian Safety" Missouri Department of Transportation Report No. cmr 22-013.

Torfs, K. and Meesmann, U. (2019). "How do Vulnerable Road Users Look at Road Safety? International comparison based on ESRA data from 25 countries." Transportation Research: Part F, 63, 144-152.

USDOT. (2022) *National Roadway Safety Strategy*. United States Department of Transportation. Washington, D.C.

Van Haperen, W., Riaz, M. S., Daniels, S., Saunier, N., Brijs, T., and Wets, G. (2019). "Observing the Observation of (Vulnerable) Road User Behaviour and Traffic Safety: A Scoping Review." Accident Analysis and Prevention, 123, 211-221.

Van Houten, R., McCusker, D., Huybers, S., Malenfant, J., and Rice-Smith, D. (2002). "Advance Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches," Journal of the Transportation Research Board, No. 1818, National Academies, Washington, D.C., pp. 119–124

Vilaca, M., Coelho, M. C., and Silva, N. (2017). "Statistical Analysis of the Occurrence and Severity of Crashes Involving Vulnerable Road Users." Transportation Research Procedia, 27, 1113-1120. https://doi.org/10.1016/j.trpro.2017.12.113.Vu, M. D., Suzuki, T., Aoki, H., Nagiri, S., Van, Q. H. N., Itou, S., and Hattori, A. (2021). "An Analysis of Vulnerable Road Users Overtaking Maneuver Along the Urban Road." Applied Sciences (Switzerland), 11(14), https://doi.org/10.3390/app11146361.

Walker, C. (2022). *Vulnerable Road User Safety Assessment Guidance*. Federal Highway Administration.

Wang, F., Hu, L., Wang, Z., Xu, H., Yu, C., and Li, F. (2021). "Evaluation of Head Injury Criteria for Injury Prediction Effectiveness: Computational Reconstruction of Real-World Vulnerable Road User Impact Accidents." Frontiers in Bioengineering and Biotechnology, 9, https://doi.org/10.3389/fbioe.2021.677982.

Wang, J., Parajuli, S., Cherry, C. R., McDonald, N. C., and Lyons, T. (2022). "Vulnerable Road User Safety and Freight Vehicles: A Case Study In North Carolina And Tennessee." Transportation Research Interdisciplinary Perspectives, 15, https://doi.org/10.1016/j.trip.2022.100650.

WHO. (2004*). ICD-10: International Statistical Classification of Diseases and Related Health Problems: Tenth Revision.* 2nd ed. World Health Organization. https://apps.who.int/iris/handle/10665/42980.

Wu, H., Pan, D., Huang, H., Han, Y., Wang, B., Mizuno, K., and Thomson, R. (2021). "The Head AIS 4+ Injury Thresholds for the Elderly Vulnerable Road User Based on Detailed Accident Reconstructions." Frontiers in Bioengineering and Biotechnology, 9, https://doi.org/10.3389/fbioe.2021.682015.

Wu, M., Kwon, T. J., and El-Basyouny, K. (2020). "A Citywide Location-Allocation Framework for Driver Feedback Signs: Optimizing Safety and Coverage of Vulnerable Road Users." Sustainability (Switzerland), 12(24), 1-20. https://doi.org/10.3390/su122410415.

Yuan, Q., Zhai, X., Ji, W., Yang, T., Yu, Y., and Yu, S. (2022). "Correlation Analysis on Accident Injury and Risky Behavior of Vulnerable Road Users Based on Bayesian General Ordinal Logit Model." Sustainability (Switzerland), 14(23), https://doi.org/10.3390/su142316048.

Zegeer, C., Seiderman, C., Lagerwey, P., Cynecki, M., Ronkin, M., and Schneider, B. (2002). *Pedestrian Facilities Users Guide*. FHWA-RD-01-102.

Zegeer, C., Steward, R., Huang, H., Lagerwey, P., Feaganes, J., and Campbell, B. (2005). *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations*. FHWA-HRT-04-100, McLean, VA.

APPENDIX A: VRU STAKEHOLDER SURVEY

Introduction Thank you for completing this short, 10-question survey on Vulnerable Road User (VRU) Safety. The University of Missouri is administering this survey on behalf of MoDOT to learn from local stakeholders such as MPOs, RPCs, and municipalities.

End of Block: Block 1

Start of Block: Default Question Block

Q1 What type of agency/organization do you work for?

- ◯ FHWA (1)
- ◯ MoDOT (2)
- ◯ MPO (3)
- ◯ RPC (4)
- ◯ Municipality (5)
- ◯ County (6)
- ◯ VRU advocacy (7)
- ◯ Other (8)

Page Break

Q2 What MoDOT district is your organization located?
https://www.modot.org/modot-near-me

- ○ Northwest (1)
- ○ Northeast (2)
- ○ Kansas City (10)
- ○ Central (3)
- ○ St. Louis (4)
- ○ Southwest (5)
- ○ Southeast (6)

Page Break

Q3 How long have you been involved with Vulnerable Road User (VRU) safety?

- 0-3 years (1)
- 4-6 years (2)
- 7-10 years (3)
- 11-15 years (4)
- 16-20 years (5)
- > 20 years (6)

Page Break

Q4 Select the highest priority intersections that you intend to focus on for VRU safety (Rural/Urban/urbaniZed, # Legs, Y/N signal). Example: Z4N = urbanized, 4-legged, unsignalized. Multiple selections are allowed.

- ▢ R3N (1)
- ▢ R3Y (2)
- ▢ R4N (3)
- ▢ U2N (4)
- ▢ U3N (5)
- ▢ U3Y (6)
- ▢ U4N (7)
- ▢ U4Y (8)
- ▢ Z2N (9)
- ▢ Z2Y (10)
- ▢ Z3N (11)
- ▢ Z3Y (12)
- ▢ Z4N (13)
- ▢ Z4Y (14)

Page Break

Q5 Select the highest priority segments that you intend to focus on for VRU safety (Rural/Urban/Urbanized, # Lanes, Divided/Undivided). Example R4D = rural, 4-lane, divided. Multiple selections are allowed.

- ☐ R2U (1)
- ☐ R4D (2)
- ☐ U2D (3)
- ☐ U2U (4)
- ☐ U4D (5)
- ☐ U4U (6)
- ☐ U6D (7)
- ☐ U6U (8)
- ☐ Z2U (9)
- ☐ Z4D (10)
- ☐ Z4U (11)
- ☐ Z6D (12)
- ☐ Z6U (13)
- ☐ Z8D (14)
- ☐ Z8U (15)

Page Break

Q6 Select the top contributing factors that you intend to focus on. Multiple selections are allowed.

- ☐ Transit stops (1)
- ☐ Controlled access highways (2)
- ☐ Equity (3)
- ☐ Nighttime/lighting (4)
- ☐ Micromobility (5)
- ☐ Vehicle speeding (6)
- ☐ Distracted driving/walking/rolling (7)
- ☐ Human behavior (8)
- ☐ Weather (9)

Page Break

Q7 Select any of the following countermeasures that your agency/organization is currently using (mainly segment). Multiple selections are allowed.

- ▢ Vehicle speed reductions (e.g., signage, feedback trailer) (1)
- ▢ Sidewalks (2)
- ▢ Paved shoulders (3)
- ▢ Narrowing travel lanes (4)
- ▢ Road diets (5)
- ▢ Raised median/median islands (6)
- ▢ Raised crosswalks (7)
- ▢ High-visibility crosswalks (8)
- ▢ Shoulder rumble strips (9)
- ▢ Lighting (10)
- ▢ VRU warning signs (11)
- ▢ Flashers and beacons (12)

Page Break

Q8 Select any of the following countermeasures that your agency/organization is currently using (mainly intersection). Multiple selections are allowed.

- ▢ Advanced stop/yield bar and signs (1)
- ▢ In-roadway "Yield to Pedestrian" signs (2)
- ▢ VRU countdown signals (3)
- ▢ Automated VRU detection (4)
- ▢ Parking restrictions (5)
- ▢ Reduced curb radii (6)
- ▢ Curb extensions/bulb-out (7)
- ▢ Remove channelized right turn (8)
- ▢ Convert two-way stop intersections to all-way stop (9)
- ▢ Leading pedestrian interval (10)
- ▢ Signal timing (e.g., permissive to protected left turn, phase recall, reduced cycle) (11)
- ▢ No right turn on red (12)
- ▢ Roundabout installation/conversion (13)

Page Break

Q9 Select any of the following countermeasures that you are interested in exploring in the future (mainly segment). Multiple selections are allowed.

- ▢ Vehicle speed reductions (e.g., signage, feedback trailer) (1)
- ▢ Sidewalks (2)
- ▢ Paved shoulders (3)
- ▢ Narrowing travel lanes (4)
- ▢ Road diets (5)
- ▢ Raised median/median islands (6)
- ▢ Raised crosswalks (7)
- ▢ High-visibility crosswalks (8)
- ▢ Shoulder rumble strips (9)
- ▢ Lighting (10)
- ▢ VRU warning signs (11)
- ▢ Flashers and beacons (12)

Page Break

Q10 Select any of the following countermeasures that you are interested in exploring in the future (mainly intersection). Multiple selections are allowed.

- ▢ Advanced stop/yield bar and signs (1)
- ▢ In-roadway "Yield to Pedestrian" signs (2)
- ▢ VRU countdown signals (3)
- ▢ Automated VRU detection (4)
- ▢ Parking restrictions (5)
- ▢ Reduced curb radii (6)
- ▢ Curb extensions/bulb-out (7)
- ▢ Remove channelized right turn (8)
- ▢ Convert two-way stop intersections to all-way stop (9)
- ▢ Leading pedestrian interval (10)
- ▢ Signal timing (e.g., permissive to protected left turn, phase recall, reduced cycle) (11)
- ▢ No right turn on red (12)
- ▢ Roundabout installation/conversion (13)

Page Break

Q14 Please feel free to enter any other comments you have about VRU safety and this survey.

____

End of Block: Default Question Block

APPENDIX B: COUNTERMEASURE CMF

Vehicular Speed Reductions

- J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
    - Bicyclist
        - Installation of speed hump or other speed reducing measure through motorized vehicles on main road
            - CMF 1.28 2-star

Reduce Speed Limit Ahead signs (W3-5)

- None

Speed Feedback Trailers

- None, speed feedback ITS systems do not denote pedestrian specifically

Sidewalks

- Alluri, Priyanka, Md Asif Raihan, Dibakar Saha, Wanyang Wu, Armana Huq, Sajidur Nafis, and Albert Gan. "Statewide Analysis of Bicycle Crashes." Florida Department of Transportation (May 2017).
    - Bicyclist CMFs
        - Install bike lanes
            - CMF 1.69 2-stars
            - CMF 0.86 3-stars
            - CMF 2.24 3-stars
        - Install shared path
            - CMF 0.75 2-stars
        - Install sidewalk barrier
            - CMF 2.18 2-stars
            - CMF 4.2 2-stars
            - CMF 1.99 3-stars
            - CMF 0.33 2-stars
            - CMF 0.36 2-stars
        - Install bicycle lane and/or bicycle slot at intersection
            - CMF 1.27 2-stars
            - CMF 1.71 2-stars
            - CMF 1.36 2-stars
        - Install sidewalk
            - CMF 0.41 2-stars
            - CMF 1.78 3-stars
            - CMF 1.87 3-stars
            - CMF 2.71 2-stars
- Raihan, M.A., P. Alluri, W. Wu, and A. Gan. "Estimation of bicycle crash modification factors (CMFs) on urban facilities using zero inflated negative binomial models". Accident Analysis and Prevention, Vol. 123, (2019), pp. 303-313.
    - Bicyclist

        - Install sidewalk barrier
            - CMF 1.83 3-star
        - Install sidewalk
            - CMF 1.53 3-star
            - CMF 3.09 3-star

Paved Shoulders

- Raihan, M.A., P. Alluri, W. Wu, and A. Gan. "Estimation of bicycle crash modification factors (CMFs) on urban facilities using zero inflated negative binomial models". Accident Analysis and Prevention, Vol. 123, (2019), pp. 303-313.
    - Bicyclist
        - Convert paved shoulder to other
            - CMF 0.48 3-star
        - Convert paved shoulder to curb and gutter
            - CMF 1.21 3-star

Narrowing Travel Lanes

- Raihan, M.A., P. Alluri, W. Wu, and A. Gan. "Estimation of bicycle crash modification factors (CMFs) on urban facilities using zero inflated negative binomial models". Accident Analysis and Prevention, Vol. 123, (2019), pp. 303-313.
    - Bicyclist
        - Reduce lane width from 12ft to less than 12ft
            - CMF 1.72 2-star
            - CMF 1.25 3-star

Road Diets (e.g. 4 to 3)

- None, plenty of road diet CMFs, none on peds or bikes

Raised Median and Median Islands

- Alluri, P., A. Gan, and K. Haleem. Safety Impacts of Converting Two-Way Left-Turn Lanes to Raised Medians and Associated Design Concerns. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., (2014).
    - Bicyclist
        - Provide raised median
            - CMF 0.978 1-star
            - CMF 1.006 1-star
            - CMF 1.031 1-star
            - CMF 0.811 1-star
            - CMF 1.018 1-star
            - CMF 0.487 1-star
            - CMF 0.973 1-star
            - CMF 0.955 1-star
            - CMF 0.705 1-star
    - Pedestrian
        - Provide raised median
            - CMF 0.596 2-star
            - CMF 1.237 1-star
            - CMF 0.709 2-star

        - CMF 0.487 1-star
        - CMF 0.661 2-star
        - CMF 1.704 1-star
        - CMF 0.734 2-star
        - CMF 0.711 2-star
        - CMF 1.37 1-star
  - Raihan, M.A., P. Alluri, W. Wu, and A. Gan. "Estimation of bicycle crash modification factors (CMFs) on urban facilities using zero inflated negative binomial models". Accident Analysis and Prevention, Vol. 123, (2019), pp. 303-313.
    - Bicyclist
      - Change median from paved to grass
        - CMF 0.72 3-star
        - CMF 0.7 3-star
      - Change paved median to raised traffic separator
        - CMF 1.27 3-star
- 8/19/23
  - J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
    - Bicyclist
      - Installation of additional travel lanes and raised island
        - CMF 1.1 2-star
      - Installation of raised island and left-turn lane
        - CMF 1.48 2-star
      - Installation of raised island with separate space for cyclists
        - CMF 1.43 2-star
  - Zegeer, C. V., Stewart, R., Huang, H., and Lagerwey, P., "Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines." FHWA-RD-01-075, McLean, Va., Federal Highway Administration, (2002)
    - Pedestrian
      - Install raised median with marked crosswalk (uncontrolled)
        - CMF 0.54 3-star
      - Install raised median with unmarked crosswalk (uncontrolled)
        - CMF 0.61 2-star
  - Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. Van Houten. "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments", National Cooperative Highway Research Program, Research Report 841, Washington, D.C., 2017.
    - Pedestrian
      - Install raised median with or without marked crosswalk (uncontrolled)
        - CMF 0.685 4-star

Raised Crosswalks

- Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004)
  - Bicyclist
    - Raised bicycle crossings
      - CMF 1.09 3-star

- Pedestrian
  - Install raised pedestrian crosswalks
    - CMF 0.55 3-star
- J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
  - Bicyclist
    - Installation of raised bicycle crossing or other speed reducing measure for vehicles entering or leaving the side road
      - CMF 0.49 3-star

High Visibility Crosswalks

- Chen, L., C. Chen, and R. Ewing. "The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012.
  - Pedestrian
    - Install high-visibility crosswalk
      - CMF 0.6 2-star
- Feldman, M., J. Manzi, and M. Mitman. "An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco." TRB 89th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C. 2010.
  - Pedestrian
    - Install high-visibility yellow, continental type crosswalks at schools
      - CMF 0.63 4-star

Shoulder Rumble Strips

- None, many CMFs on rumble strips, none about peds or bikes

Lighting

- Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004)
  - Pedestrian
    - Provide intersection illumination
      - CMF 0.22 3-star
      - CMF 0.58 3-star (nighttime)
      - CMF 0.19 3-star
      - CMF 0.41 3-star
- Wanvik, W., "Effects of road lighting: An analysis based on Dutch accident statistics 1987-2006." Accident Analysis and Prevention, Vol. 41, No. 1, Oxford, N.Y., Pergamon Press, (2009) pp. 123-128.
  - Pedestrian
    - Install lighting (highway lighting)
      - CMF 0.3 2-star (nighttime)
  - Bicycle
    - Install lighting (highway lighting)
      - CMF 0.4 2-star (nighttime)
- Ye, X., R.M. Pendyala, S.P. Washington, K. Konduri, and J. Oh (2008). A Simultaneous Equations Model of Crash Frequency By Collision Type for Rural Intersections, 87th Annual Meeting of the Transportation Research Board, TRB 2008 Annual Meeting CD-ROM.

- Pedestrian
  - Provide intersection illumination
    - CMF 0.56 3-star

Pedestrian Warning Signs (W11-2)

- None

Road Safety Audit

- None

High-Visibility Crosswalks

- See previous

Enhanced Signing and Pavement Markings

- J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
  - Bicyclist
    - Installation of high quality markings for bicycle crossings with cyclist priority at intersections
      - CMF 1.74 2-star
    - Installation of red color and high quality markings for bicycle crossings with cyclist priority at intersections
      - CMF 2.53 3-star
    - Installation of red color for bicycle crossings with cyclist priority at intersections
      - CMF 1.47 2-star
- Turner, S. A., Wood, G., Hughes, T., and Singh, R., "Safety Performance Functions for Bicycle Crashes in New Zealand and Australia." Presented at the 90th Annual Meeting of the Transportation Research Board, Paper #11-3156, Washington, D.C., (2011).
  - Bicycle
    - Installation of colored bicycle lanes at signalized intersections
      - CMF 0.61 2-star

Enhanced Crosswalk Lighting

- See previous

Rectangular Rapid Flashing Beacon (RRFB)

- Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. Van Houten. "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments", National Cooperative Highway Research Program, Research Report 841, Washington, D.C., 2017.
  - Pedestrian
    - Install rectangular rapid flashing beacon (RRFB)
      - CMF 0.526 3-star
- Monsere, C., S. Kothuri, A. Razmpa, and M. Figliozzi. "An Analysis of The Safety Effectiveness of Pedestrian Crossing Enhancements in Oregon". Presented at the 97th Annual Meeting of the Transportation Research Board, Paper No. 18-00737, Washington, D.C., (2018).
  - Pedestrian

        - Install enhanced RRFB pedestrian crossing at mid-block crossing location
            - CMF 0.64 1-star
- Goswamy, A., Abdel-Aty, M., and N. Mahmoud. "Safety Effectiveness of Rectangular Rapid Flashing Beacons (RRFB) Pedestrian Enhancement." (2022).
    - Pedestrian
        - Install rectangular rapid flashing beacon (RRFB)
            - CMF 0.31 4-star
            - CMF 0.3 4-star
            - CMF 0.27 4-star

Pedestrian Hybrid Beacon (PHB or HAWK Signal)

- Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. Van Houten. "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments", National Cooperative Highway Research Program, Research Report 841, Washington, D.C., 2017.
    - Pedestrian
        - Install a pedestrian hybrid beacon (PHB or HAWK)
            - CMF 0.453 3-star
        - Install pedestrian hybrid beacon (PHB or HAWK) with advanced yield or stop markings and signs
            - CMF 0.432 4-star
- Fitzpatrick, K., M.J. Cynecki, M.P. Pratt, E.S. Park, and M.E. Beckley. "Evaluation of Pedestrian Hybrid Beacons on Arizona Highways." Report No. FHWA-AZ-19-756. Arizona Department of Transportation. Phoenix, Arizona. (September 2019).
    - Pedestrian
        - Install a pedestrian hybrid beacon (PHB or HAWK)
            - CMF 0.567 5-star
            - CMF 0.755 4-star
            - CMF 0.63 4-star
            - CMF 0.591 4-star
            - CMF 0.543 5-star
            - CMF 0.55 5-star
- Fitzpatrick, K. and Park, E.S. Safety Effectiveness of the HAWK Pedestrian Crossing Treatment, FHWA-HRT-10-042, Federal Highway Administration, Washington, DC. (2010). Also published in: Fitzpatrick, K., E.S.Park, and S. Turner. "Effectiveness of the HAWK Pedestrian Crossing Treatment". ITE Journal, Vol. 82, No. 4, Washington, D.C., (2012).
    - Pedestrian
        - Install a pedestrian hybrid beacon (PHB or HAWK)
            - CMF 0.309 3-star

Automated VRU Detection

- Maxwell, A., Kennedy, J., Routledge, I., Knight, P., and Wood, K. "Puffin Pedestrian Crossing Accident Study." Transport Research Laboratory, Berkshire, United Kingdom, (2011).
    - Pedestrian
        - Convert Pelican crossing or farside pedestrian signal to Puffin crossing
            - CMF 0.76 3-star
            - CMF 0.61 2-star

- CMF 0.78 2-star

Pedestrian Countdown Signals

- Markowitz, F., Sciortino, S., Fleck, J. L., and Yee, B. M., "Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation." Institute of Transportation Engineers Journal, Vol. January 2006, ITE, (1-1-2006) pp. 43-48. Updated by Memorandum, Olea, R., "Collision changes 2002-2004 and countdown signals," (February 7th, 2006)
    - Pedestrian
        - Replace existing WALK / DON'T WALK signals with pedestrian countdown signal heads
            - CMF 0.75 1-star

Danish Offset

- None

High-Visibility Crosswalks

- See previous

Advance Stop/Yield Bar and Signs

- Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. Van Houten. "Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments", National Cooperative Highway Research Program, Research Report 841, Washington, D.C., 2017.
    - Pedestrian
        - Install advanced yield or stop markings and signs
            - CMF 0.75 3-star

In-Roadway "Yield to Pedestrian" Signs

- None

Pedestrian Warning Signs

- None

Parking Restrictions

- Alluri, Priyanka, Md Asif Raihan, Dibakar Saha, Wanyang Wu, Armana Huq, Sajidur Nafis, and Albert Gan. "Statewide Analysis of Bicycle Crashes." Florida Department of Transportation (May 2017).
    - Pedestrian
        - Allow parking on both sides of road
            - CMF 2.65 2-stars
            - CMF 0.48 2-stars

Reduced Curb Radii

- None

Curb Extensions/Bulb-Out

- None

ADA Ramps

- None

Install Sidewalks

- See previous

Remove Channelized Right Turn

- None

Convert Two-Way Stop Intersections to All-Way Stop

- Lovell, J. and Hauer, E., "The Safety Effect of Conversion to All-Way Stop Control." Transportation Research Record 1068, Washington, D.C., Transportation Research Board, National Research Council, (1986) pp. 103-107.
  - Pedestrian
    - Convert minor-road stop control to all-way stop control
      - CMF 0.57 4-star
- Deng, Z., S. Kyrychenko, T. Lee, and R. Retting. “Estimate of the Safety Effect of All-Way Stop Control Conversion in Washington, DC.” Transportation Research Record No. 2674, Transportation Research Board of the National Academies of Science, Washington, D.C., (2020).
  - Pedestrian
    - Convert minor-road stop control to all-way stop control
      - CMF 2.37 3-star
  - Bicycle
    - Convert minor-road stop control to all-way stop control
      - CMF 1.29 3-star

Pedestrian Signal Timing

- Chen, L., C. Chen, and R. Ewing. "The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012.
  - Pedestrian
    - Install traffic signal
      - CMF 1.12 2-star
    - Provide split phases
      - CMF 0.61 2-star
    - Implement Barnes Dance
      - CMF 0.49 2-star
    - Increase cycle length for pedestrian crossing
      - CMF 0.5 2-star

Leading Pedestrian Interval (LPI)

- Goughnour, E., D. Carter, C. Lyon, B. Persaud, B. Lan, P. Chun, I. Hamilton, and K. Signor. "Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety." Report No. FHWA-HRT-18-044. Federal Highway Administration. (October 2018)
  - Pedestrian
    - Modify signal phasing (implement a leading pedestrian interval)
      - CMF 0.81 5-star
      - CMF 0.81 5-star
      - CMF 0.9 4-star

            - CMF 0.91 4-star
            - CMF 0.54 3-star
            - CMF 0.87 5-star
- Fayish, A.C. and F. Gross, "Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups." Transportation Research Record: Journal of the Transportation Research Board, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 15–22. DOI: 10.3141/2198-03
    - Pedestrian
        - Modify signal phasing (implement a leading pedestrian interval)
            - CMF 0.413 4-star

All Red Stop

- None

Additional Signal Heads with Reflective Backplates

- None

Pedestrian Phase Recall

- None

Reduced Signal Cycle

- None

Permissive Left-Turn Phasing to Protected

- Raihan, M.A., P. Alluri, W. Wu, and A. Gan. "Estimation of bicycle crash modification factors (CMFs) on urban facilities using zero inflated negative binomial models". Accident Analysis and Prevention, Vol. 123, (2019), pp. 303-313.
    - Bicyclist
        - Provide protected left-turn phase
            - CMF 0.69 3-star
- Goughnour, E., D. Carter, C. Lyon, B. Persaud, B. Lan, P. Chun, I. Hamilton, and K. Signor. "Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety." Report No. FHWA-HRT-18-044. Federal Highway Administration. (October 2018)
    - Pedestrian
        - Change permissive left-turn phasing to protected only or protected/permissive
            - CMF 1.136 4-star
            - CMF 0.718P 4-star
            - CMF 1.106 5-star
            - CMF 1.091 4-star

Change paved median to raised

- See previous

Pedestrian Countdown Timers

- See previous

Passive Pedestrian Detection System

- Puffin? See previous, otherwise none

No Right Turn on Red

- Preusser, D. F., Leaf, W. A., DeBartolo, K. B., Blomberg, R. D., and Levy, M. M., "The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents." Journal of Safety Research, Vol. 13, No. 2, Oxford, N.Y., Pergamon Press, (1982) pp. 45-55.
    - Pedestrian
        - Permit right-turn on red
            - CMF 1.43 2-star
            - CMF 2.08 2-star
            - CMF 1.57 2-star
            - CMF 1.43 2-star
            - CMF 2.07 2-star
            - CMF 1.57 2-star
            - CMF 1.81 2-star
    - Bicycle
        - Permit right-turn on red
            - CMF 1.81 2-star
            - CMF 1.82 2-star
            - CMF 1.73 2-star
            - CMF 1.8 2-star
            - CMF 1.82 2-star
            - CMF 1.73 2-star
            - CMF 1.8 2-star

Bus Transit Access

- None

Crosswalk Lighting

- See previous

Education and Outreach

- None

Bicycle lanes (added this one, could not find a countermeasure that fit)

- J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
    - Bicyclist
        - Installation of cycle track 0-2m from side of main road with cyclist priority at intersection
            - CMF 1.03 2-star
        - Installation of cycle track 2-5m from side of main road with cyclist priority at intersection
            - CMF 0.55 3-star
        - Installation of cycle track 5m from side of main road with cyclist priority at intersection
            - CMF 0.93 2-star
        - Moving a separate bicycle crossing to a four-legged intersection
            - CMF 1.28 2-star

            - Moving a separate bicycle crossing to a three-legged intersection
                - CMF 0.83 2-star
    - Pedestrian
        - Installation of two-way cycle path with cyclist priority at intersections
            - CMF 1.75 3-star
- Turner, S. A., Wood, G., Hughes, T., and Singh, R., "Safety Performance Functions for Bicycle Crashes in New Zealand and Australia." Presented at the 90th Annual Meeting of the Transportation Research Board, Paper #11-3156, Washington, D.C., (2011).
    - Bicycle
        - Installation of bicycle lanes at signalized intersections
            - CMF 1.37 2-star
            - CMF 0.8 2-star
            - CMF 0.63 2-star
            - CMF 1.33 2-star
            - CMF 1.01 2-star
            - CMF 2.03 2-star
            - CMF 0.42 2-star
            - CMF 1.02 2-star
        - Installation of bicycle lanes at signalized intersections with exclusive right-turn lanes
            - CMF 1.36 2-star
            - CMF 0.97 2-star
        - Installation of bicycle lanes at signalized intersections with shared through/right-turn lanes
            - CMF 1.4 2-star
            - CMF 0.6 2-star

APPENDIX C: STAKEHOLDER CONTACT INFORMATION

Attendance at 7/17/23 meeting.

Name	Email/Organization
Jenni Hosey	Jennifer.J.Hosey@modot.mo.gov
Kelsey Buford	kbuford@stpetersmo.net
Trevor Tutt	trevor@mo-kan.org
Maximilian Schieber	mschieber@stjosephmo.gov
Joshua Stephens	jstephens@stjosephmo.gov
Olivia Spencer	ojeffers@gus.pittstate.edu
Greg Wallace	greg.wallace@wentzvillemo.org
Melissa Theiss	melissa.theiss@ewgateway.org
Alicia Hunter	AHunger@marc.org
Jim Gillam	james.gillam@stshcarlescitymo.gov
Kataryna C. Kraemer	Kataryna.Kraemer@modot.mo.gov
Henry Brown	brownhen@missouri.edu
Jennifer Harper	Jennifer.Harper@modot.mo.gov
Andrew Murphy	andrew@ofrpc.org
Selina Zapata Bur	SBur@MARC.ORG
Dillon Harness	dharness@kaysinger.com
Joseph L. Reneker	jlr7g3@mail.missouri.edu
Nicole Gibbs	ngibbs@nwarpc.org
Matt Seggerman	mseggerman@sccmo.org
Carlos Sun	csun@missouri.edu
Anna Musial	anna.musial@ewgateway.org
Machelle Watkins	Machelle.Watkins@modot.mo.gov
Carrie Campbell HSTCC	ccampbell@hstcc.org
Rachael Pawlak	rachael.pawlak@ewgateway.org
Dan Mann	daniel.mann@stcharlescitymo.gov
Saranya Konala	saranya.konala@ewgateway.org
Jonathan A. Nelson	Jonathan.Nelson@modot.mo.gov
Praveen Edara	edarap@missouri.edu
Alex Weidenbenner	Alex.Weidenbenner@stcharlescitymo.gov
Burt Benesek	bbenesek@stpetersmo.net
Sara Nelson	snelson@sccmo.org
Katrina Williams	Kawilliams@jeffersoncitymo.gov
Clint Smith	Csmith@jeffersoncitymo.gov
Eric Barron	Ebarron@jeffersoncitymo.gov
Kortney Bliss	Kbliss@jeffersoncitymo.gov
Grayson Johnston	Gjohnston@jeffersoncitymo.gov
Chris Hess	chris@trailsrpc.org
John Miller	john.p.miller@dot.gov

Attendance at 8/17/23 meeting.

Name	Email/Organization
Jenni Hosey	Jennifer.J.Hosey@modot.mo.gov
Katy Harlan	Katy.Harlan@modot.mo.mgov
John Miller	John.P.Miller@modot.mo.gov
Lubna Shoaib	Lubna.Shoaib@ewgateway.org
Tony Friedman	tfriedman@ofallon.mo.us
Carlos Sun	csun@missouri.edu
Wade Montgomery	Wmontgomery@ofallon.mo.us
Jonathan A. Nelson	Jonathan.Nelson@modot.mo.gov
Henry Brown	brownhen@missouri.edu
Karen S. Miller	Karen.Miller@modot.mo.gov
David Knaut	dknaut@ozarkstransportation.org
Natasha Longpine	nlongpine@ozarkstransportation.org
Michael Kelley	Michael.kelley@bikewalkkc.com
Alex Weidenbenner	Alex.Weidenbenner@stcharlescitymo.gov
Mandy Buettgen	mbuettgen@springfieldmo.gov
Bailey Waters	Bailey.Waters@kcmo.org
Christopher S. Crocker	Christopher.Crocker@modot.mo.gov
Aishwarya Shrestha	AishwaryaShrestha@MissouriState.edu
Matt Seggerman	mseggerman@sccmo.org
John Greifzu	JGreifzu@sccmo.org
Sara Nelson	snelson@sccmo.org
Terry Rigdon	trigdon@LakeSaintLouis.com
Anna Gill	agill@marktwaincog.com

Additional contacts for the City of St. Louis and St. Louis County.

Name	Email/Organization
Betherny Williams	williamsbeth@stlouis-mo.gov
Joseph Kulessa	JKulessa@stlouiscountymo.gov
Glenn Henninger	GHenninger@stlouiscountymo.gov

APPENDIX D: HIGH-CRASH INTERSECTION LIST

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
KANSAS CITY	E 31ST ST	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	E 31ST ST	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	E 31ST ST	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	E 31ST ST	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	E 31ST ST	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	160551	11	Y	4	17202
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	WASHINGTON AVE	URBANIZED	MINOR ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	276029	9	Y	3	19849
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	276029	9	Y	3	19849
SPRINGFIELD	W GRAND ST	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
SPRINGFIELD	W GRAND ST	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	CAMPBELL AVE	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	W GRAND ST	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	CAMPBELL AVE	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	W GRAND ST	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	CAMPBELL AVE	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
SPRINGFIELD	CAMPBELL AVE	URBANIZED	MINOR ARTERIAL	519984	8	Y	3	23754
ST. LOUIS	WALNUT ST	URBANIZED	MAJOR COLLECTOR	278115	8	Y	3	27492
ST. LOUIS	WALNUT ST	URBANIZED	MAJOR COLLECTOR	278115	8	Y	3	27492
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	278115	8	Y	3	27492
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	278115	8	Y	3	27492
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	278115	8	Y	3	27492
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	278115	8	Y	3	27492
ST. LOUIS	BROADWAY	URBANIZED	PRINCIPAL ARTERIAL	278115	8	Y	3	27492
ST. LOUIS	WALNUT ST	URBANIZED	MAJOR COLLECTOR	278115	8	Y	3	27492
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	WHITTIER ST	URBANIZED		273114	8	Y	3	12741
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	273114	8	Y	3	12741
ST. LOUIS	WHITTIER ST	URBANIZED		273114	8	Y	3	12741

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	266360	8	Y	3	19116
ST. LOUIS	MORGANFORD RD	URBANIZED	MAJOR COLLECTOR	290177	7	Y	4	25533
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290177	7	Y	4	25533
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290177	7	Y	4	25533
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290177	7	Y	4	25533
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290177	7	Y	4	25533
ST. LOUIS	MORGANFORD RD	URBANIZED	MAJOR COLLECTOR	290177	7	Y	4	25533
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290177	7	Y	4	25533
ST. LOUIS	30	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	30	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	30	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	GRAND BLVD	URBANIZED	MINOR ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	30	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811
ST. LOUIS	30	URBANIZED	PRINCIPAL ARTERIAL	289109	7	Y	4	35811

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
MAPLEWOOD	SUTTON BLVD	URBANIZED	MAJOR COLLECTOR	283241	7	N	4	17401
MAPLEWOOD	SUTTON BLVD	URBANIZED	MAJOR COLLECTOR	283241	7	N	4	17401
MAPLEWOOD	100	URBANIZED	PRINCIPAL ARTERIAL	283241	7	N	4	17401
MAPLEWOOD	SUTTON BLVD	URBANIZED	LOCAL	283241	7	N	4	17401
MAPLEWOOD	100	URBANIZED	PRINCIPAL ARTERIAL	283241	7	N	4	17401
MAPLEWOOD	SUTTON BLVD	URBANIZED	LOCAL	283241	7	N	4	17401
MAPLEWOOD	100	URBANIZED	PRINCIPAL ARTERIAL	283241	7	N	4	17401
ST. LOUIS	EUCLID AVE	URBANIZED	MAJOR COLLECTOR	272402	7	Y	4	17228
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	272402	7	Y	4	17228
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	272402	7	Y	4	17228
ST. LOUIS	EUCLID AVE	URBANIZED	MAJOR COLLECTOR	272402	7	Y	4	17228
ST. LOUIS	EUCLID AVE	URBANIZED	MAJOR COLLECTOR	272402	7	Y	4	17228
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	272402	7	Y	4	17228
ST. LOUIS	LINDELL BLVD	URBANIZED	MINOR ARTERIAL	272402	7	Y	4	17228
ST. LOUIS	DELMAR BLVD	URBANIZED	MINOR ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	DELMAR BLVD	URBANIZED	MINOR ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	DELMAR BLVD	URBANIZED	MINOR ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	DELMAR BLVD	URBANIZED	MINOR ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	DELMAR BLVD	URBANIZED	MINOR ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	KINGSHIGHWAY BLVD	URBANIZED	PRINCIPAL ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	KINGSHIGHWAY BLVD	URBANIZED	PRINCIPAL ARTERIAL	269659	7	Y	4	42168
ST. LOUIS	KINGSHIGHWAY BLVD	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
ST. LOUIS	KINGSHIGHWAY BLVD	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
ST. LOUIS	115	URBANIZED	PRINCIPAL ARTERIAL	261368	7	Y	3	23084
FLORDELL HILLS	WEST FLORISSANT AVE	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	JENNINGS STATION RD	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	JENNINGS STATION RD	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	JENNINGS STATION RD	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	JENNINGS STATION RD	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	JENNINGS STATION RD	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
FLORDELL HILLS	WEST FLORISSANT AVE	URBANIZED	MINOR ARTERIAL	249535	7	Y	4	30430
COLUMBIA	763	URBANIZED	MINOR ARTERIAL	193741	7	Y	4	23489
COLUMBIA	763	URBANIZED	MINOR ARTERIAL	193741	7	Y	4	23489
COLUMBIA	UNIVERSITY AVE	URBANIZED	LOCAL	193741	7	Y	4	23489
COLUMBIA	763	URBANIZED	MINOR ARTERIAL	193741	7	Y	4	23489
COLUMBIA	UNIVERSITY AVE	URBANIZED	LOCAL	193741	7	Y	4	23489
COLUMBIA	763	URBANIZED	MINOR ARTERIAL	193741	7	Y	4	23489
COLUMBIA	763	URBANIZED	MINOR ARTERIAL	193741	7	Y	4	23489
KANSAS CITY	E 39TH ST	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	E 39TH ST	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	E 39TH ST	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	E 39TH ST	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	PROSPECT AVE	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	E 39TH ST	URBANIZED	MINOR ARTERIAL	164120	7	Y	4	17979
KANSAS CITY	BROADWAY BLVD	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	W 39TH ST	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	BROADWAY BLVD	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	W 39TH ST	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	BROADWAY BLVD	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	W 39TH ST	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
KANSAS CITY	BROADWAY BLVD	URBANIZED	MINOR ARTERIAL	163533	7	Y	4	28230
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	366	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	GRAND BLVD	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	GRAND BLVD	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	GRAND BLVD	URBANIZED	MINOR ARTERIAL	290759	6	Y	4	20761
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992
ST. LOUIS	GRAND BLVD TO FOREST PARK AVE W	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992

CITY	TRAVELWAY	DENSITY	FUNC. CLASS	INTER. #	CRA.	SIG.	# OF LEGS	ENTERING VOLUME
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992
ST. LOUIS	GRAND BLVD	URBANIZED	PRINCIPAL ARTERIAL	275254	6	Y	3	25992
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
HAZELWOOD	NORTH HANLEY RD	URBANIZED	MINOR ARTERIAL	231621	6	Y	3	24632
KANSAS CITY	MAIN ST	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777
KANSAS CITY	ARMOUR BLVD	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777
KANSAS CITY	MAIN ST	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777
KANSAS CITY	ARMOUR BLVD	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777
KANSAS CITY	ARMOUR BLVD	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777
KANSAS CITY	ARMOUR BLVD	URBANIZED	MINOR ARTERIAL	161934	6	Y	4	17777

APPENDIX E: HIGH-CRASH CORRIDOR LIST

COUNTY NAME	CITY NAME	TRAVELWAY NAME	FUNCTIONAL CLASS	CRA.
ST. LOUIS CITY	ST. LOUIS	GRAND BLVD	MINOR ARTERIAL	103
ST. LOUIS CITY	ST. LOUIS	KINGSHIGHWAY BLVD	PRINCIPAL ARTERIAL	74
JACKSON	KANSAS CITY	INDEPENDENCE AVE	PRINCIPAL ARTERIAL	55
ST. LOUIS CITY	ST. LOUIS	WEST FLORISSANT AVE	MINOR ARTERIAL	54
ST. LOUIS CITY	ST. LOUIS	30	PRINCIPAL ARTERIAL	52
ST. LOUIS	NON-CITY OR UNINCORPORATED	CHAMBERS RD	PRINCIPAL ARTERIAL	44
JACKSON	KANSAS CITY	PROSPECT AVE	MINOR ARTERIAL	43
ST. LOUIS	HAZELWOOD	67	PRINCIPAL ARTERIAL	42
ST. LOUIS	PAGEDALE	180	PRINCIPAL ARTERIAL	41
ST. LOUIS CITY	ST. LOUIS	100	MINOR ARTERIAL	40
ST. LOUIS	DES PERES	100	PRINCIPAL ARTERIAL	40
JACKSON	KANSAS CITY	40	PRINCIPAL ARTERIAL	39
ST. LOUIS CITY	ST. LOUIS	115	PRINCIPAL ARTERIAL	38
ST. LOUIS CITY	ST. LOUIS	BROADWAY	PRINCIPAL ARTERIAL	37
ST. LOUIS CITY	ST. LOUIS	H	PRINCIPAL ARTERIAL	37
JACKSON	KANSAS CITY	TROOST AVE	MINOR ARTERIAL	36
ST. LOUIS CITY	ST. LOUIS	LINDELL BLVD	MINOR ARTERIAL	35
ST. LOUIS CITY	ST. LOUIS	70	INTERSTATE	32
ST. LOUIS CITY	ST. LOUIS	DR MARTIN LUTHER KING DR	MINOR ARTERIAL	32
ST. LOUIS CITY	ST. LOUIS	D	PRINCIPAL ARTERIAL	31
JACKSON	KANSAS CITY	E 31ST ST	MINOR ARTERIAL	31
ST. LOUIS CITY	ST. LOUIS	30	PRINCIPAL ARTERIAL	31
GREENE	SPRINGFIELD	CAMPBELL AVE	PRINCIPAL ARTERIAL	30
ST. LOUIS	BALLWIN	CLAYTON RD	MINOR ARTERIAL	30
JEFFERSON	CRYSTAL CITY	61	MAJOR COLLECTOR	28
JACKSON	KANSAS CITY	E 39TH ST	MINOR ARTERIAL	28
ST. LOUIS	UNIVERSITY CITY	BIG BEND BLVD	MINOR ARTERIAL	28
ST. LOUIS CITY	ST. LOUIS	UNION BLVD	MINOR ARTERIAL	27
JACKSON	KANSAS CITY	70	INTERSTATE	26
ST. LOUIS	HAZELWOOD	NORTH HANLEY RD	MINOR ARTERIAL	26
ST. LOUIS CITY	ST. LOUIS	44	INTERSTATE	25
ST. LOUIS CITY	ST. LOUIS	55	INTERSTATE	25
WARREN	WARRENTON	47	MINOR ARTERIAL	25
PETTIS	SEDALIA	50	PRINCIPAL ARTERIAL	25
ST. LOUIS CITY	ST. LOUIS	366	PRINCIPAL ARTERIAL	25
ST. LOUIS	UNIVERSITY CITY	HANLEY RD	PRINCIPAL ARTERIAL	25
JACKSON	KANSAS CITY	MAIN ST	MINOR ARTERIAL	25
GREENE	SPRINGFIELD	NATIONAL AVE	PRINCIPAL ARTERIAL	25

ST. LOUIS CITY	ST. LOUIS	WASHINGTON AVE	MINOR ARTERIAL	25
ST. LOUIS	PINE LAWN	JENNINGS STATION RD	MINOR ARTERIAL	25
JACKSON	KANSAS CITY	24	PRINCIPAL ARTERIAL	24
ST. LOUIS CITY	ST. LOUIS	366	PRINCIPAL ARTERIAL	23
GREENE	SPRINGFIELD	13	FREEWAY	22
JACKSON	KANSAS CITY	BROADWAY BLVD	MINOR ARTERIAL	22
ST. LOUIS CITY	ST. LOUIS	HAMPTON AVE	PRINCIPAL ARTERIAL	22
GREENE	SPRINGFIELD	44	PRINCIPAL ARTERIAL	21
JACKSON	KANSAS CITY	TRUMAN RD	MINOR ARTERIAL	21
JEFFERSON	HILLSBORO	21	PRINCIPAL ARTERIAL	20
ST. LOUIS	NON-CITY OR UNINCORPORATED	231	PRINCIPAL ARTERIAL	20
ST. LOUIS CITY	ST. LOUIS	TUCKER BLVD	PRINCIPAL ARTERIAL	20
ST. LOUIS CITY	ST. LOUIS	DELMAR BLVD	MINOR ARTERIAL	20
JACKSON	KANSAS CITY	LINWOOD BLVD	MINOR ARTERIAL	20
ST. LOUIS	ST. JOHN	180	PRINCIPAL ARTERIAL	20
FRANKLIN	ST. CLAIR	44	INTERSTATE	19
HENRY	CLINTON	7	PRINCIPAL ARTERIAL	19
GREENE	SPRINGFIELD	744	PRINCIPAL ARTERIAL	19
ST. LOUIS	FERGUSON	AC	PRINCIPAL ARTERIAL	19
ST. LOUIS CITY	ST. LOUIS	ARSENAL ST	MINOR ARTERIAL	19
GREENE	SPRINGFIELD	GRANT AVE	MINOR ARTERIAL	19
ST. LOUIS CITY	ST. LOUIS	115	PRINCIPAL ARTERIAL	19
ST. LOUIS CITY	ST. LOUIS	115	PRINCIPAL ARTERIAL	19
ST. LOUIS	FERGUSON	AIRPORT RD	PRINCIPAL ARTERIAL	18
JACKSON	KANSAS CITY	WORNALL RD	PRINCIPAL ARTERIAL	18
ST. LOUIS	UNIVERSITY CITY	340	PRINCIPAL ARTERIAL	17
ST. LOUIS	NON-CITY OR UNINCORPORATED	BELLEFONTAINE RD	MINOR ARTERIAL	17
JACKSON	KANSAS CITY	BLUE RIDGE BLVD	MINOR ARTERIAL	17
JACKSON	KANSAS CITY	71	FREEWAY	16
PLATTE	KANSAS CITY	29	INTERSTATE	16
BOONE	COLUMBIA	BROADWAY	MINOR ARTERIAL	16
GREENE	SPRINGFIELD	SUNSHINE ST	PRINCIPAL ARTERIAL	16
LEWIS	CANTON	61	FREEWAY	16
HOWELL	WEST PLAINS	63	PRINCIPAL ARTERIAL	15
LACLEDE	LEBANON	5	PRINCIPAL ARTERIAL	15
CEDAR	EL DORADO SPRINGS	54	PRINCIPAL ARTERIAL	15
GREENE	SPRINGFIELD	65	PRINCIPAL ARTERIAL	15
JACKSON	INDEPENDENCE	78	PRINCIPAL ARTERIAL	15
ST. LOUIS	KIRKWOOD	270	INTERSTATE	15
GREENE	SPRINGFIELD	JEFFERSON AVE	MINOR ARTERIAL	15

ST. LOUIS CITY	ST. LOUIS	JEFFERSON AVE	MINOR ARTERIAL	15
GREENE	SPRINGFIELD	744	PRINCIPAL ARTERIAL	15
ST. LOUIS	FLORISSANT	67	PRINCIPAL ARTERIAL	15
ST. LOUIS CITY	ST. LOUIS	BROADWAY ST	PRINCIPAL ARTERIAL	15
JACKSON	KANSAS CITY	W 39TH ST	MINOR ARTERIAL	15
ST. FRANCOIS	FARMINGTON	32	PRINCIPAL ARTERIAL	14
CLAY	KANSAS CITY	291	PRINCIPAL ARTERIAL	14
BOONE	COLUMBIA	763	MINOR ARTERIAL	14
ST. LOUIS CITY	ST. LOUIS	14TH ST	MINOR ARTERIAL	14
ST. LOUIS	NON-CITY OR UNINCORPORATED	NEW HALLS FERRY RD	PRINCIPAL ARTERIAL	14
JACKSON	INDEPENDENCE	NOLAND RD	PRINCIPAL ARTERIAL	14
ST. LOUIS CITY	ST. LOUIS	OLIVE ST	LOCAL	14
JACKSON	KANSAS CITY	STERLING AVE	MAJOR COLLECTOR	14
TANEY	BRANSON	76 COUNTRY BLVD	PRINCIPAL ARTERIAL	14
ST. LOUIS	NON-CITY OR UNINCORPORATED	267	MINOR ARTERIAL	13
NEWTON	NON-CITY OR UNINCORPORATED	60	PRINCIPAL ARTERIAL	13
JACKSON	KANSAS CITY	E 27TH ST	MINOR ARTERIAL	13
ST. LOUIS CITY	ST. LOUIS	COMPTON AVE	MAJOR COLLECTOR	13
ST. LOUIS CITY	ST. LOUIS	55	INTERSTATE	12
TANEY	KIRBYVILLE	76	MINOR ARTERIAL	12
GREENE	SPRINGFIELD	DIVISION ST	MINOR ARTERIAL	12
ST. LOUIS CITY	ST. LOUIS	FLORISSANT AVE	MINOR ARTERIAL	12
ST. LOUIS	UNIVERSITY CITY	FORSYTH BLVD	MINOR ARTERIAL	12
JACKSON	KANSAS CITY	GRAND BLVD	MINOR ARTERIAL	12
ST. LOUIS	NON-CITY OR UNINCORPORATED	HALLS FERRY RD	PRINCIPAL ARTERIAL	12
JACKSON	KANSAS CITY	HARDESTY AVE	MINOR ARTERIAL	12
JACKSON	KANSAS CITY	INDIANA AVE	MAJOR COLLECTOR	12
ST. LOUIS CITY	ST. LOUIS	SKINKER BLVD	PRINCIPAL ARTERIAL	12
ST. LOUIS CITY	ST. LOUIS	KINGSHIGHWAY BLVD	PRINCIPAL ARTERIAL	12
CASS	BELTON	58	MINOR ARTERIAL	11
CLAY	KANSAS CITY	169	FREEWAY	11
BARTON	LAMAR	160	MINOR ARTERIAL	11
ST. LOUIS	BRENTWOOD	S BRENTWOOD BLVD	PRINCIPAL ARTERIAL	11
CAPE GIRARDEAU	CAPE GIRARDEAU	BROADWAY	MINOR ARTERIAL	11
JACKSON	KANSAS CITY	BROOKSIDE BLVD	MINOR ARTERIAL	11
GREENE	SPRINGFIELD	44	FREEWAY	11
ST. LOUIS CITY	ST. LOUIS	MORGANFORD RD	MINOR ARTERIAL	11
CLAY	KANSAS CITY	N OAK TRFY	MINOR ARTERIAL	11
ST. LOUIS	UNIVERSITY CITY	340	PRINCIPAL ARTERIAL	11

ST. LOUIS CITY	ST. LOUIS	ST LOUIS AVE	MAJOR COLLECTOR	11
JASPER	JOPLIN	49	PRINCIPAL ARTERIAL	11
GASCONADE	HERMANN	19	MINOR ARTERIAL	10
DUNKLIN	KENNETT	25	PRINCIPAL ARTERIAL	10
GREENE	SPRINGFIELD	BATTLEFIELD RD	PRINCIPAL ARTERIAL	10
GREENE	SPRINGFIELD	W GRAND ST	MINOR ARTERIAL	10
ST. LOUIS CITY	ST. LOUIS	NEWSTEAD AVE	LOCAL	10
ST. LOUIS	NON-CITY OR UNINCORPORATED	D	PRINCIPAL ARTERIAL	10
ST. LOUIS	OVERLAND	WOODSON RD	MINOR ARTERIAL	10
ST. LOUIS	FRONTENAC	67	PRINCIPAL ARTERIAL	9
NEWTON	SENECA	43	MINOR ARTERIAL	9
ST. LOUIS CITY	ST. LOUIS	64	INTERSTATE	9
JACKSON	KANSAS CITY	435	INTERSTATE	9
ST. LOUIS	MOLINE ACRES	367	FREEWAY	9
BOONE	COLUMBIA	B	MINOR ARTERIAL	9
JACKSON	KANSAS CITY	E 12TH ST	MAJOR COLLECTOR	9
JACKSON	KANSAS CITY	ARMOUR BLVD	MINOR ARTERIAL	9
JACKSON	KANSAS CITY	N BROADWAY BLVD	MINOR ARTERIAL	9
ST. LOUIS CITY	ST. LOUIS	CALIFORNIA AVE		9
ST. LOUIS CITY	ST. LOUIS	EUCLID AVE	MAJOR COLLECTOR	9
ST. LOUIS	FERGUSON	N	MINOR ARTERIAL	9
GREENE	SPRINGFIELD	MOUNT VERNON ST	MAJOR COLLECTOR	9
ST. LOUIS CITY	ST. LOUIS	N SARAH ST	MINOR COLLECTOR	9
ST. LOUIS CITY	ST. LOUIS	4TH ST	PRINCIPAL ARTERIAL	9
ST. LOUIS	DES PERES	100	PRINCIPAL ARTERIAL	9
PETTIS	SEDALIA	65	PRINCIPAL ARTERIAL	8
GREENE	SPRINGFIELD	13	FREEWAY	8
JASPER	JOPLIN	66	PRINCIPAL ARTERIAL	8
PLATTE	KANSAS CITY	45	PRINCIPAL ARTERIAL	8
JACKSON	KANSAS CITY	435	INTERSTATE	8
JEFFERSON	NON-CITY OR UNINCORPORATED	141	FREEWAY	8
JEFFERSON	BYRNES MILL	30	PRINCIPAL ARTERIAL	8
ST. CHARLES	O'FALLON	K	PRINCIPAL ARTERIAL	8
JACKSON	INDEPENDENCE	35TH ST	MINOR ARTERIAL	8
JACKSON	KANSAS CITY	E 63RD ST	MINOR ARTERIAL	8
ST. LOUIS CITY	ST. LOUIS	FOREST PARK AVE	PRINCIPAL ARTERIAL	8
ST. LOUIS	FLORISSANT	HOWDERSHELL RD	PRINCIPAL ARTERIAL	8
ST. LOUIS	COUNTRY CLUB HILLS	U	PRINCIPAL ARTERIAL	8
ST. LOUIS	BRENTWOOD	100	PRINCIPAL ARTERIAL	8
ST. LOUIS CITY	ST. LOUIS	MARKET ST	PRINCIPAL ARTERIAL	8

ST. LOUIS CITY	ST. LOUIS	MERAMEC ST	MAJOR COLLECTOR	8
ST. CHARLES	O'FALLON	MEXICO RD	PRINCIPAL ARTERIAL	8
ST. LOUIS	UNIVERSITY CITY	MIDLAND BLVD	MINOR ARTERIAL	8
PLATTE	KANSAS CITY	ROME CIR		8
ST. LOUIS CITY	ST. LOUIS	TAYLOR AVE	MAJOR COLLECTOR	8
ST. LOUIS	NON-CITY OR UNINCORPORATED	231	PRINCIPAL ARTERIAL	8
GREENE	SPRINGFIELD	WALNUT ST		8
ST. CHARLES	NON-CITY OR UNINCORPORATED	WENTZVILLE PKWY	PRINCIPAL ARTERIAL	8
ST. LOUIS	NON-CITY OR UNINCORPORATED	267	MINOR ARTERIAL	8
JACKSON	KANSAS CITY	CLEAVER II BLVD	MINOR ARTERIAL	8
ST. LOUIS CITY	ST. LOUIS	44	INTERSTATE	8
JACKSON	KANSAS CITY	DR MARTIN LUTHER KING JR BLVD	PRINCIPAL ARTERIAL	8

APPENDIX F: HIGH-CRASH SEGMENT LIST

TRAVELWAY NAME	FUNCTIONAL CLASS	CRA.
70	INTERSTATE	31
55	INTERSTATE	25
44	INTERSTATE	24
70	INTERSTATE	23
67	PRINCIPAL ARTERIAL	19
40	PRINCIPAL ARTERIAL	19
44	INTERSTATE	17
61	MAJOR COLLECTOR	16
GRAND BLVD	MINOR ARTERIAL	16
WEST FLORISSANT AVE	MINOR ARTERIAL	16
100	PRINCIPAL ARTERIAL	16
270	INTERSTATE	14
30	PRINCIPAL ARTERIAL	13
47	MINOR ARTERIAL	12
29	INTERSTATE	12
CAMPBELL AVE	PRINCIPAL ARTERIAL	12
LINDELL BLVD	MINOR ARTERIAL	12
H	PRINCIPAL ARTERIAL	12
AC	PRINCIPAL ARTERIAL	11
180	PRINCIPAL ARTERIAL	11
CLAYTON RD	MINOR ARTERIAL	11
21	PRINCIPAL ARTERIAL	10
5	PRINCIPAL ARTERIAL	10
D	PRINCIPAL ARTERIAL	10
100	MINOR ARTERIAL	10
DR MARTIN LUTHER KING DR	MINOR ARTERIAL	10
67	PRINCIPAL ARTERIAL	10
STERLING AVE	MAJOR COLLECTOR	10
55	INTERSTATE	9
63	PRINCIPAL ARTERIAL	9
32	PRINCIPAL ARTERIAL	9
13	FREEWAY	9
71	FREEWAY	9
24	PRINCIPAL ARTERIAL	9
NEW HALLS FERRY RD	PRINCIPAL ARTERIAL	9
76 COUNTRY BLVD	PRINCIPAL ARTERIAL	9
435	INTERSTATE	8
435	INTERSTATE	8

366	PRINCIPAL ARTERIAL	8
231	PRINCIPAL ARTERIAL	8
30	PRINCIPAL ARTERIAL	8
60	PRINCIPAL ARTERIAL	8
160	MINOR ARTERIAL	8
NORTH HANLEY RD	MINOR ARTERIAL	8
ROME CIR		8
7	PRINCIPAL ARTERIAL	7
291	PRINCIPAL ARTERIAL	7
170	INTERSTATE	7
115	PRINCIPAL ARTERIAL	7
CHAMBERS RD	PRINCIPAL ARTERIAL	7
DELMAR BLVD	MINOR ARTERIAL	7
GRAHAM RD	MINOR ARTERIAL	7
180	PRINCIPAL ARTERIAL	7
SUNSHINE ST	MINOR ARTERIAL	7
JENNINGS STATION RD	MINOR ARTERIAL	7
70	LOCAL	7
61	FREEWAY	7
19	MINOR ARTERIAL	6
76	MINOR ARTERIAL	6
54	PRINCIPAL ARTERIAL	6
13	FREEWAY	6
44	PRINCIPAL ARTERIAL	6
65	PRINCIPAL ARTERIAL	6
169	FREEWAY	6
29	INTERSTATE	6
60	FREEWAY	6
BIG BEND BLVD	MINOR ARTERIAL	6
BLUE RIDGE BLVD	MINOR ARTERIAL	6
49	INTERSTATE	6
52	MINOR ARTERIAL	5
63	FREEWAY	5
OO	MAJOR COLLECTOR	5
65	FREEWAY	5
64	INTERSTATE	5
50	PRINCIPAL ARTERIAL	5
50	FREEWAY	5
270	INTERSTATE	5
367	FREEWAY	5
55	INTERSTATE	5
N BOARDWALK AVE	LOCAL	5
CALIFORNIA AVE		5

GRANT AVE	MINOR ARTERIAL	5
GREEN VALLEY DR		5
JUNGERMANN RD	PRINCIPAL ARTERIAL	5
744	PRINCIPAL ARTERIAL	5
KINGSHIGHWAY BLVD	PRINCIPAL ARTERIAL	5
MAIN ST	MINOR ARTERIAL	5
NATIONAL AVE	PRINCIPAL ARTERIAL	5
115	PRINCIPAL ARTERIAL	5
ST LOUIS AVE	MAJOR COLLECTOR	5
44	PRINCIPAL ARTERIAL	5
67	PRINCIPAL ARTERIAL	4
51	MINOR ARTERIAL	4
25	PRINCIPAL ARTERIAL	4
53	PRINCIPAL ARTERIAL	4
14	MINOR ARTERIAL	4
43	MINOR ARTERIAL	4
29	INTERSTATE	4
12	MINOR ARTERIAL	4
D	MINOR ARTERIAL	4
340	PRINCIPAL ARTERIAL	4
740	PRINCIPAL ARTERIAL	4
763	MINOR ARTERIAL	4
PP	MINOR ARTERIAL	4
BATTLEFIELD RD	PRINCIPAL ARTERIAL	4
BELLEFONTAINE RD	MINOR ARTERIAL	4
BROADWAY	MINOR ARTERIAL	4
44	FREEWAY	4
ENRIGHT AVE		4
GRAND BLVD	MINOR ARTERIAL	4
30	PRINCIPAL ARTERIAL	4
HALLS FERRY RD	PRINCIPAL ARTERIAL	4
HANLEY RD	PRINCIPAL ARTERIAL	4
MID RIVERS MALL DR	PRINCIPAL ARTERIAL	4
NOLAND RD	PRINCIPAL ARTERIAL	4
340	PRINCIPAL ARTERIAL	4
RAYTOWN RD	MINOR ARTERIAL	4
WELLS DR	MINOR COLLECTOR	4
WENTZVILLE PKWY	PRINCIPAL ARTERIAL	4
267	MINOR ARTERIAL	4
413	PRINCIPAL ARTERIAL	4