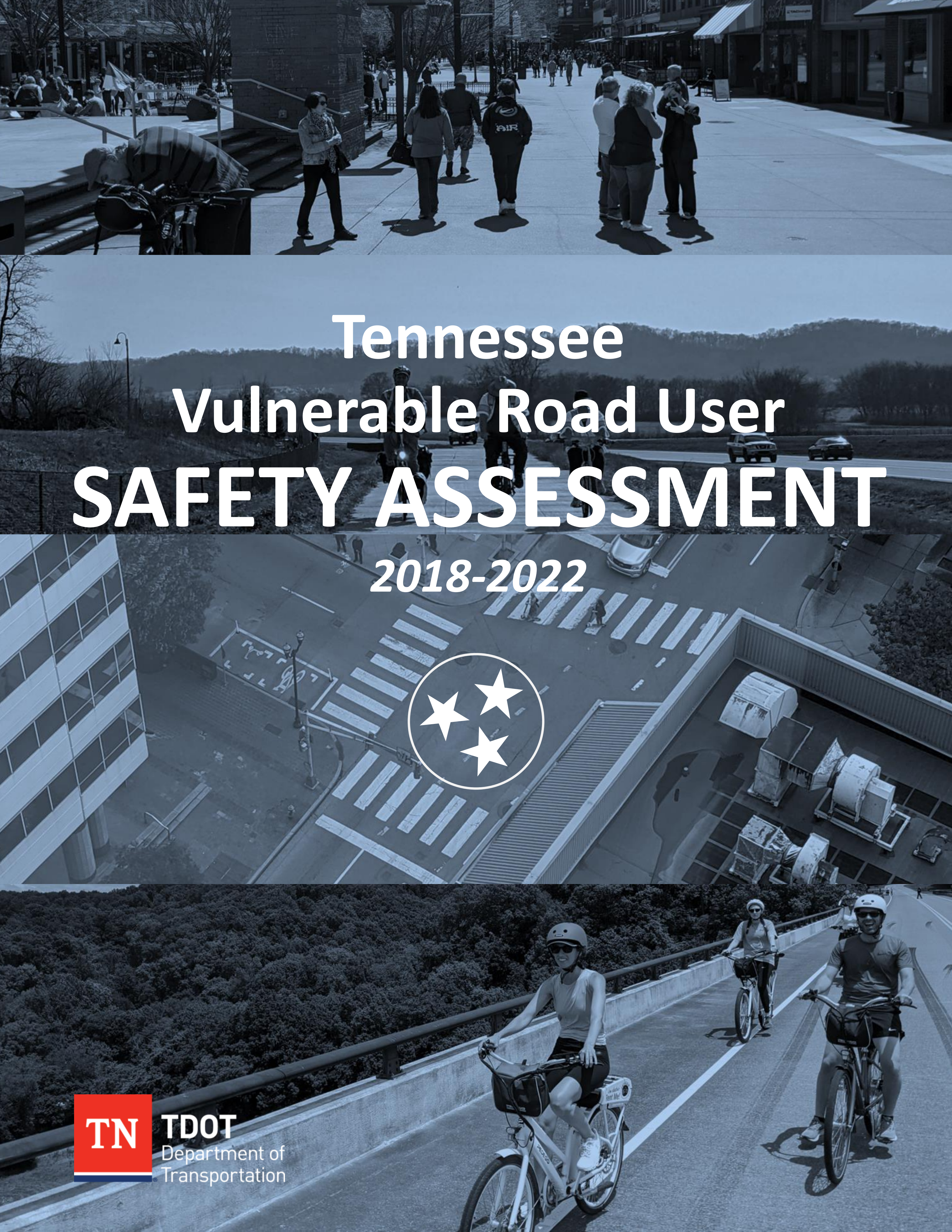
Tennessee Vulnerable Road User SAFETY ASSESSMENT

2018-2022



TN TDOT Department of Transportation

Executive Summary

The Tennessee Vulnerable Road User (VRU) Safety Assessment is a comprehensive initiative aimed at understanding the factors contributing to the increasing number of VRU crashes in Tennessee. VRUs include pedestrians, cyclists, and users of non-motorized transportation, and their vulnerability on the road necessitates a focus on safety. In Tennessee, the proportion of severe crashes involving a Vulnerable Road User (VRU) has steadily increased yearly over the last five years. Fatal and serious injury pedestrian and cyclist crashes increased by over 44% and 18%, respectively, from 2018 to 2022.

This assessment aligns with a Safe System Approach, prioritizing the elimination of fatalities and serious injuries on the road. It seeks to identify high-risk areas, infrastructure deficiencies, and existing programs impacting VRUs to propose evidence-based recommendations for integration into Tennessee's Strategic Highway Safety Plan. Beyond the immediate goal of reducing VRU crashes, this assessment promotes sustainable and active transportation, acknowledges social equity concerns, and aims to create a safer and more inclusive transportation network. The assessment also fulfills federal and state mandates to systematically evaluate and improve VRU safety, adhering to core principles of the Safe System Approach, which prioritizes human life above all else and considers human vulnerabilities and errors in road design and safety measures.

By adhering to the most current, evidence-based practices in road safety, this assessment takes a data-driven approach to systemically and equitably reduce VRU fatalities and serious injuries. Predictive modeling and descriptive analysis revealed high-risk area characteristics: transit stop presence, retail density, parking structure density, five or more lanes, local roads, locations with higher speeds, and locations with high social vulnerabilities (precisely household characteristics and racial and ethnic minority status). These findings contribute to the expansion of the Multimodal Priority Tool to include an Expected Crash Toolbox that allows a systemic look for VRU crashes based on all high-risk area characteristics.

Consultation was held with local governments, public agencies, and VRU advocacy groups through an online survey and workshop. The stakeholder input further supported the areas of concern identified within the High-Risk Network, encompassing 150 miles of roadway and including 25% of all VRU crashes. Stakeholder engagement has undoubtedly enriched the VRU Safety Assessment, making it more resilient, actionable, and aligned with its overarching goal of reducing VRU fatalities and injuries.

The quantitative analysis and stakeholder consultation led to the identification of five critical priority areas to guide the enhancement of VRU safety in Tennessee. These priority areas encompass VRU Crossing Safety, Safe and Accessible Roadways, Vehicle Speed Reduction, VRU Daily Needs, and System Longevity. They form the cornerstone of a comprehensive Safe System Approach, addressing both human behavior and road environment design to promote VRU safety. A Program of Strategies was developed in response to these priorities focuses on improving physical infrastructure, addressing user behavior, and ensuring long-term sustainability. Strategies and actions are laid out to provide overarching guidance and specific steps for achieving the objectives of the VRU Safety Assessment, reinforcing TDOT's commitment to creating a safer transportation environment for all road users in Tennessee.

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Introduction and Background

The primary purpose of the Tennessee Vulnerable Road User (VRU) Safety Assessment is to develop a comprehensive and data-driven understanding of the factors contributing to the rising number of VRU crashes within Tennessee. This initiative aims to identify high-risk areas, assess infrastructure deficiencies, and evaluate existing programs that impact VRUs, which include all using human-powered means of travel, which includes walking and bicycling, with or without the use of mobility aids, and may also include using other human-scaled or micro-mobility devices that may be electric-powered or electric-assisted, such as e-bikes and e-scooters.[1] VRU also provides for transit riders waiting at a transit stop and road workers in work zones. Informed by this analysis, the assessment proposes evidence-based recommendations for interventions and safety enhancements that can be integrated into Tennessee's Strategic Highway Safety Plan (SHSP)[2].

Beyond reducing fatal and serious injury crashes involving VRUs, this assessment is aligned with a Safe System Approach in which VRU safety is integral to the design and operation of transportation facilities. This assessment also reflects the involvement of underserved communities to ensure equity and considers the importance of sustainability in transportation planning. The goal is to foster a safer, more inclusive, and sustainable active transportation network across Tennessee.

Why VRU Safety?

VRUs encompass a broad category of individuals at an increased risk when navigating roadways. This group primarily includes pedestrians, cyclists, and users of other non-motorized modes of transportation. VRUs are characterized by their lack of protective shielding compared to those in motorized vehicles, making them particularly susceptible to serious injury or fatality in the event of a crash.

The safety of VRUs is a critical concern for multiple reasons. First, the increased vulnerability of these road users often results in a higher rate of severe injuries and fatalities in road crashes relative to drivers and vehicle passengers, leading to significant social and economic impacts. Second, promoting the safety of VRUs encourages the use of sustainable and active forms of transportation, such as walking and cycling, which have many community benefits, including improved public health, reduced traffic congestion, and lower greenhouse gas emissions. Finally, focusing on VRU safety is a matter of social equity, ensuring that all individuals—regardless of their mode of transportation—have safe and equitable access to transportation networks.

By identifying risk factors, high-risk locations, and effective countermeasures through this assessment, TDOT and its local partners are better positioned to take measures that will significantly improve the safety and well-being of VRUs across Tennessee.

Regulatory Background

Federal

This Tennessee VRU Safety Assessment is designed to fulfill the federal mandate established under 23 U.S.C. 148(l), as recently amended by the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL), Public Law 117-58. This legislation requires states to develop a Vulnerable Road User

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[1] VRU definition from AASHTO Council of Active Transportation, https://transportation.org/active/.

[2] TDOT, Tennessee Strategic Highway Safety Plan (SHSP), 2020, https://www.tn.gov/content/dam/tn/tdot/strategic/SHSP-2020.pdf

Safety Assessment as a component of their Strategic Highway Safety Plan (SHSP). This mandate aims to systematically evaluate and propose solutions for enhancing the safety of VRUs, including pedestrians, cyclists, wheelchairs or other mobility devices, and users of public transportation. By adhering to the most current, evidence-based practices in road safety, this assessment serves as a comprehensive plan to reduce fatalities and serious injuries among these vulnerable groups. In compliance with 23 U.S.C. 148(l), the strategies outlined in this assessment will be integrated into Tennessee's SHSP to ensure a safer road environment for all.

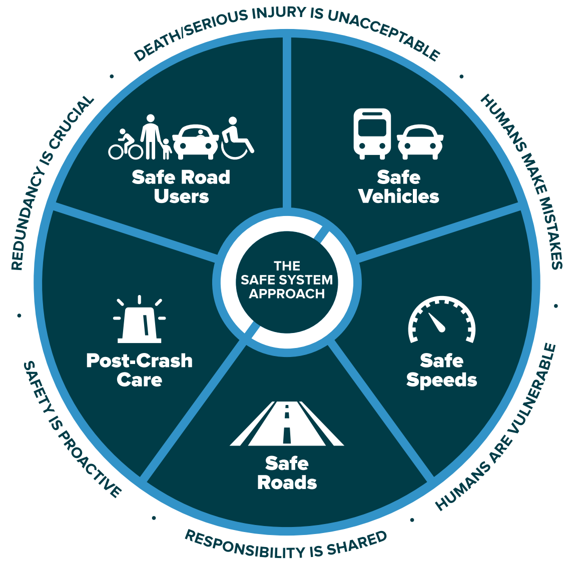
State

The Tennessee Code Annotated § 54-1-104 requires the Tennessee Department of Transportation (TDOT) to report findings regarding roads with elevated injuries to bicyclists and pedestrians, identify design factors, and disseminate the report to the local governments with the highest number of pedestrian safety problems.[3]

The VRU Safety Assessment addresses the Tennessee Code by identifying the locations of state and local government roads where VRU sever crashes are elevated compared to the statewide average within a High-Risk Network. During the VRU Consultation, the six local governments with the highest number of safety concerns were invited to give their input through an online survey an participate in a workshop to discuss the High-Risk Network. Each of the

Safe System Approach

The Safe System Approach, as defined by the FHWA, represents a sea change in how roadway crashes are viewed and aims to reduce road fatalities and serious injuries to zero.[4] It acknowledges that even responsible road users can make mistakes and, therefore, calls for the design of roads and road-related systems to anticipate human error and mitigate the severity of the impact of human error. The approach involves a holistic understanding of the interaction between road users, vehicles, road infrastructure, and speed, and it calls for shared responsibility among system designers and road users to enhance safety.



Core Principles

The Safe System Approach is anchored on six fundamental principles:

1. **Death/Serious Injury Is Unacceptable**: The Safe System approach prioritizes preventing crashes resulting in death and serious injury, emphasizing that no one should be killed or injured on the road.
2. **Humans Make Mistakes**: Acknowledging that road users will make errors, the system is designed to accommodate these mistakes and minimize harm, such as adding median barriers to prevent head-on collisions.
3. **Humans Are Vulnerable**: Designing a transportation system that considers human vulnerability focuses on managing kinetic energy transfer within survivable limits to prevent fatal or serious injuries.

[3] Tennessee Annotated Code, *Tenn. Code Ann. § 54-1-104, https://casetext.com/statute/tennessee-code/title-54-highways-bridges-and-ferries/chapter-1-department-of-transportation/part-1-general-provisions/section-54-1-104.*
[4] FHWA, https://highways.dot.gov/safety/zero-deaths.

4. **Responsibility Is Shared**: All stakeholders, including road users, system managers, law enforcement, and vehicle manufacturers, collaborate to prevent fatalities and injuries through various safety measures and responsibilities.
5. **Safety Is Proactive**: Roadway system managers use a proactive approach to identify and mitigate risks in the system before accidents occur, considering systemic factors and applying countermeasures.
6. **Redundancy Is Crucial**: Strengthening all parts of the system ensures that if one component fails, others can still protect road users, exemplified by features like rumble strips for added safety.

Safe System Elements

The Safe System Approach focuses on five major elements to reduce crash severity:

1. **Safe Road Users**: The safety of all road users is equitably addressed, including those who walk, bike, drive, ride transit, or travel by other modes.
2. **Safe Vehicles**: Vehicles are designed and regulated to minimize the frequency and severity of collisions using safety measures that incorporate the latest technology.
3. **Safe Speeds**: Humans are less likely to survive high-speed crashes. Reducing speeds can accommodate human-injury tolerances in three ways: reducing impact forces, providing additional time for drivers to stop, and improving visibility.
4. **Safe Roads**: Designing transportation infrastructure to accommodate human mistakes and injury tolerances can greatly reduce the severity of crashes that do occur. Examples include physically separating people traveling at different speeds, providing dedicated times for different users to move through spaces, and alerting users to hazards and other road users.
5. **Post-Crash Care**: People who are injured in collisions rely on emergency first responders to quickly locate and stabilize their injuries and transport them to medical facilities. Post-crash care also includes forensic analysis at the crash site, traffic incident management, and other activities.[5]

A core tenet of the Safe System Approach is the belief that no loss of life on our roads is acceptable. It prioritizes the preservation of human life above all else. By focusing on the inherent vulnerabilities of the human body and understanding that human errors are inevitable, the approach moves beyond traditional road safety measures.

Especially for VRUs, who are at an increased risk due to their lack of protective barriers compared to vehicle occupants, the Safe System Approach fosters the provision of a comprehensive safety net. It acknowledges the dynamic interplay between speed, road design, vehicle design, and road user behavior. In the context of design, it means creating roads and systems that consider the most vulnerable – making intersections safer, ensuring clear visibility, and reducing conflict points.

[5] FHWA, *Making our Roads Safer through a Safe System Approach*, https://highways.dot.gov/public-roads/winter-2022/01

Figure 1 - Five elements of the Safe System approach and their relevance to Pedestrians and Bicyclists[6]

[6]FHWA, Primer on Safe System Approach for Pedestrians and Bicyclists, https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa21065.pdf

Data and Methodology

Spatial data was assembled from various sources for this analysis. The primary datasets include (a) crash data shapefiles with associated characteristics, (b) roadway inventory shapefiles with geometric and operational characteristics, and (c) 2020 US Census tract shapefiles with related data tables.

Data sources used in the analysis include:

- Crash tables – *Tennessee Integrated Traffic Analysis Network (TITAN)*
- Roadway network inventory – *Tennessee Roadway Information Management System (TRIMS)*
- Transit stop locations – *Bureau of Transportation Statistics National Transportation Atlas Database*
- Social vulnerability statistics – *Agency for Toxic Substances and Disease Registry (ATSDR/CDC)*
- Building primary use database – *Federal Emergency Management Agency (FEMA)*

Crash Data

Crash data was obtained from TITAN for the previous five calendar years, from January 2018 through December 2022. This data is maintained and accessed through the TRIMS. Local law enforcement agencies or associated third parties submit crash records to TDOT and the Tennessee Department of Safety & Homeland Security to be incorporated into TRIMS and TITAN, respectively. The data is organized in a series of related tables.

The primary crash table contains one row for each reported crash involving at least one motor vehicle. Incidents not reported include crashes only involving VRUs or VRU crashes with a vehicle not in transport. The primary table contains general information about the location, time, date, weather conditions, and roadway characteristics at the time of the crash.

Separate tables exist for individual vehicles and persons, related to the primary table by a unique crash identifier. These tables contain information unique to each individual vehicle, driver, pedestrian, cyclist, or other person involved in the crash. Information provided (when available) includes pre-crash maneuvers, intoxication status, direction of travel, injury status, and additional characteristics unique to each individual.

For this study, a VRU crash is defined as any crash that has a related person (in the *Crash-Motorist/NonMotorist* table of the TRIMS query) coded as "pedestrian," "bicyclist," or "other cyclist." This query includes drivers that have exited their vehicles prior to the crash, such as drivers involved in secondary crashes, emergency services personnel, drivers of disabled vehicles on the shoulder, and other similar situations.

Throughout this report, crashes are regularly classified as severe and non-severe. A **severe crash**, also referred to as fatal or serious injury, is one coded in the TITAN crash report as a fatal or suspected incapacitating injury type. On the KABCO injury scale commonly used by law enforcement, severe crashes are also commonly referred to as "KA" or "K-SI" crashes. The KABCO scale measures the injury severity for any person involved in the crash: K for fatal injury, A for suspected serious injury (SI), B for suspected minor injury, C for possible injury, and O for no apparent injury.

Roadway Inventory Data

Roadway characteristics were primarily derived from four shapefiles available through the TRIMS inventory. A polyline feature class of roadway centerline contains route information as well as administrative and jurisdictional information. Another polyline feature class includes cross-section characteristics, including lanes of pavement and shoulder, medians, drainage types, and auxiliary lanes such as parking lanes and bike lanes. A third set of polyline features includes geometric characteristics, such as curvature of the roadway, terrain type, adjacent land use, access control, right-of-way width, and, in some cases, speed limit.

The fourth feature class contains point features for locations along the routes. These points contain information about points-of-interest, such as churches, schools, hospitals, parks, etc. Traffic control is also included in this dataset, including intersection control types for each approach. Turn restrictions, changes in speed limit, over and underpasses, rail crossings, intersection traffic control, warning devices, and many other spot features are present as well. Several roadway characteristics were derived from the available data and appended to the data tables. For example, divided, undivided, or two-way left-turn lane median types were joined onto road segments based on the presence of a median in the cross-section table.

Defining an Intersection

No spatial dataset for intersections was available to associate with the roadway centerline network. To create such a network, a query of points containing any turn movements onto cross-streets was created to define points of intersection. This query also included points coded as approach traffic control.

Intersections are defined by the point (or points) at which roadways intersect. This includes roundabouts, offset intersections, and other complex intersection geometries. Points of intersection were combined into a single, multipoint feature if they were within a 100-foot buffer of one another and assigned the same route number. Sets of multipoint features that overlapped were then combined (see Figure 2). Upon inspection of the data, this process was insufficient to capture larger roundabouts. A wider 150-foot search radius was used exclusively on intersection points containing "1-way yield" as a traffic control.

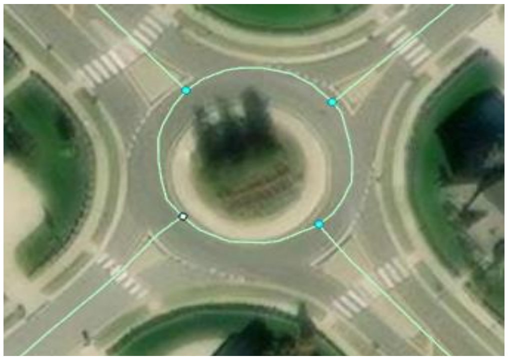


Figure 2 - Multiple Sets of Nearby Points Combined into a Single Intersection

Defining Segment Attributes

Roadway segment features from TRIMS were dissolved into a single polyline for each route, split only at or near major changes to the route, such as speed limit or significant changes to the cross-section alignment. These route lines were then divided into approximately half-mile lengths, except for Interstate and freeway routes, which were subdivided into approximately 1-mile lengths. If a split point occurred within 500 feet of the end of a route, the segment was not split at that point. If a split occurred within 500 feet of an intersection, the route was split at the intersection instead.

Roadway characteristics that change frequently, such as cross-section descriptions and widths, were aggregated onto each segment by average value along segment length for numerical attributes or by percent of overall length for categorical attributes.

Analysis Methods

To develop a relational database, unique intersection or segment IDs were joined to each crash. A unique census tract ID was also joined to each crash, segment, and intersection. Using these as keys, the tables were related, and crash data was aggregated onto roadway features.

Descriptive Analysis

Crash statistics are quantified in several ways throughout this report. In the Tennessee VRU Safety Performance section, an initial statewide summary provides crash totals for various characteristics aggregated at the crash level. For example, the report discusses the number of crashes at intersections versus the number on segments. When evaluating safety risk, intersection crashes are typically aggregated by average crashes at each intersection for each category, and segment-related crashes are aggregated by crashes per roadway mile. Demographic relationships to crash risk are usually reported as average crashes per mile versus the percent of the characteristic population in associated census tracts, which is binned into 5% increments.

High-Risk Network

To understand where VRUs are at the greatest risk, a subset of roadways statewide with the greatest concentration of observed VRU crashes was identified. Because VRU crashes already represent a small sample size compared to motor vehicle crashes, as well as the fact that these users are at significant risk from even minor collisions, all VRU crashes were included in this analysis rather than only fatal and serious injury crashes.

Roadway segments were sorted based on total VRU crashes per mile, including crashes at both intersections and on roadway segments. The group of roadway segments with the highest number of incidents along individual segments, was identified as the High-Risk Network (HRN). The combined length of the HRN segments is only 150 miles of roadway and represents 25% of all VRU crashes statewide between 2018 and 2022.

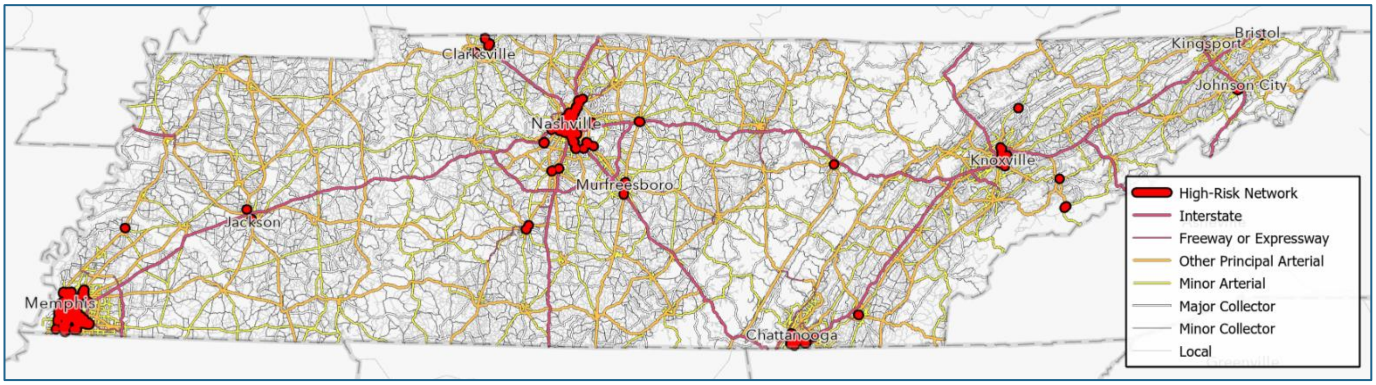


Figure 3 - Statewide High-Risk Network for Vulnerable Road Users

Predictive Modeling

Reported crash data was modeled against characteristics derived from roadway inventory data to establish a data-based crash risk for roadway facilities statewide. No statewide inventory of intersection characteristics was available, so many of the attributes included were derived from segment features.

Based on the Random Forest machine learning algorithm, forest-based regression was performed in ArcGIS to produce predictive models for vulnerable road user crash risk. Independent regression analyses were performed for intersection and roadway segment crashes, as well as cyclist and pedestrian-related crashes. Because additional roadway inventory data was available exclusively for state routes, the models were also split between intersections and existing segments along state routes. Roadway attribute variables vary between categorical and numeric, and model relationships are often not linear. Forest-based decision tree modeling is best equipped to handle these characteristics with minimal data transformation.

Over the five-year study period, more than 98% of all intersections and roadway segments statewide had zero observed crashes. When predicting the number of crashes, these zero-instance locations bias the model. To counteract this effect, a binomial model was first run to predict the probability that each segment or intersection would have zero crashes. The output of this model was included in the forest-based models as an explanatory variable.

Limitations

The lack of a robust VRU demand or volume dataset creates difficulty in drawing conclusions from crash quantities. Typically, in crash analysis, occurrences would be normalized by traffic volume to report crash rates in crashes per vehicle-mile or crashes per entering vehicle. Without this capability, crash totals are driven by VRU exposure as much as risks due to unsafe roadway characteristics. This is especially critical in suggesting countermeasures since typical infrastructure that mitigates crash risk is implemented at locations with significant VRU presence. This leads to the presence of features such as crosswalks, pedestrian signals, sidewalks, bike lanes, etc., correlating strongly with increased crash risk. Caution and engineering judgment are critical in avoiding drawing the wrong conclusions from data.

The relationships between roadway characteristics, location, demographics, and their interactions are complicated and introduce quite a bit of variance and heteroskedasticity (variance in the data increases the further it gets from zero) into the data. Scatter plots shown in this report usually have the data binned with the average values plotted on the y-axis to display the relationships better visually that are not always visible on an unbinned scatter plot. In these instances, symbol size corresponds to the total number of data points included in each bin.

An example showing the relationship between motor vehicle volume and average intersection crash occurrences is shown in the following figures. The scatter plot in Figure 4 shows unbinned data points, whereas Figure 5 shows data points binned into ranges of 2,000 vehicles per day.

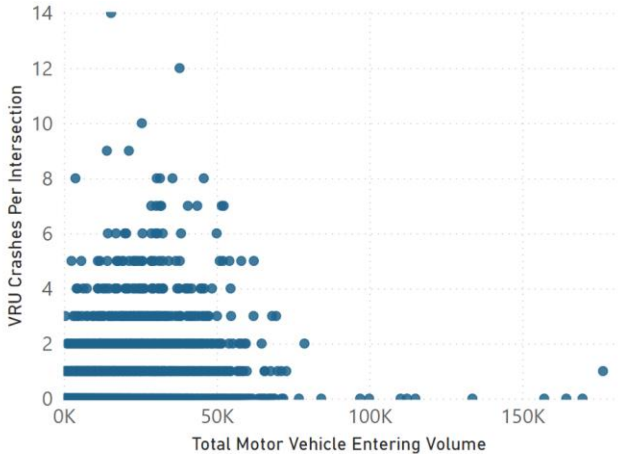


Figure 4 - Unbinned Scatter Plot Example

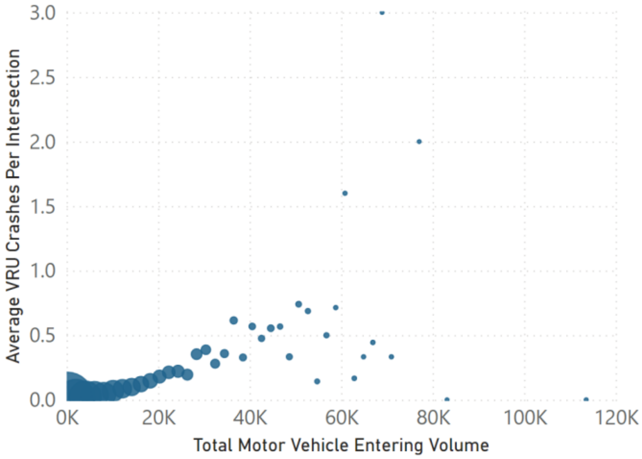


Figure 5 - Binned X-Axis Scatter Plot Example

Additional Data Sources Considered

In addition to the data sources listed at the beginning of this section, several of the following data sources were also considered. The Intermodal Passenger Connectivity Database[7] includes major passenger mode transfer points nationwide; however, detailed information about the nature of each node was limited in the dataset. The National Transportation Atlas Database (NTAD)[8] was used for nationwide transit map locations. Several other datasets are available within NTAD, including means of transportation to work and household size by vehicle availability. These metrics were included in some capacity through the Social Vulnerabilities Index (SVI) and were not localized enough to provide additional benefit to the analysis. VRU trip information was obtained from Replica[9], but mode choice classification was inadequate for projecting accurate pedestrian volumes statewide. Other data sources considered, which were either aggregated too coarsely or provided incomplete coverage, include National Household Travel Survey (NHTS) origin-destination data, bicycle and pedestrian volume counts from multiple sources, land use data from the Tennessee Comptroller, and transportation disadvantaged Census tracts from the US Department of Transportation (USDOT).

Further Analysis Opportunities

The forest-based regression performed in this study provides a reliable predictive look at crash risk statewide and can accommodate the available data formats. The nature of the decision tree methodology used by the forest-based algorithm means that the output can only provide the relative importance of each variable included in the model. No direct conclusions about the nature of the relationships can be drawn. A narrowed focus on modeling certain roadways or characteristics using a linear or generalized linear model could provide insight into the relationships of each variable to the VRU crash risk.

A good starting point for expanding the predictive capabilities of this study would be an analysis of the model residuals. By studying locations and characteristics consistently over- or under-predicted in the regression model, a better understanding of the need for additional data or closer study can be obtained.

[7] Bureau of Transportation Statistics (BTS), Intermodal Passenger Connectivity Database (IPCD), Geospatial at the BTS, https://data-usdot.opendata.arcgis.com/datasets/intermodal-passenger-connectivity-database-ipcd/explore?location=29.863188%2C-68.937345%2C3.98

[8] BTS, National Transportation Atlas Database, Geospatial at the BTS, https://maps.dot.gov/BTS/National_Transportation_Atlas/

[9] Replica, https://www.replicahq.com/

Tennessee VRU Safety Performance

As Tennessee continues to grow in population and traffic, so do its active transportation needs and challenges. Between 2018 and 2022, the state's population increased by 3.3%, placing additional demands on the state's existing infrastructure. Accompanying this demographic shift are changes in how Tennesseans choose to get around. Active transportation modes, including walking and cycling, have not only gained popularity but have also been revolutionized by a surge in new personal mobility device technologies, such as e-scooters and e-bikes. During and after the COVID-19 pandemic, non-motorized trips increased for both recreational and commuting purposes. These trends directly impact the number of VRUs on Tennessee's roadways and their safety. This section will delve into the VRU crash data to identify trends, hotspots, and underlying risk factors, setting the stage for targeted interventions to improve road user safety significantly.

Performance Targets

As per the Safety PM Final Rule[10], a fifth performance measure was established to assess the number of non-motorized fatalities and serious injuries. This performance measure is calculated on a 5-year rolling average. Table 1 contains the safety performance assessment from 2018 to 2021. Only half of the

Table 1 - Tennessee's VRU Safety Performance Target Assessment from 2018 to 2021[11]

	2018	2019	2020	2021
Analysis Years	2014-2018	2015-2019	2016-2020	2017-2021
Safety Performance Target	493.2	546.8	527.2	521.0
Actual (5-Year Average)	495.2	508.0	522.2	545.8
Safety Performance Targets Met	No	Yes	Yes	No

Tennessee's VRU Safety Progress

The mission statement of the SHSP of the Tennessee Department of Transportation (TDOT) reads as follows: "Using education, enforcement, engineering, and emergency response initiatives to work toward zero (0) deaths and serious injuries by reducing the number and severity of crashes on Tennessee's roadways." From 2018 to 2022, a total of 2,724 crashes resulted in at least one VRU death or serious injury.

Implementation Plans

To address this alarming statistic, TDOT launched the Statewide Active Transportation Plan (SATP)[12] in July 2021, superseding the 2005 Statewide Bicycle and Pedestrian Plan. The SATP is an ambitious initiative that lays down a

[10] National Archives, Federal Register, National Performance Management Measures: Highway safety Improvement Plan, March 2016, https://www.federalregister.gov/documents/2016/03/15/2016-05202/national-performance-management-measures-highway-safety-improvement-program.

[11] FHWA, Transportation Performance Management, State Highway Safety Report – Tennessee, https://www.fhwa.dot.gov/tpm/reporting/state/safety.cfm?state=Tennessee

[12] TDOT, Tennessee Statewide Active Transportation Plan (SATP), 2021, https://www.tn.gov/content/dam/tn/tdot/multimodaltransportation/TDOT_SATP_Plan%20Document_Final_2021_07_23.pdf

collaborative, long-term vision and identifies solid goals and strategies to make that vision a reality. Figure 6 encapsulates the four cornerstone goals highlighted in the SATP.

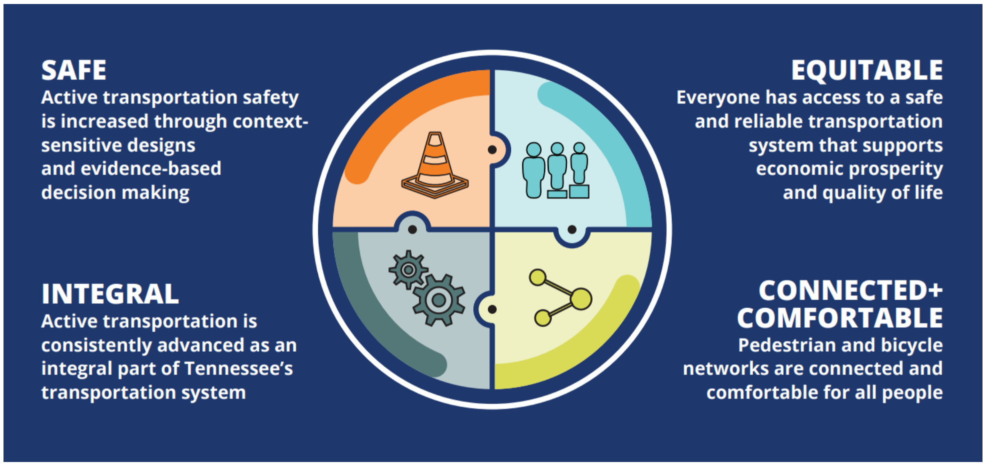


Figure 6 - Statewide Active Transportation Goals

In addition to these goals, the SATP outlined 13 strategies and 35 actions that influence the planning and programming stages of projects impacting vulnerable road users: resurfacing projects, operational and safety enhancements, and corridor reconstruction or new construction projects. TDOT and its external partners have committed to steering the future of active transportation in Tennessee, participating in all project phases, from planning and programming to maintenance. The Program of Strategies within this VRU Safety Assessment is a continuation of the SATP's goals, strategies, and actions.

The 2020-2024 SHSP contained a Vulnerable Road Users emphasis area. The SHSP developed strategies, actions, and performance measures related to the Four E's of Transportation Safety: Engineering, Enforcement, Education, and Emergency Response.

Research Projects

From 2019 to the present, TDOT has funded four research projects on pedestrian safety, including a study addressing traffic safety to reduce pedestrian injuries and fatalities performed by the University of Tennessee, Knoxville.[13] The study proposed a decision framework to identify crash hot spots and evaluate and select countermeasures. Contrary to popular belief, this study found that the rise in sport utility vehicles, the surge in e-commerce delivery vehicles, and an aging demographic are not the primary drivers of VRU crash severity in Tennessee. High speeds and multiple-lane roadways did correlate with VRU-involved crash incidence and severity. Other research undertakings include a near-miss analysis at intersections led by the University of Tennessee, Chattanooga; a study on induced demand conducted by the University of Memphis; and a bicycle and pedestrian counting assessment conducted by the University of Tennessee, Knoxville.

Pedestrian Road Safety Initiative

In 2018, TDOT started the Pedestrian Road Safety Initiative (PSRI). In 2021, TODOT identified 12 high pedestrian crash locations, designing safety upgrades for these areas and using Highway Safety Improvement Program

[13] TDOT, *Addressing Traffic Safety to Reduce Pedestrian Injuries and Fatalities in Tennessee*, 2022, https://www.tn.gov/content/dam/tn/tdot/long-range-planning/research/final-reports/res2021-final-reports/RES2021-11_Final_Report_Approved.pdf

(HSIP) funds to employ countermeasures at these locations. In 2023, the PRSI program has 32 active projects in planning, design or construction, with ten more entering the planning phase before the end of the year. Unfortunately, results from these projects will not be evident during the current target-setting cycle. Still, it is expected that these projects will decrease non-motorist fatalities and serious injuries in the future.

Multimodal Prioritization Tool

TDOT's Multimodal Division worked with TDOT's Data Visualization office to create an FHWA-approved methodology to prioritize all collectors and arterials in Tennessee. The Multimodal Prioritization Tool is currently being updated to version 2 to become more data-driven and incorporate the findings of this VRU Safety Assessment.

Multimodal Access Grants

TDOT has awarded 151 Multimodal Access Grants (MMAG) representing over $127.8 million in state funds from 2014 to 2022.[14] Most of these grants cover sidewalk and pedestrian improvements. The MMAG projects are state funded at 90 or 95 percent, depending on the economic status of the project county, up to a total project value of $1,250,000.[15] Since 2014, the financial support for the MMAG projects has increased yearly, as well as the number of awardees.

Table 2 - Summary of Multimodal Access Grants from 2014 to 2022

Year(s)	Grants Awarded	Total Value
2014	13	$9,938,979
2015	14	$10,247,809
2016	14	$10,264,935
2019	16	$13,530,972
2020	18	$14,361,442
2020-2021	23	$20,734,404
2021	26	$22,125,960
2022	27	$26,610,870
Total	151	$127,815,371

Other Active Transportation Projects

Countless projects to increase roadway capacity have been identified within Tennessee. While these projects are necessary to alleviate congestion or other transportation problems, they tend to decrease pedestrian safety. To assist with this, TDOT is taking steps to improve bicyclist and pedestrian facilities through enhancements to identifying the existing inventory and continuing to implement multimodal policies.

To better identify the existing VRU infrastructure, the following has been completed:

- Updated state bike route network in 2021.
- Identified all marked crosswalks within a radius of schools to determine needed enhancements in 2022. Identified enhancements include signs, Rectangular Rapid Flashing Beacons (RRFB), and Pedestrian Hybrid Beacons (PHB). Funding is still unidentified for these improvements.
- Identified all raised concrete medians six feet or wider to examine possible pedestrian refuge islands in 2022.

The following sub-sections discuss other project programs underway at TDOT to improve VRU safety.

[14] TDOT, Multimodal Access Grant Award Summary, https://www.tn.gov/content/dam/tn/tdot/multimodaltransportation/multimodal-access-grant/2022%20MMAG_Award%20Summary_for%20website.pdf.
[15] TDOT, Multimodal Access Grant, https://www.tn.gov/tdot/multimodal-transportation-resources/bicycle-and-pedestrian-program/multimodal-access-grant.html.

Curb Ramp Program

The Curb Ramp Program (CRP), supported by the TDOT's Roadway Design Guidelines (Section 1-200.12), is vital in enhancing VRU safety. This program's primary objective is to ensure that pedestrian and bicyclist accommodations are integrated into resurfacing projects effectively. One key aspect is installing or retrofitting curb ramps in areas where they are absent or do not meet ADA/PROWAG standards. By doing so, TDOT aims to create accessible pathways for individuals of all abilities, prioritizing safety and inclusivity.

In 2023, TDOT broke apart the curb ramp inventory, design, and construction from resurfacing projects. This separation ensured that all curb ramps were of the highest quality, not just the easiest fixes. The second round of the CRP is already underway for 2024. The Multimodal Planning Office will explore how to better incorporate local government and MPO input and funding during the second round.

Quick Build Projects

TDOT advised and coordinated for this Center for Disease Control and Prevention (CDC)-funded program to pilot 3 Quick Build pedestrian infrastructure projects in Memphis, Nashville, and Chattanooga. The Nashville Department of Transportation and others are working on designing a guide to continue this initiative.

The Memphis location is on an active Pedestrian Road Safety Initiative (PRSI) project, where the crosswalk was modified with temporary items before a PHB is installed with the PRSI. The Nashville is within TDOT's Dickerson Pike complete streets project. Quick Build projects are proven to be great temporary solutions in high-risk areas, while a permanent solution is in design or under construction.

Project Review

Each year, the Office of Multimodal Planning completes over 500 project reviews; many reviews may be for the same project through several phases. These reviews help to ensure active transportation facilities are kept in the plans and follow TDOT standards, policy, and guidelines. In the earlier project phases, the Office will make a case to increase safety and connectivity by integrating facilities into the design. Depending on the scope and how early involved, the chance of getting the facility in the plans fluctuates. A success story, for example, is a State Industrial Access project that reconstructed an entire large intersection that originally included one crosswalk. Several more crosswalks, sidewalks, and 2 RRFBs were added through project reviews.

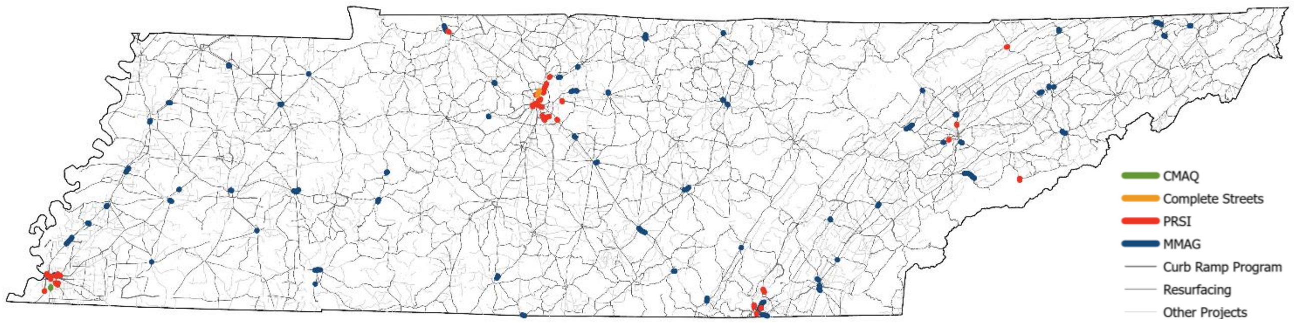


Figure 7 - Map of all Current TDOT Projects with VRU Components

Reported VRU Crash Analysis

From 2018 to 2022, 8,948 VRU crashes were reported on Tennessee public roadways. This amount includes fatalities, serious injury crashes, and crashes that did not result in serious injury. However, it does not include the unknown number of VRU crashes that occurred but were not reported to local officials, nor does it include near-miss situations.

Pedestrian crashes increased 12% between 2018 and 2022, an average annual increase of approximately 2.4%. Although the total number of pedestrian crashes fell significantly in 2020 and then began rising again, fatal and serious injury crashes have increased every single year. Fatal and serious injury pedestrian crashes increased by over 44% during this same timeframe.

Cyclist crash rates fluctuate from year to year. From 2018 to 2022, total cyclist-related crashes increased by approximately 4.5%, with an 18% increase in fatal and serious injury crashes. However, 2021 represented the lowest totals for both categories from the 5-year period.

Figure 8 - Total Cyclist and Pedestrian Crashes from 2018 to 2022

When examining the landscape of VRU crashes, the distribution of crashes on non-interstate state routes versus local roadways provides enlightening insights into areas of focus for road safety improvements. The majority of VRU crashes, accounting for 55% of total incidents, occur on local roadways. However, given that Tennessee has approximately 13,000 miles of state roadways (including Interstates) and 82,000 miles of local roadways, the per-mile incidence of VRU crashes is significantly higher on state roadways. Of the crashes on local roadways, 54% occur on segments of roadway between intersections, while the remaining 46% occur at intersections. Figure 9 contains the crash tree for VRU crashes on state routes and local roadways.

Switching attention to state routes, the data uncovers a different dynamic. Here, VRU crashes are split almost evenly between intersections and roadway segments. Of the severe or fatal crashes, 64% occurred on roadway segments between intersections, while 36% occurred at intersections.

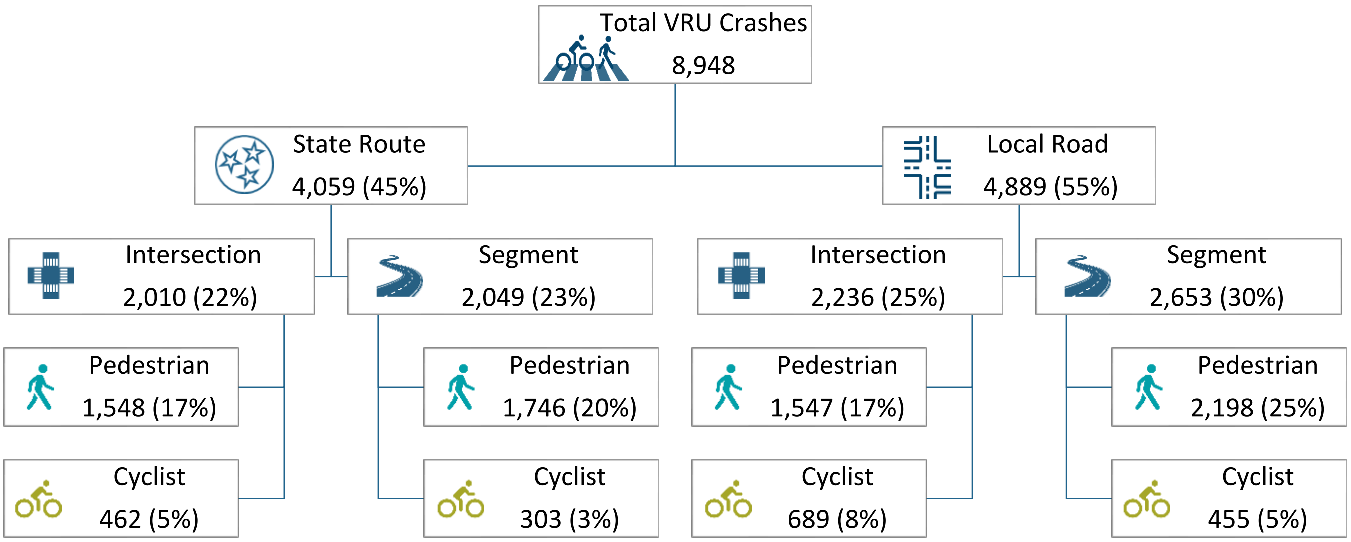


Figure 9 - Crash Tree of VRU Crashes on State Routes and Local Roads (2018-2022)

Crashes by Severity

Crash severity is correlated with the level of risk and harm faced by VRUs. Table 3 presents a breakdown of the severity of pedestrian and cyclist crashes over the study period. A noteworthy finding is that over 30% of VRU-involved crashes result in serious injuries or fatalities. Conversely, around half of such incidents result in minor or potential injuries, while less than 10% are confined to property damage alone. It's essential to consider that the reported severity levels may not fully represent the actual risk landscape due to potential reporting limitations in VRU crash data.

Table 3 - VRU Crash Severity (2018-2022)

Type of Crash	Cyclist	Pedestrian	Total VRU	% of Total
Fatal	47	886	933	10.4%
Serious Injury	271	1,520	1,791	20.0%
Minor Injury	907	2,875	3,782	42.3%
Possible Injury	347	1,269	1,616	18.1%
Property Damage	337	489	826	9.2%
Total	1,909	7,039	8,948	

Figure 10 illustrates the severity of crashes for pedestrians, cyclists, and motorists. The "Severity Ratio" is a metric used to quantify the ratio of severe crashes (fatal and serious injury crashes) to the total number of crashes for each category of road user: people walking, people biking, and people in vehicles. The severity ratio is an important indicator of road safety performance, offering insight into the effectiveness of existing safety measures and identifying areas where additional interventions may be required to enhance road user safety. The severity ratio for pedestrians is the highest of the three users at 34%. Cyclists and motorists have a 16% and 2.5% severity ratio, respectively. High severity ratios indicate locations or conditions that warrant urgent attention since they suggest that crashes are more likely to result in severe outcomes.

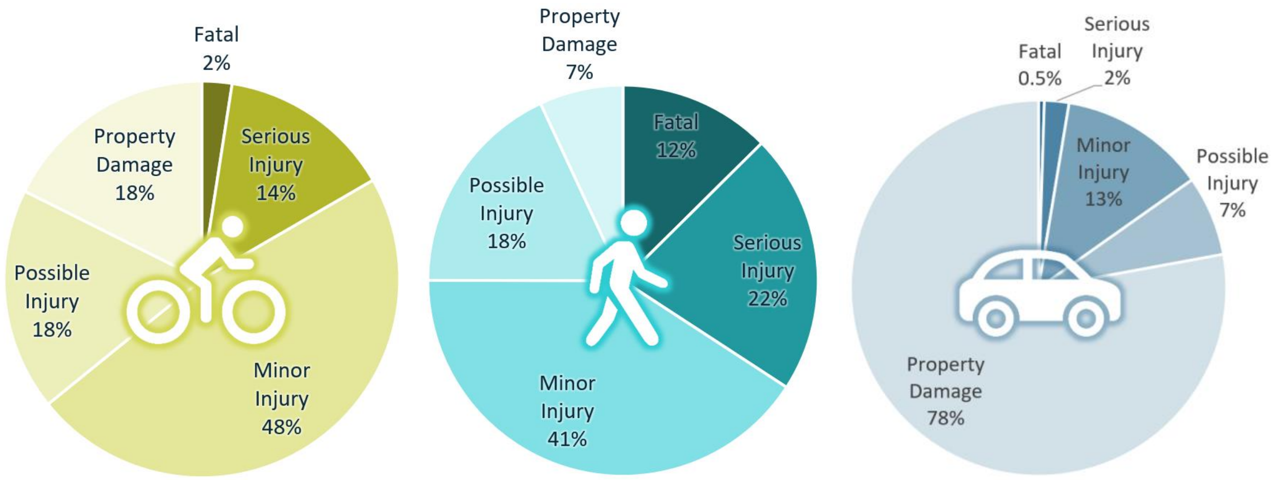


Figure 10 - Cyclist, Pedestrian, and Motorist Crashes by Severity (2018-2022)

Crashes by Motorists' Pre-Crash Actions and Contributing Factors

Analyzing motorists' pre-crash actions provides valuable insights into the behavior patterns often preceding crashes involving pedestrians and cyclists. In descending order, the most frequently occurring pre-crash actions are going straight, turning left, and turning right. This information is instrumental in understanding the conditions under which VRU crashes are most likely. For instance, the predominance of incidents happening while going straight could point to issues like insufficient signage, poor lighting, or crosswalk design flaws that need to be addressed to improve VRU safety. Similarly, the frequency of left and right turns in crash data might warrant additional countermeasures such as improved signal timing or the introduction of exclusive turn lanes. Figure 11 shows a VRU crash breakdown by motorists' pre-crash actions.

The motorist's contributing factors in VRU crashes present a somewhat nebulous picture, as around 75% of the recorded incidents list the contributing factors as 'other and unknown' or state that there were 'no contributing actions.' This high percentage suggests a possible gap in the data collection or reporting mechanisms, which could be obscuring actionable insights into driver behavior. Nonetheless, among the remaining 25% where contributing factors are identified, the most common are failing to yield or obey traffic controls, unsafe driving, and distraction. This indicates that compliance with traffic rules and attention to the road are areas needing particular focus for safety improvement measures. As these contributing factors may directly lead to crashes involving VRUs, targeted interventions addressing these issues may prove highly effective in reducing VRU crashes. Figure 12 contains the driver's contributing factors for VRU crashes.

Between 2018 and 2022, 2,192 (24%) VRU-involved crashes were reported as hit-and-runs, and 4,855 (54%) were not recorded as hit-and-runs. The remaining 1,901 (21%) are missing that data attribute. Severity ratios across each category remain consistent.

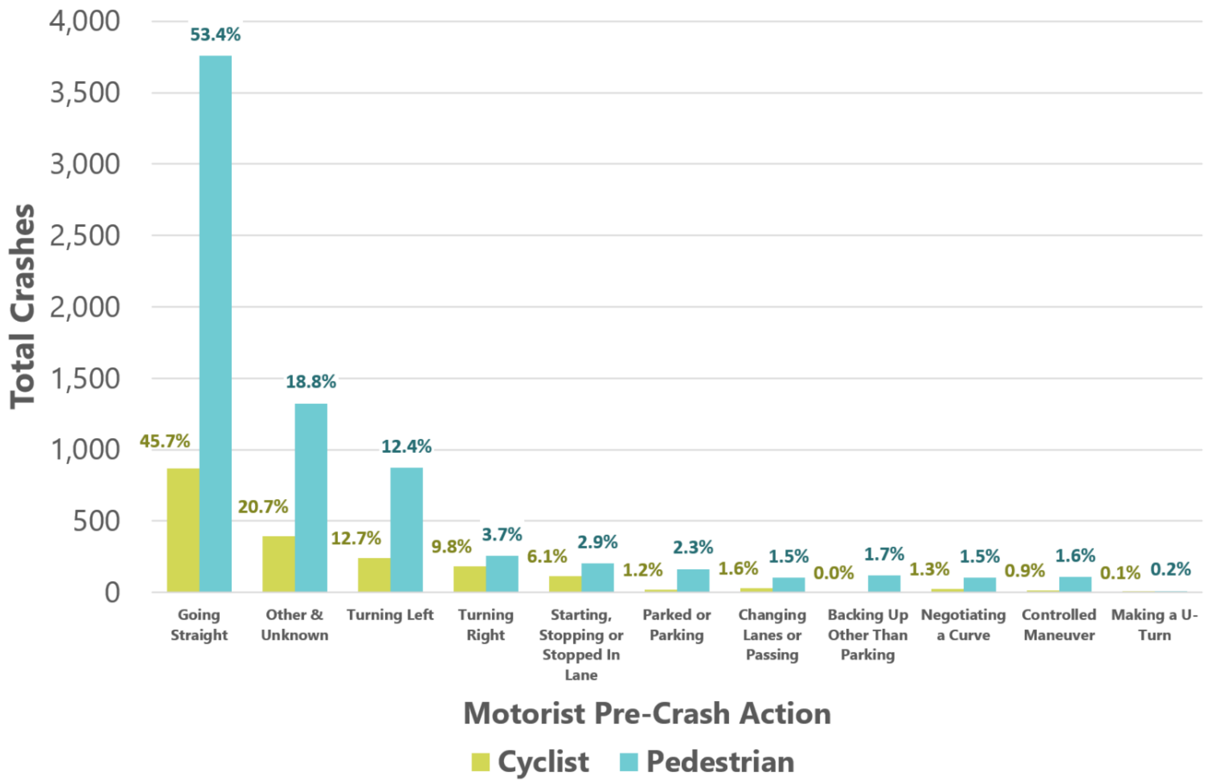


Figure 11 - Total Cyclist and Pedestrian Crashes by Motorists' Pre-Crash Action (2018-2022)

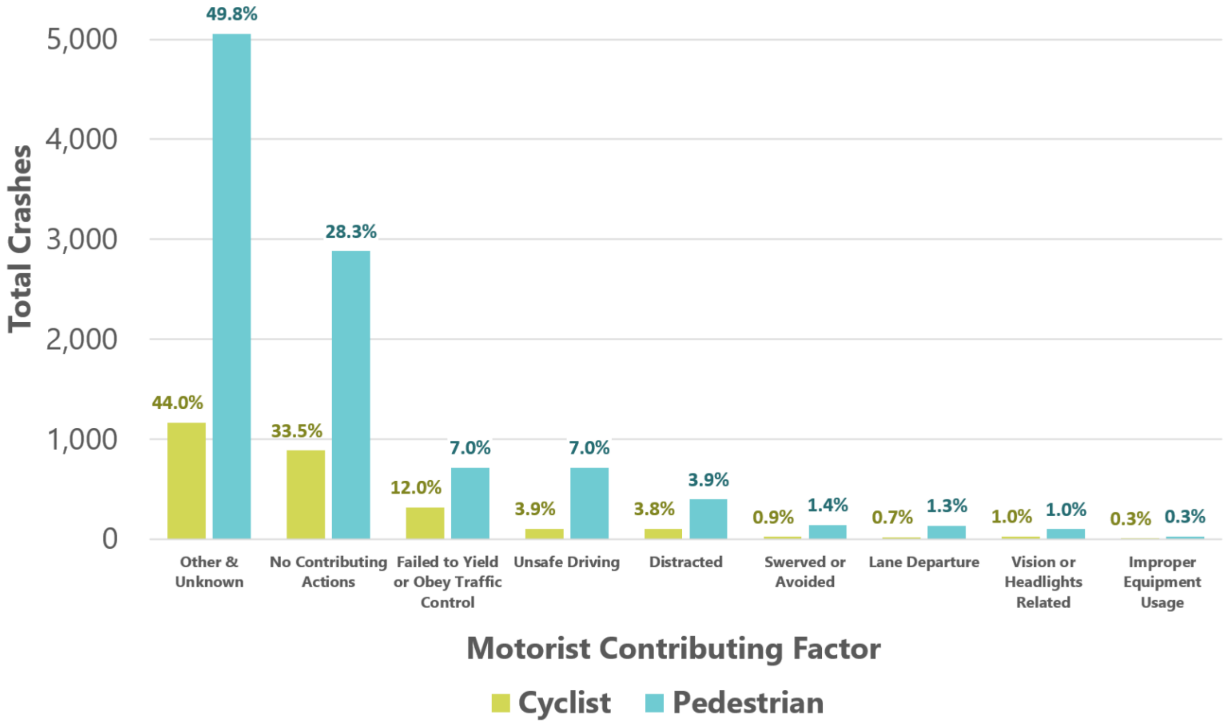


Figure 12 - Total Cyclist and Pedestrian Crashes by Motorists' Contributing Factor (2018-2022)

Crashes by Lighting Condition

Lighting conditions appear to play a minor role in pedestrian crashes statewide. In Table 4, pedestrian crashes occur almost equally in both dark and light conditions, suggesting that lighting alone is not a predominant factor in the overall occurrence of these incidents. However, a closer examination reveals an important distinction based on the type of roadway. During light conditions, pedestrian crashes are roughly evenly distributed between intersections and segments, showing no apparent pattern. In contrast, 39% of crashes occur at intersections during dark conditions, while a more substantial 61% happen at roadway segments between intersections. This disparity implies that while lighting conditions may not dramatically influence the overall rate of crashes, they may affect where these crashes are more likely to occur. Therefore, enhancing pedestrian-scale lighting at roadway segments between intersections could be a targeted approach to improve pedestrian safety during dark conditions.

Table 4 - Pedestrian Crash Lighting Conditions by Roadway Characteristic (2018-2022)

Location Type	Dark	Light	Unknown
Intersection	1,383	1,661	54
Segment	2,156	1,732	53
Total	3,539	3,393	107

The impact of lighting conditions on cyclist crashes reveals a distinct pattern that diverges from pedestrian crashes. Table 5 contains the breakdown of cyclist crashes by lighting conditions and roadway characteristics. Notably, only 22% of cyclist crashes occur in dark conditions. This could be due to fewer cyclists on the road in dark conditions, or it could suggest that visibility plays a less significant role in these types of incidents than pedestrian crashes. In lighted conditions, however, 61% of crashes happen at intersections. This suggests that for cyclists, intersections become particularly challenging zones during well-lit conditions, possibly due to complexities related to traffic flow, signage, or cyclist behavior. This pattern underscores the need for targeted interventions at intersections to improve safety for cyclists.

Table 5 - Cyclist Crash Lighting Conditions by Roadway Characteristics (2018-2022)

Location Type	Dark	Light	Unknown
Intersection	224	882	46
Segment	182	556	19
Total	406	1,438	65

Spatial Crash Trends

Understanding the spatial characteristics of VRU–involved crashes is pivotal for creating targeted, effective safety interventions. Examining crashes through various lenses—rural versus urban settings, the types of traffic control measures at intersections, roadway functional classification, the number of lanes, or adjacent land use—enables us to pinpoint specific areas or conditions under which VRUs are at elevated risk. This nuanced understanding of location-based factors offers valuable insights for policymakers and planners, allowing them to allocate resources and implement safety measures where they are most needed. By focusing on the role of location in VRU crashes, one can develop more strategic, data-driven approaches to improve road safety for all users. Figure 13 shows the urban areas that crash density is highest statewide.

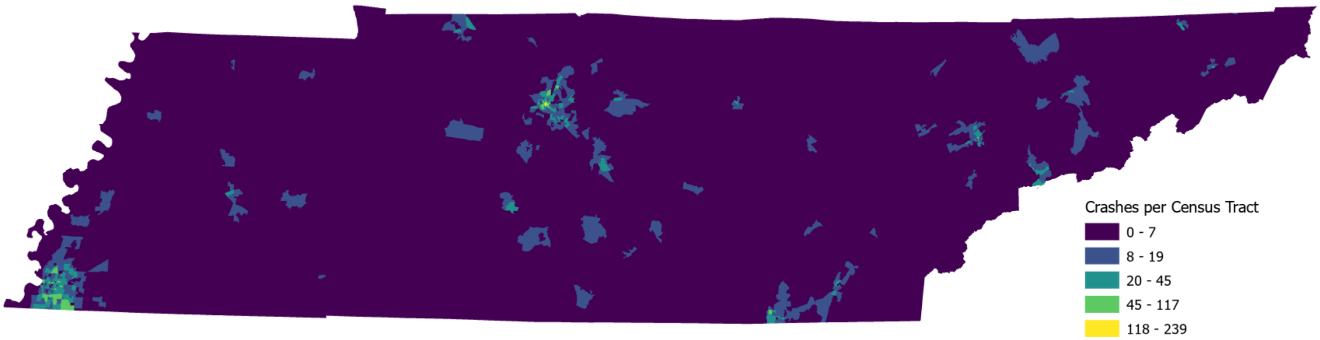


Figure 13 - Statewide VRU Crashes per Census Tract (2018-2022)

Crashes by Roadway Site

The distribution of VRU crashes in Tennessee reveals a stark contrast between urban and rural settings, pointing to a greater urgency for interventions in urban areas. Figure 14 shows a significant 91% of all VRU crashes and 87% of all severe crashes occur in urban locations. Within these urban settings, crashes are evenly distributed between intersections and roadway segments; however, of the urban crashes with severe outcomes, 53% of total VRU crashes happen on urban segments and 34% at urban intersections. This indicates a heightened risk associated with urban roadway segments.

In rural areas, the distribution is notably different; only 2% of total VRU crashes occur at rural intersections and 7% at rural segments between intersections. Moreover, severity is higher on rural segments, accounting for 85% of severe crashes in rural areas. These insights provide valuable guidance on where to prioritize safety interventions and allocate resources effectively.

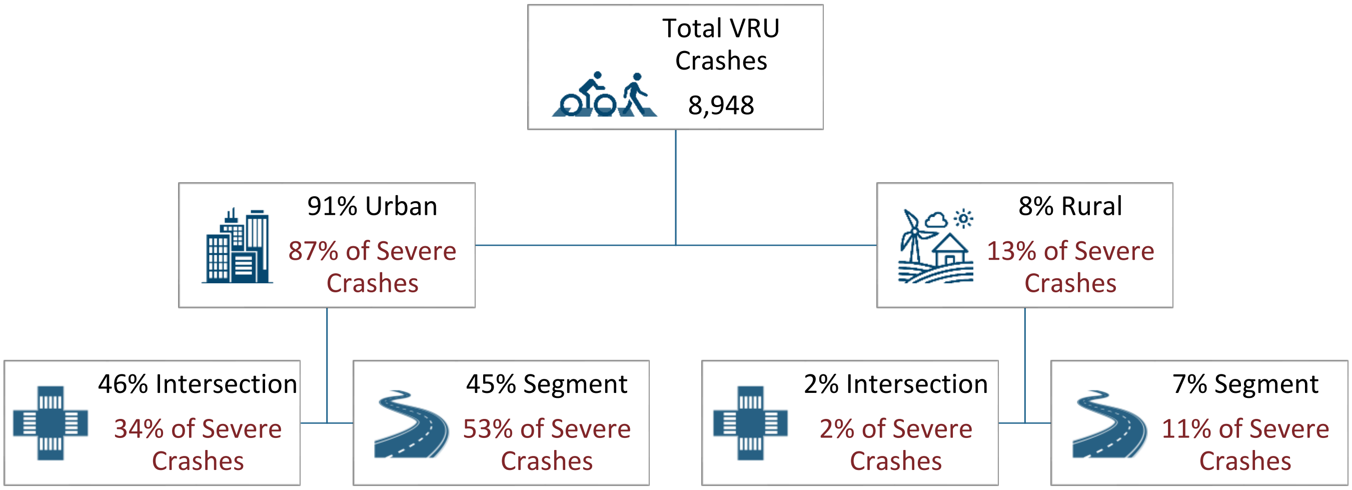


Figure 14 - Total VRU Crash Tree (2018-2022)

As shown in Figure 15, more than 90% of pedestrian and cyclist crashes occur in urban areas, revealing a critical need for focused interventions in urban areas. One key difference emerges when these urban crashes are examined more granularly: a slight majority of pedestrian crashes occurred at urban roadway segments, whereas 58% of total cyclist crashes occurred at urban intersections.

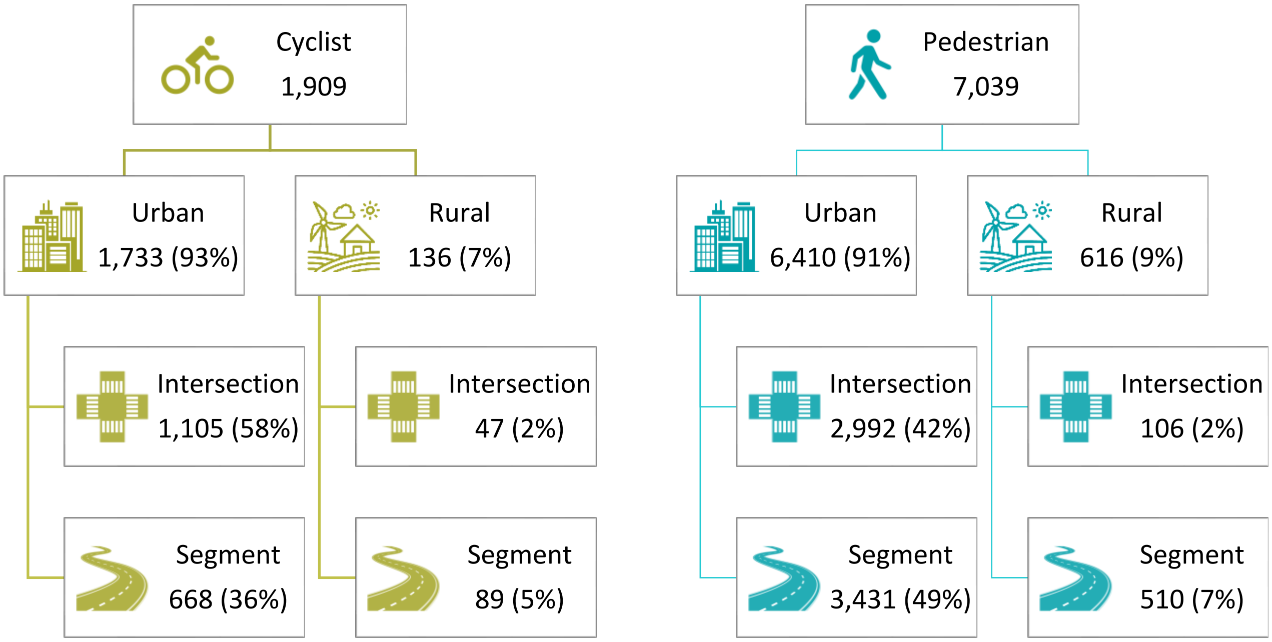


Figure 15 - Cyclist and Pedestrian Crash Trees (2018-2022)

Rural settings tell a slightly different story: a significant 83% of rural pedestrian crashes occur on rural segments, whereas a slightly smaller proportion—65% of all rural cyclist crashes—also occur on rural segments. This nuanced understanding aids in targeting effective safety measures specific to the needs of pedestrians and cyclists in diverse environments. Specifically, pedestrians see more danger at urban segments, closely followed by urban intersections, and cyclists see the most risk at urban intersections.

Crashes by Intersection Traffic Control

The statewide analysis of pedestrian and cyclist crashes reveals notable disparities in the average number of crashes occurring at different traffic control mechanisms. Figure 16 analyzes the average number of cyclist and pedestrian crashes by type of traffic control at intersections. Intersections equipped with traffic signals have the highest average number of crashes, with an average that is four to five times higher than at roundabouts, the next highest category. This does not indicate that traffic signals or roundabouts are inherently dangerous to VRUs because on-average traffic signals exist at significantly higher volume intersections. The same is true of roundabouts, to some degree.

Following roundabouts, the average number of crashes decreases further at intersections with four-way stops, and even fewer occur at locations with partial stops and yield signs. This data hierarchy indicates that while traffic signals are designed to regulate both vehicular and pedestrian traffic systematically, they may also be hotspots for conflicts between vulnerable road users and vehicles. This is not surprising since traffic signals are located to address a volume of vehicular traffic in conflict. In contrast, roundabouts, four-way stops, partial stops, and yield signs—which require varying degrees of attentiveness and caution from drivers—exhibit progressively fewer average crashes. Understanding these nuances helps create targeted interventions to enhance safety for pedestrians and cyclists across different traffic control settings.

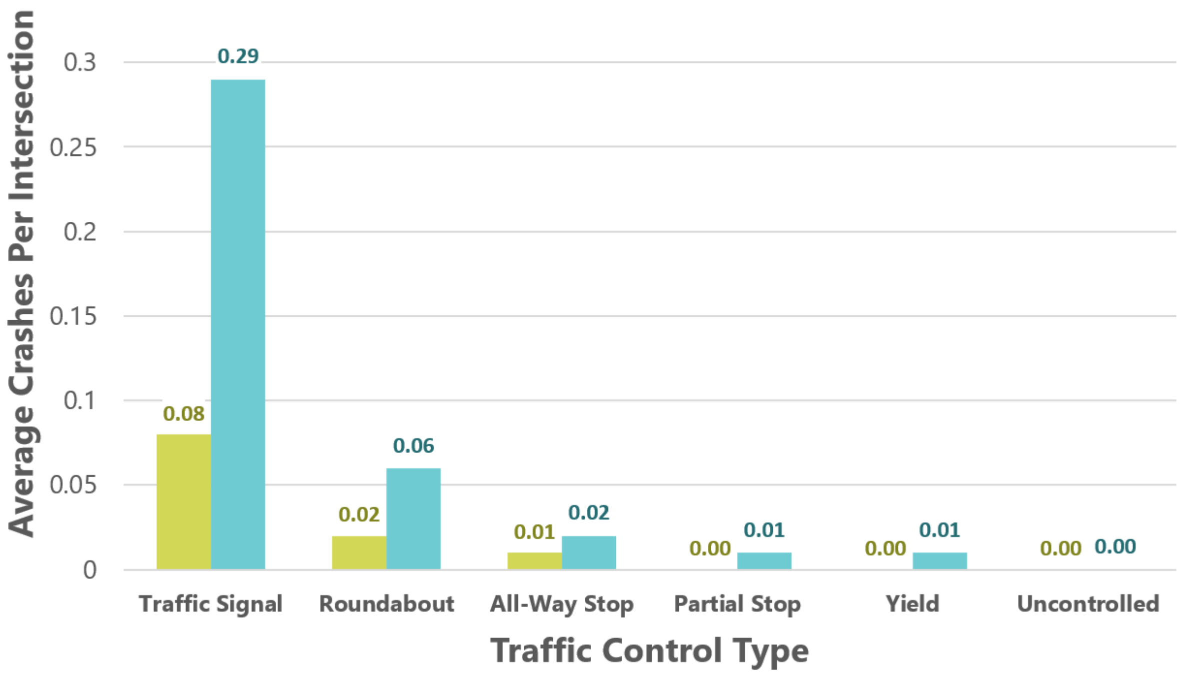


Figure 16 - Average Crashes per Intersection by Traffic Control Type (2018-2022)

Crashes by Functional Classification

A comprehensive analysis of VRU crashes and severity, based on roadway functional classifications, demonstrates stark differences between urban and rural settings. Roads are classified as follows:

- Local - Provides direct access to abutting land and are not intended for long-distance travel, often designed to discourage through traffic.
- Collector - Gathers traffic from local roads and connects to the arterial network.
- Minor Arterial - Provides moderate-length trips and offers connectivity to the higher arterial system, providing intracommunity continuity.
- Principal Arterial - Provides high mobility through urban and rural areas, and abutting land uses can be served directly.
- Freeway - Directional travel lanes that are usually separated by a physical barrier, and access and egress points are limited to on- and off-ramp locations or a minimal number of at-grade intersections.
- Interstate - The highest classification of arterials, designed and constructed with mobility and long-distance travel in mind. Directional lanes, separated by a barrier and ramp-only access.[16]

Figure 17 shows the distribution of rural and urban crashes by roadway functional classification. Within urban areas, the sequence from highest to lowest crash occurrence after principal arterial is as follows: minor arterial, interstates/freeways, collector roads, and local roads. Interstates/freeways experience the highest severity ratio for urban VRU crashes.

[16] Highway Functional Classification Concepts, Criteria and Procedures, Federal Highway Administration, Washington, D.C., 2013, https://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/section00.cfm.

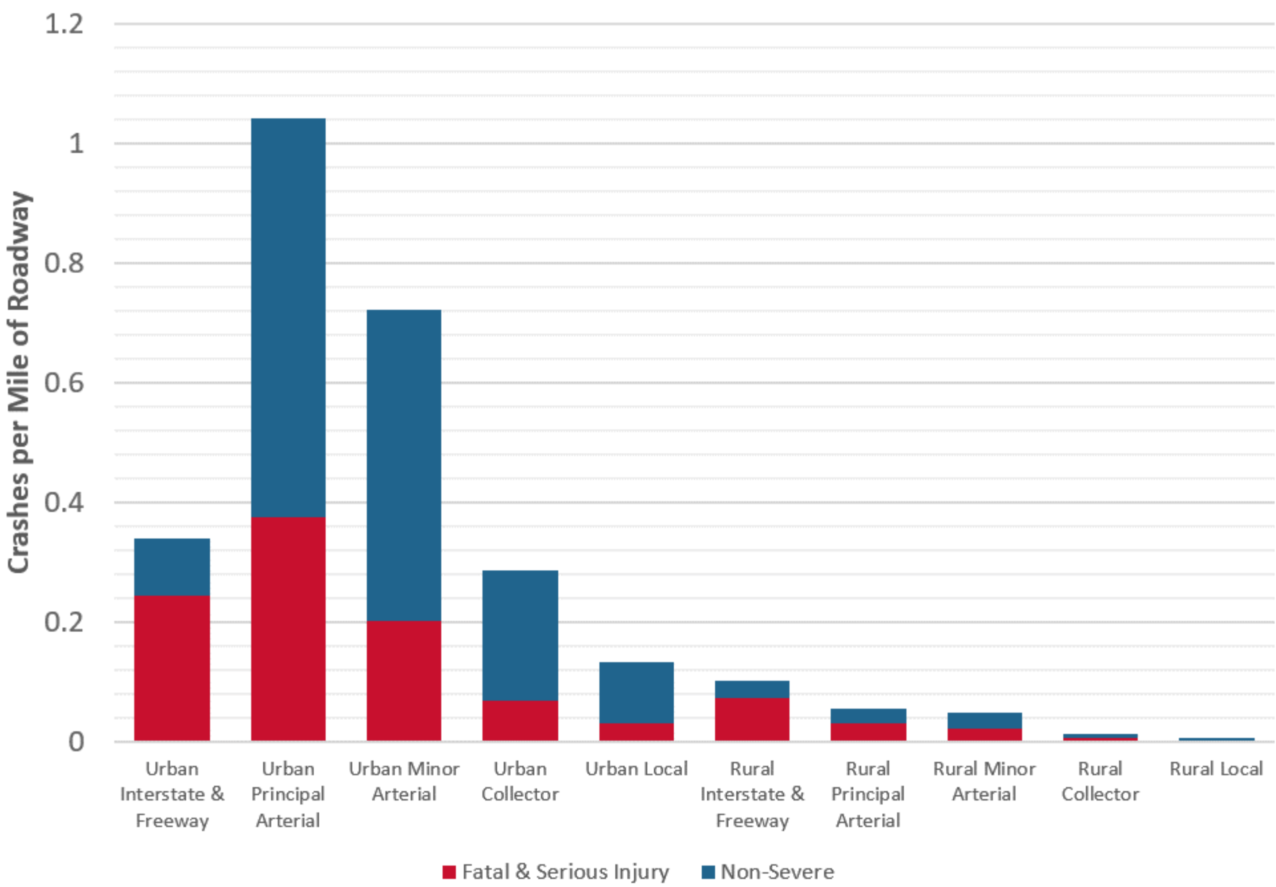


Figure 17 - VRU Crashes per Mile by Roadway Functional Classification and Severity (2018-2022)

In contrast, all categories of rural roadways register fewer crashes than even the least prevalent urban category. Regarding crash severity, urban principal arterials have the highest percentage of fatal and serious injuries, closely followed by urban local roads and other urban classifications. Despite lower overall crash numbers, rural roadways exhibit notably high severity ratios. This implies that although rural roads are less prone to VRU crashes, they tend to result in more severe outcomes when such incidents occur.

Crashes by Number of Lanes

Table 6 presents VRU crashes in relation to the number of lanes on road segments. Over half of all VRU-involved crashes, precisely 50.5%, occur on two-lane roads. Four-lane roads account for 34.1% of VRU-involved crashes, followed by six-lane roads at 10.1%. However, it's crucial to contextualize these statistics: these percentages are significantly influenced by the total mileage of each road type across the state. Therefore, while the raw numbers indicate a higher incidence of VRU-involved crashes on two-lane

Table 6 - Total VRU Crashes on Segments by Number of Lanes in Both Directions (2018-2022)

Number of Lanes	Total VRU Crashes	% of Total
1	40	0.9%
2	2,372	50.5%
3	32	0.7%
4	1,602	34.1%
5	76	1.6%
6	475	10.1%
7	10	0.2%
8	84	1.8%
9	4	0.1%
10	3	0.1%
Total	4,698	

roads, it is essential to consider these crashes as a proportion of total segment miles for a more nuanced understanding of VRU safety across different road types.

An increased lane count due to higher traffic demand increases the exposure for motor vehicles, pedestrians, and cyclists present in the facility. Figure 18 shows the relationship between the number of lanes on a roadway segment and the average number of observed pedestrian and cyclist crashes per mile.

Figure 18 exhibits two overlapping distribution curves for pedestrian crashes, with peaks at both 6 lanes and 10 lanes. The data on the right side of the chart (6+ lanes) is primarily Interstate segments. Many pedestrians involved in these crashes are drivers who have exited a damaged or disabled vehicle. Only 318 (3.6%) of VRU crashes occurred on Interstates and freeways, but 72% of these crashes resulted in a fatality or serious injury.

Table 7 - Total VRU Crashes at Intersections by Maximum Number of Lanes at Approach (2018-2022)

Maximum Lanes at Approach	Total VRU Crashes	% of Total
1	2	0.0%
2	1,268	29.8%
3	96	2.3%
4	1,796	42.3%
5	143	3.4%
6	610	14.4%
7	12	0.3%
8	8	0.2%
Unknown	315	7.4%
Total	4,250	

The distribution of total VRU crashes at intersections presents a similar pattern when compared to segment crashes. Table 7 contains the total VRU crashes occurring at an intersection based on the maximum number of approach lanes. Most prominently, intersections with four lanes record the highest occurrence of VRU crashes, accounting for 42.3% of the total. This is a significant proportion, especially when compared against the 29.8% observed at intersections with two lanes. When averaged statewide, the general trend is that intersections with larger approaches average more crashes, as seen in Figure 19.

Image 1 - Aerial View of Downtown Nashville Intersection with Varying Intersection Approaches

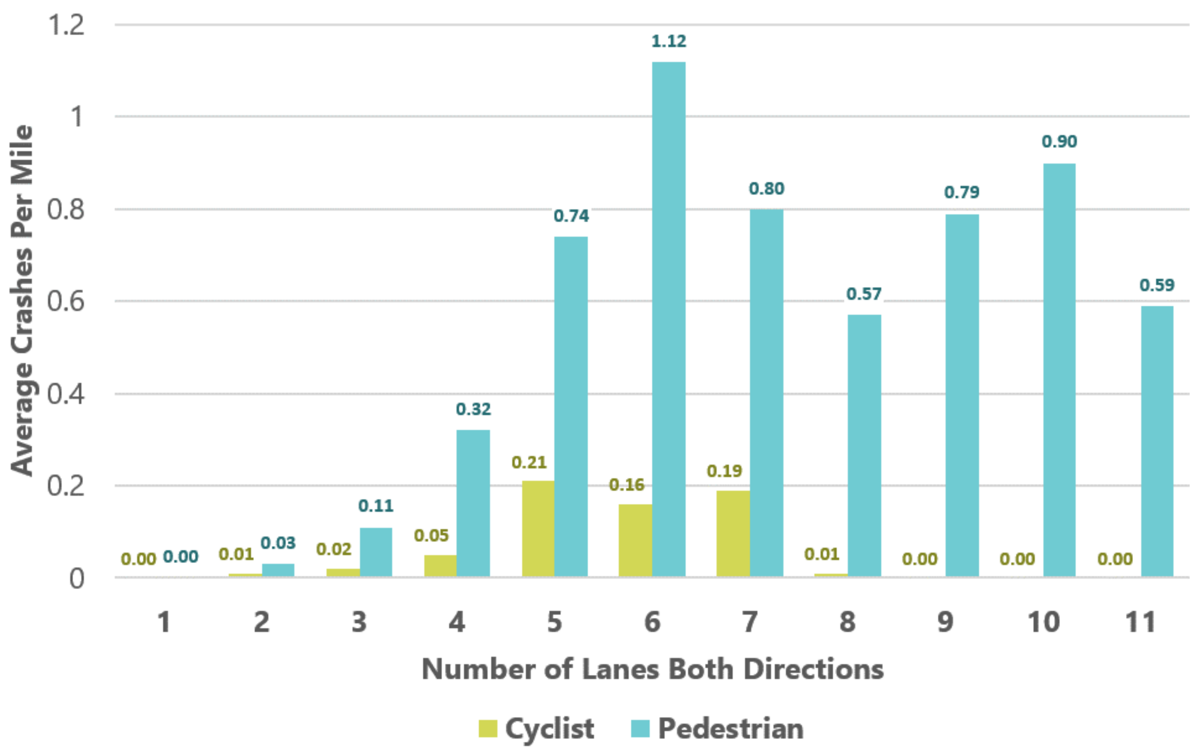


Figure 18 - Average VRU Crashes per Segment Mile by Number of Lanes in Both Directions (2018-2022)

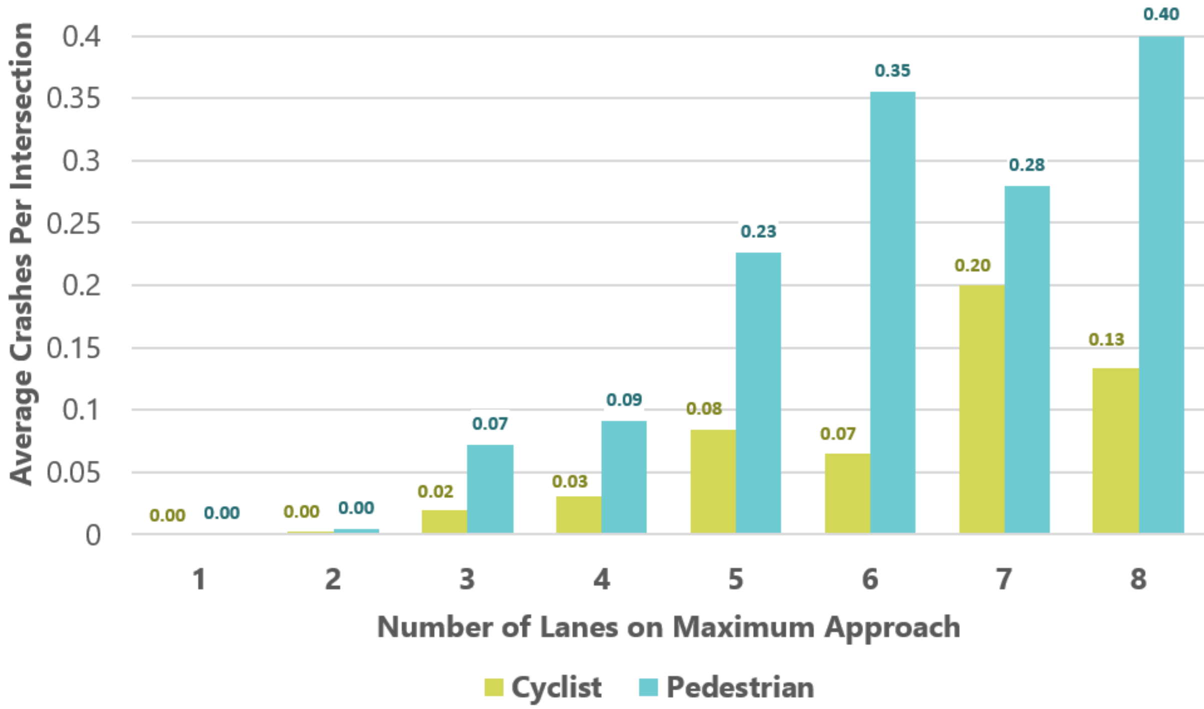


Figure 19 - Average VRU Crashes per Intersection by Number of Lanes on Widest Approach

Crashes by Adjacent Land Use

Land use adjacent to the crash location is an attribute recorded in the TRIMS crash data. This data is tied to the roadway inventory classification. Within the inventory, the “rural” classification of land use makes up over 70% of the roadway miles in Tennessee but only 20% of VRU crashes. Residential land use accounts for 23% of roadway miles and 20% of VRU crashes. Crashes occur disproportionally in commercial areas, with 39% of VRU crashes in commercial areas representing only 2.6% of roadway miles statewide. Pedestrian crashes are also 4-5 times greater than cyclists in commercial areas, likely due to an increased number of pedestrians.

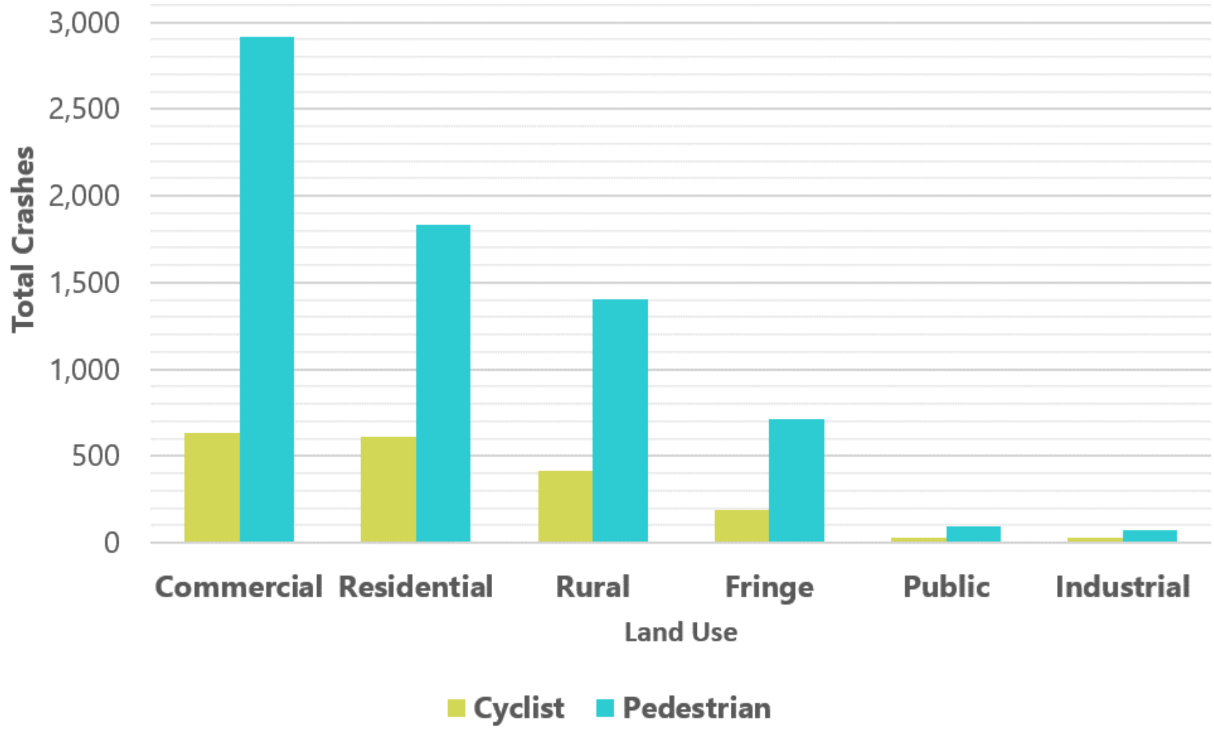


Figure 20 - Total VRU Crashes by Adjacent Land Use (2018-2022)

Temporal Crash Trends

Understanding temporal VRU crash trends is important for a holistic analysis of traffic safety. Examining crash fluctuations based on the time of day, week, month, and year offers insights into periods of heightened vulnerability for road users. These temporal patterns can highlight recurring conditions or factors that contribute to crashes, from the routine behavior of commuters to seasonal variations or yearly developments in infrastructure and traffic regulation. By dissecting the temporal dimensions of VRU crashes, one can better design targeted interventions, allocate resources effectively, and develop strategies that are attuned to the cyclical rhythms of the transport systems. This section evaluates these patterns, shedding light on when the roads are most treacherous for VRUs.

Crashes by Time of Day

Roadway crashes tend to increase later in the afternoon into the evening hours, corresponding to the time of days when there are generally more vehicles on the roadways. Figure 21 presents cyclist crashes by time of day. A key observation is the low frequency of crashes between midnight and 5 AM. Beginning around 5 AM, there is a gentle increase in crashes, with a morning peak during the AM vehicle peak hour period, similar to the pedestrian crashes. There is a pronounced surge in both severe and non-severe crashes between 3 PM and 6 PM. All cyclist crashes spike during the typical vehicle peak periods, indicating a substantial risk for cyclists during peak times.

The pattern of cyclist crashes aligns closely with that of pedestrian crashes, with the riskiest times being the morning and, more prominently, the evening rush hours. However, the peak in severe cyclist crashes during the evening rush is even more pronounced than in pedestrian crashes. This can imply that cyclists may face amplified risks during these hours, making the case for enhanced safety and awareness campaigns specifically targeting this vulnerable group during peak traffic periods.

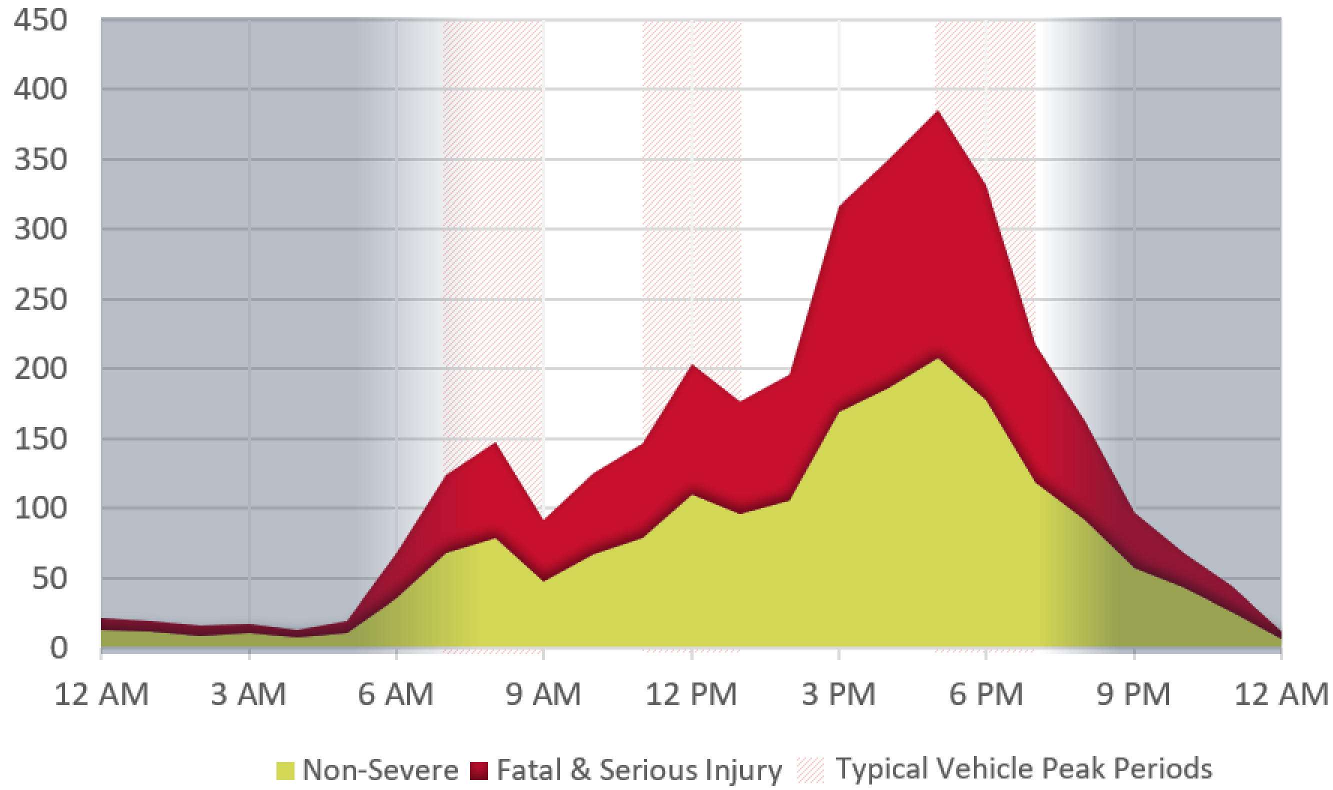


Figure 21 - Cyclist Crashes by Time of Day and Severity (2018-2022)

Figure 22 illustrates the distribution of pedestrian crashes by time of day, differentiating between non-severe crashes and crashes where pedestrians were killed or seriously injured (KSI). A noticeable trend is the low number of crashes during the early hours, between 12 AM and 6 AM. Starting from 6 AM, there is a gradual increase in hourly pedestrian crashes, reaching a morning peak at around 8 AM. This spike corresponds with typical morning rush hours. As the day progresses, the total number of crashes remains relatively stable until 3 PM, after which a pronounced surge in both severe and non-severe crashes is evident, peaking at around 6 PM. This PM vehicle peak period suggests that the evening rush hours pose a particularly high risk for pedestrians. The frequency then decreases gradually post 6 PM, reducing significantly by midnight. It is evident that the riskiest times for pedestrians align with heavy vehicular traffic periods, especially during the late afternoon and early evening.

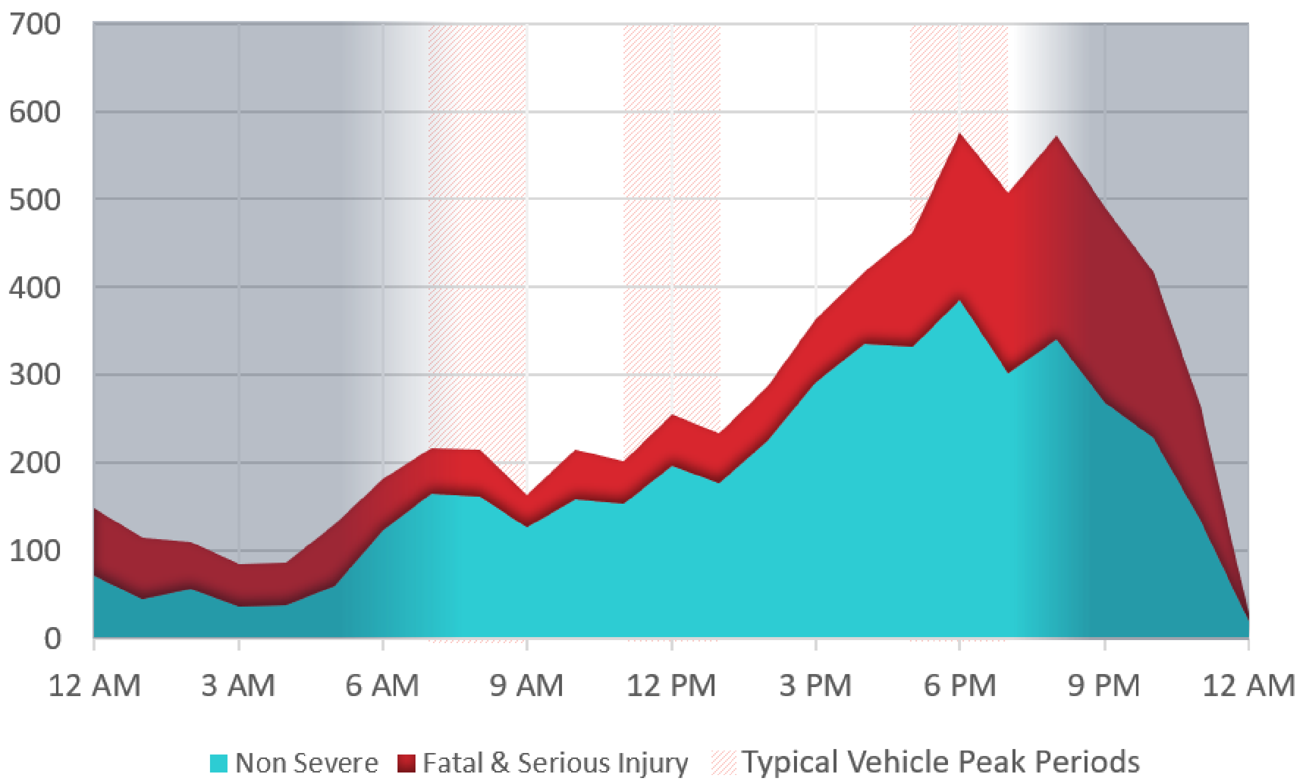


Figure 22 - Pedestrian Crashes by Time of Day and Severity (2018-2022)

Crashes by Day of Week

Figure 23 compares total crashes involving cyclists and pedestrians against the day of the week, further differentiating between all incidents and those resulting in fatal or serious injuries. For pedestrian crashes, the highest number of crashes occur on Friday, while Sunday sees the lowest. For cyclists, the crashes trend upward until Wednesday and then trends back down. When examining fatal and serious injuries, the trend line for cyclist-related incidents remains relatively steady across the week. In contrast, pedestrian fatal and serious injuries rise notably from Sunday to Friday, with the curve peaking on Saturday.

Crashes by Month of Year

Figure 24 presents the total number of cyclist and pedestrian crashes by month, differentiating between all incidents and those resulting in fatal or serious injuries. A seasonal pattern emerges for both cyclists and pedestrians. Cyclist crashes see a pronounced rise starting in March and peaking between May and October. This surge in the warmer months could be attributed to favorable weather conditions and the increased inclination towards outdoor activities. Pedestrian crashes see a pronounced rise starting in August and trend upwards until October before trending down. The severe pedestrian crashes also follow the same seasonal trend but start trending upwards beginning in June. The overall severity ratios are relatively constant year-round for both pedestrian and cyclist crashes.

Total VRU crashes are highest during the late summer and early fall months of August, September, and October. Typically characterized by students returning to school, this period suggests that the cooling weather and return of school traffic could contribute to the spike.

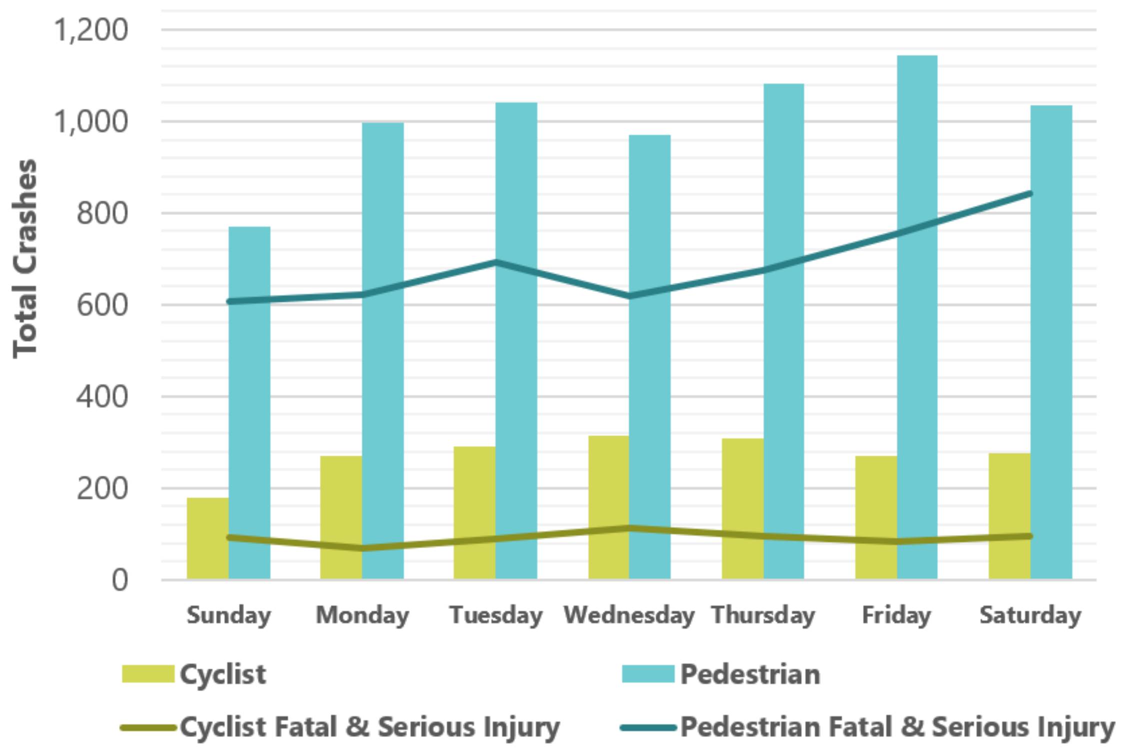


Figure 23 - Cyclist and Pedestrian Crashes by Day of Week and Severity (2018-2022)

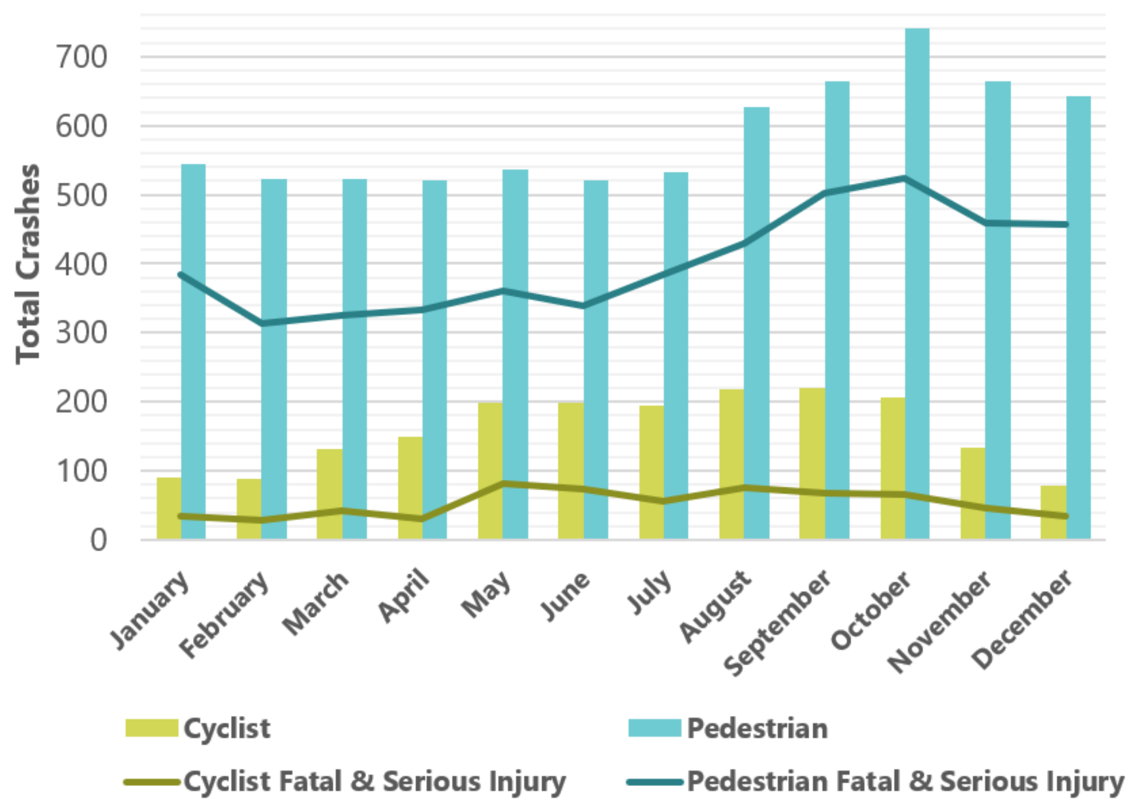


Figure 24 - Cyclist and Pedestrian Crashes by Month of Year and Severity (2018-2022)

Over the five-year analysis period, pedestrian crashes have risen at a higher rate than both motorist and cyclist crashes. A sharp decline in motor vehicle and pedestrian crashes occurred during the COVID lockdowns. Figure 25 provides an in-depth examination of VRU crashes, segmented by pedestrians, cyclists, and motor vehicles, over five years. A striking feature evident from the visualization is the pronounced dip marked "COVID-19" around the beginning of 2020. This suggests a significant decrease in crashes across all categories during this period, likely due to pandemic-induced lockdowns and a subsequent reduction in mobility. Post this sharp decline, a visible resurgence in crashes is observed, especially among motor vehicles, which show a dramatic spike towards the end of 2020 and continue with fluctuating yet elevated levels in the subsequent months.

Pedestrian-involved crashes exhibit a certain cyclic pattern, albeit with some monthly anomalies. Post the pandemic-induced decline, there's a marked increase, with crashes rising until a peak in mid-2021 before settling into a slightly lower yet fluctuating trend. Cyclist-related incidents portray a more consistent trend compared to the other two categories. While they also experienced a pandemic-related dip, their numbers remained relatively stable over the years, with mild seasonal fluctuations.

One noteworthy observation is the widening gap in 2022 between pedestrian and cyclist crashes. While pedestrian-related incidents increase, cyclist crashes maintain consistency, indicating differing factors or interventions affecting these two VRU groups.

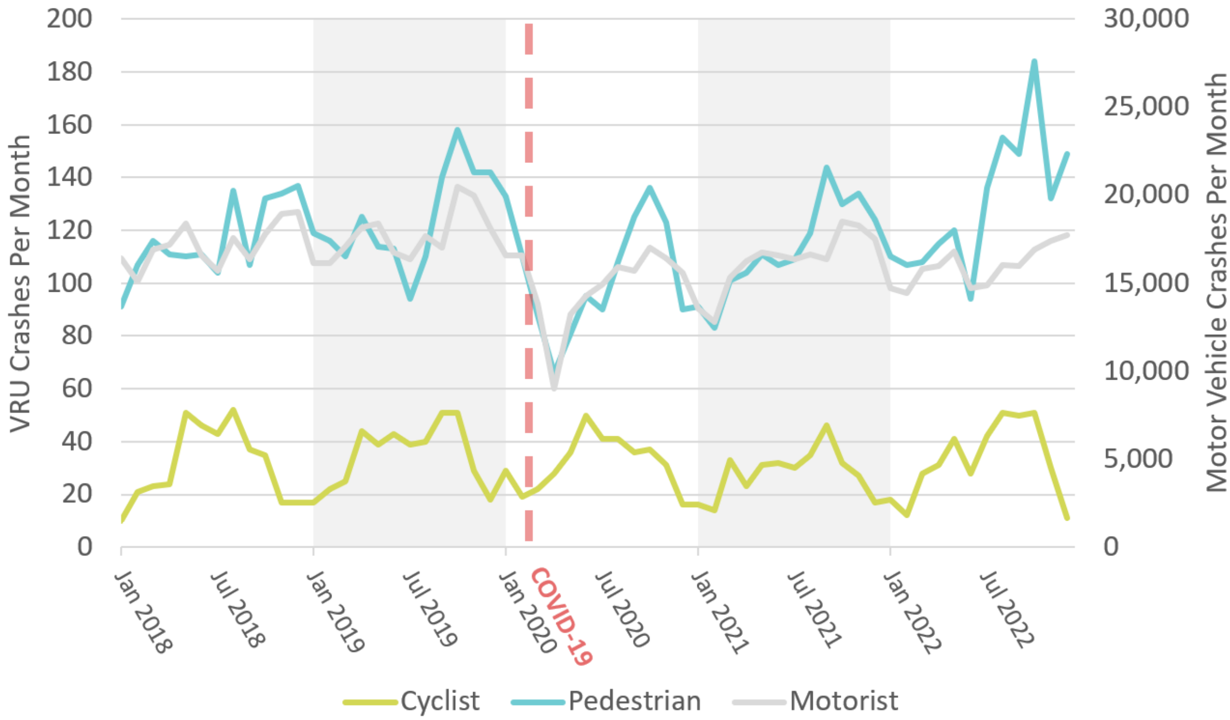


Figure 25 - Cyclist, Pedestrian, and Motorist Crashes Monthly from 2018 to 2022

Crashes by Year

Figure 26 reveals an interesting trend in cyclist-related incidents over the years. The total number of crashes sees minor fluctuations, indicating a relatively consistent number of cyclist crashes yearly. The year 2020 marks a slight decline, possibly influenced by global events such as the COVID-19 pandemic, which saw increased outdoor activities but decreased vehicular traffic volumes. However, by 2022, the number of cyclist crashes bounced back close to pre-pandemic levels.

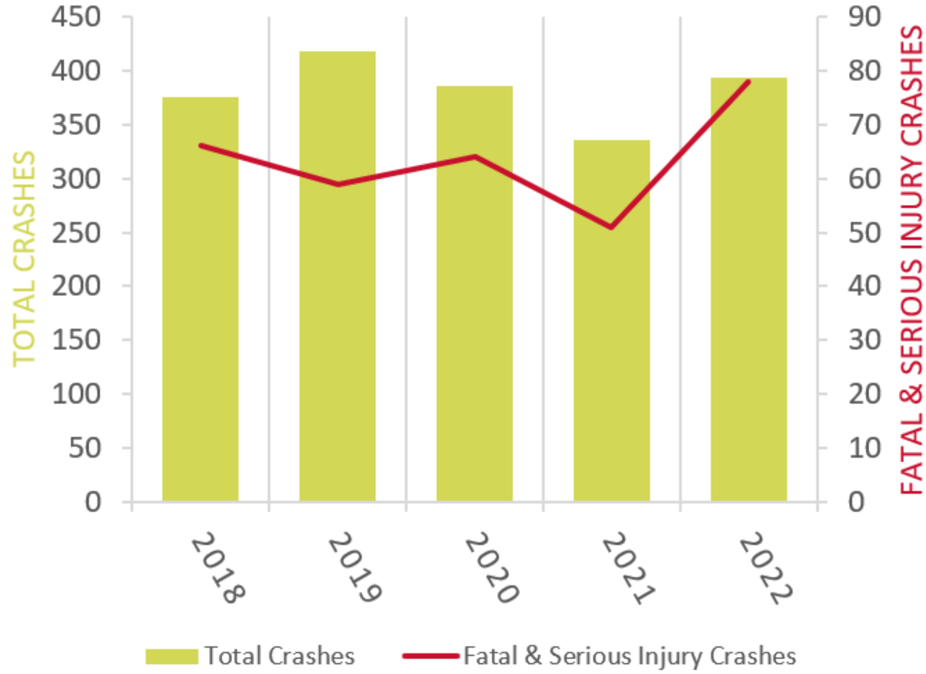


Figure 26 - Cyclist Crashes by Year and Severity (2018-2022)

The more severe cyclist crashes, indicated by the red line, show a notable dip in 2020, followed by a sharp uptick in 2021. This could be due to increased post-lockdown activities or other external factors affecting cyclist safety.

On the other hand, the pedestrian crash trends present a slightly different narrative. Figure 27 shows a decline in the total number of crashes from 2019 to 2020. However, in 2021 and 2022, the number of pedestrian crashes increased. As with cyclist crashes, external factors such as reduced vehicular traffic during the pandemic might have influenced the 2020 dip.

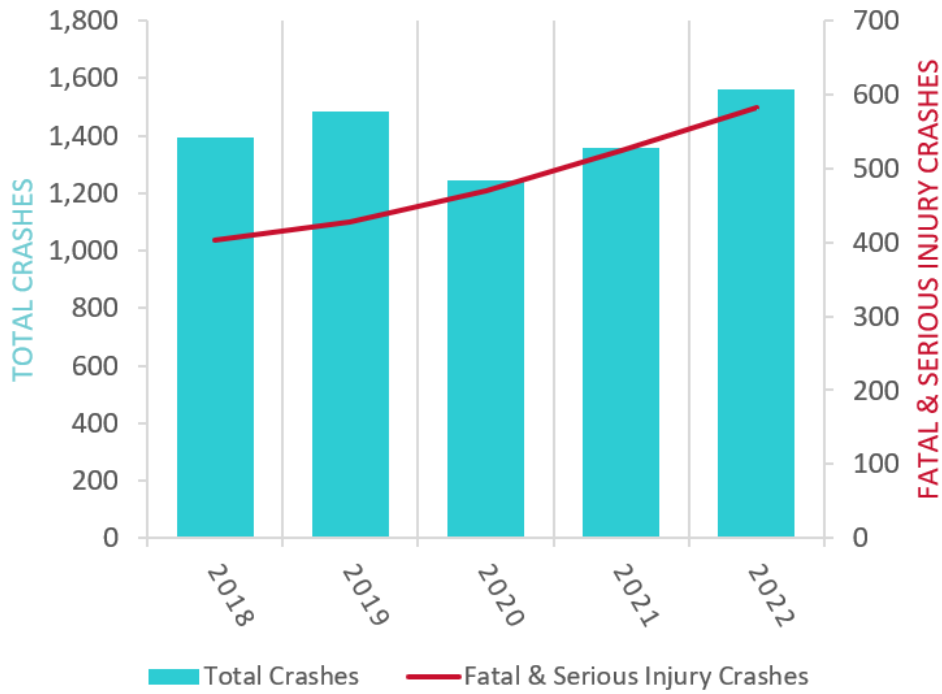


Figure 27 - Pedestrian Crashes by Year and Severity (2018-2022)

The severe crashes involving pedestrians reveal a steady upward trend over the five years. **This suggests that while the total number of crashes might have decreased, the severity of these pedestrian crashes has increased.**

Vulnerable Road User Trends

Evaluating parameters such as age and sex can provide valuable insights into specific at-risk groups, allowing for targeted interventions and tailored safety campaigns. However, the TRIMS datasets included in this analysis do not capture data on the race of the VRUs involved in crashes. In future iterations, including such data from TITAN could be helpful, offering a more holistic view of vulnerable groups and potentially uncovering additional trends that intersect race with road safety.

Age Range of Vulnerable Road Users

Analyzing age-based trends for both cyclists and pedestrians provides a vivid snapshot of the vulnerability of different age groups. For cyclists, Figure 28 reveals that individuals in the age bracket of 0-17 face the highest number of severe and non-severe crashes. As age progresses, there is a discernible decline in crash numbers, although individuals aged 25-34 still face significant risks. Beyond the age of 45, cyclist crash instances barely fluctuate until age 65. It's worth noting that while the total crash counts for individuals 65+ are lower, the proportion of fatal and serious injuries remains a concern.

For pedestrians, the pattern is slightly different. Figure 28 shows that the highest number of crashes occurs in the 25-34 age bracket, followed by the 35-44 and 55-64 age groups. The data also indicates that older pedestrians face considerable risks. Greater than 35% of crashes involving pedestrians 55 and older result in a fatality or serious injury, compared to less than 25% for other age groups.

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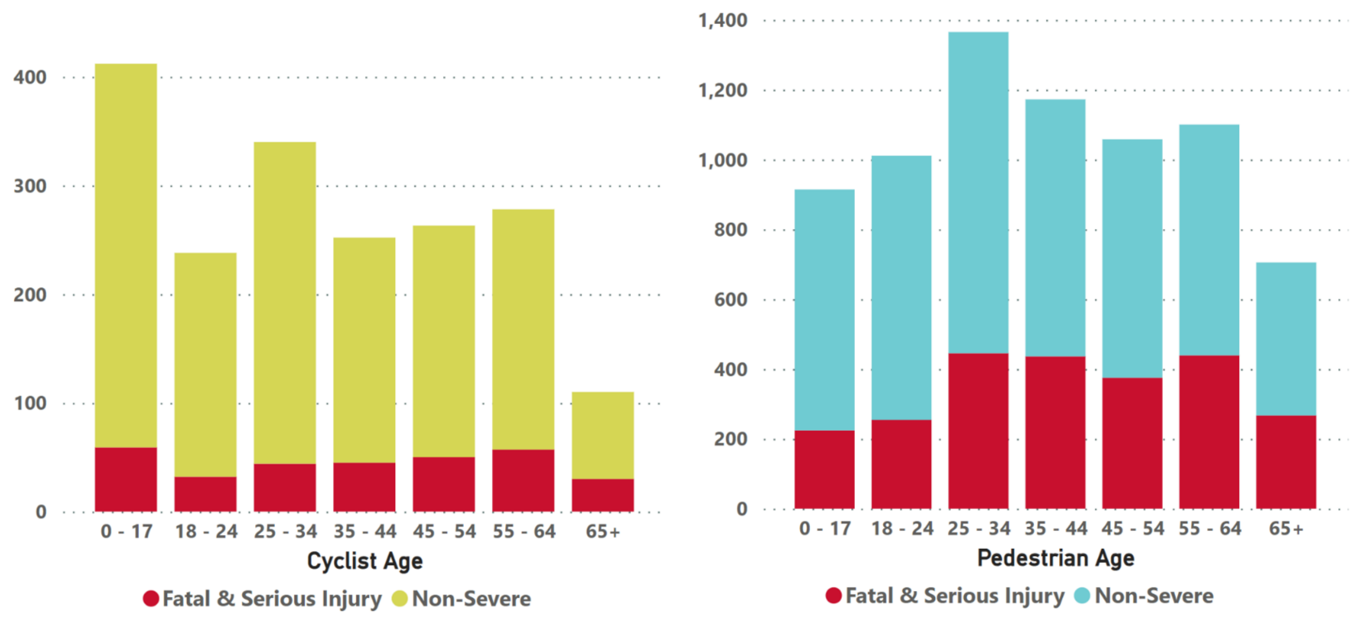

Figure 28 - Cyclist and Pedestrian Crashes by Age (2018-2022)

The severity ratio of pedestrian crashes is higher than that of cyclist crashes across all age groups. Moreover, the 65+ age bracket cannot be overlooked, given the concerning proportions of more severe incidents within their total crash counts.

Gender of Vulnerable Road Users

When evaluating the trends of cyclist and pedestrian crashes segmented by sex, a pronounced disparity is observed. For cyclists, males demonstrate a substantially higher number of crashes in comparison to females. Of the total crashes involving male cyclists, a significant portion led to fatal or serious injuries. On the other hand, female cyclists face fewer crashes overall, as well as a smaller proportion resulting in fatal or serious injuries.

The data presents a more balanced picture of pedestrian crashes, although discrepancies still exist. Male pedestrians experience a higher number of total crashes, with a significant count leading to fatal and serious injuries. Female pedestrians, while having a lower total crash count compared to males, still see a concerning ratio of fatal and serious injury incidents. Interestingly, the proportion of fatal and serious injuries to non-severe incidents is comparable for both sexes within the pedestrian category.

In summary, male VRUs, cyclists and pedestrians seem more susceptible to crashes. However, the proportion of severe incidents to non-severe ones remains a concern across all genders, emphasizing the importance of enhancing safety measures universally. The reasons behind the gender disparities in crashes could be manifold, including exposure rates, risk-taking behaviors, or infrastructure design, warranting further investigation to implement targeted interventions.

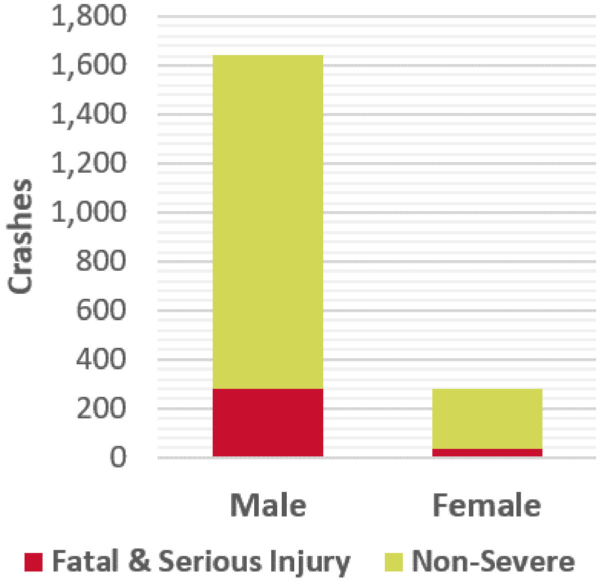

Figure 29 - Cyclist Crashes by Sex (2018-2022)

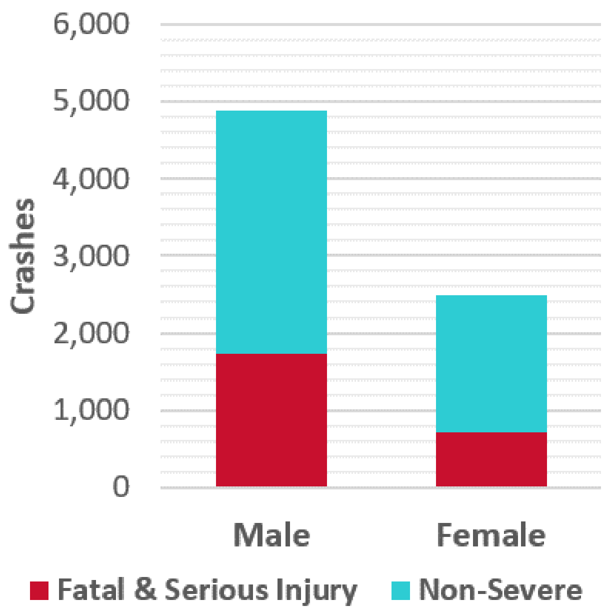

Figure 30 - Pedestrian Crashes by Sex (2018-2022)

Quantitative Analysis

High-Risk Areas

Developing a High-Risk Network (HRN) aims to determine a subset of roadway segments and intersections statewide representative of locations where VRU-involved crashes have occurred with the most significant frequency. This subset of roadways helps to indicate locations and characteristics that may elevate crash risks to pedestrians and other vulnerable users.

Reported and mapped crash data for VRUs is a relatively small sample size when distributed across a statewide roadway system. Pedestrian and cyclist volumes are exceedingly low on the majority of roadways statewide due to the lack of availability of active transportation infrastructure. Pedestrian and cyclist volumes are generally located on urban roadways containing sidewalks and bike lanes. In fact, the severe VRU crashes between 2018 and 2022 occurred on just 654 miles of roadway, 0.7% of Tennessee's statewide roadway network. For this reason, as well as the inherent risk to all VRUs during a crash, all VRU crashes were included in the statistical breakdown to determine the state's HRN, regardless of injury code.

The combined length of the HRN segments is only 150 miles of roadway and represents 25% of all VRU crashes statewide between 2018 and 2022.

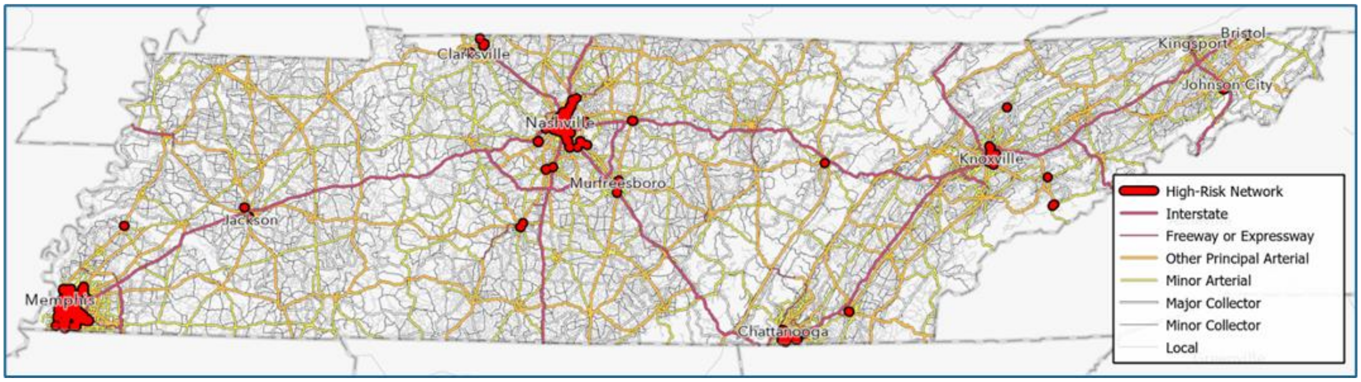

Figure 31 - Statewide High-Risk Network for VRUs

Demographics

Characteristics of the built environment are only part of the puzzle when assessing factors contributing to the safety of VRUs. Demographic information provides insight into an area's socio-economic characteristics, which may correlate to the need for one to travel as a VRU and thereby become vulnerable in their use of the transportation system. For some populations, traveling as a VRU is a choice; for others, it is necessary. Understanding these factors can serve as a predictive element. When socio-economic factors common amongst VRUs are identified, appropriate safety measures can be put in place pre-emptively in appropriate areas. Doing so shifts safety from a reactionary approach to a proactive and humane approach to crash prevention, which attempts to prevent their occurrence.

To identify common demographic trends, the 2020 Census tracts containing HRN segments were isolated. The tract level was chosen as it is the smallest unit of Census geography for which the necessary demographic data is available from the US Census Bureau's American Community Survey (ACS). The ACS does not report block data, and doing so would carry exorbitant margins of error or weak levels of confidence. Moreover, the utilization of

Census tracts allowed for direct comparison with the Agency for Toxic Substances and Disease Registry's (ATSDR) Social Vulnerability Index (SVI).

Social Vulnerability Index

The SVI utilizes demographic data from the American Community Survey to develop a composite score indicating the degree of social vulnerability of each Census tract. While the tool was developed to assess needs in response to hazardous events, it has a wide range of applications, including this assessment of VRU safety. Four groups of variables influence the SVI score: Socioeconomic Status, Household Characteristics, Racial and Ethnic Minority Status, and Housing Type and Transportation. Relevant Census tables for these four categories were consolidated and ranked, producing an overall summary ranking for each tract. Figure 32 shows these factors warrant consideration in assessing VRU safety.

Based on composite scores, the SVI classifies tracts into four levels of vulnerability: Most Vulnerable, High Vulnerability, Low-Medium Vulnerability, and Least Vulnerable, with the distinction between them occurring at quartile break points in the scoring range from 0 (Least Vulnerable) to 1 (Most Vulnerable).

Each of the four groups of variables included in the SVI was assigned a nationwide percentile ranking. The sums of these statistics were then included for each category and referred to as themes. High scores in all four themes were found to correlate with increased crash risk.

Socioeconomic Status	Below 150% Poverty Unemployed Housing Cost Burden No High School Diploma No Health Insurance
Household Characteristics	Aged 65 & Older Aged 17 & Younger Civilian with a Disability Single-Parent Households English Language Proficiency
Racial & Ethnic Minority Status	Hispanic or Latino (of any race); Black and African American, Not Hispanic or Latino; American Indian and Alaska Native, Not Hispanic or Latino; Asian, Not Hispanic or Latino; Native Hawaiian and Other Pacific Islander, Not Hispanic or Latino; Two or More Races, Not Hispanic or Latino; Other Races, Not Hispanic or Latino
Housing Type & Transportation	Multi-Unit Structures Mobile Homes Crowding No Vehicle Group Quarters

Figure 32 - SVI Theme Summary[17]

Of the 283 Census tracts containing roadway segments in the HRN, 212, or 75%, are classified as being Most Vulnerable or High Vulnerability. Statewide, roadway segments and intersections that are part of the HRN are located in 283 Census tracts or 17% of the total tracts in the state. Together, these tracts constitute less than 2%

[17] CDC, SVI Vulnerability Index, https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

of the state's total land area and include 16% of its total population. The overall population density of these 283 Census tracts is 1,556 people per square mile compared to 164 people per square mile statewide.

SVI Theme 1 - Socioeconomic Status

The SVI score includes measures related to employment, income, and education. Figure 33 describes the distribution of roadway miles by SVI, which appears close to a normal distribution, with a mean just above 2.0. The red line shows the distribution of scores according to total miles of roadway identified in the HRN, which is considerably right biased compared to the statewide distribution, indicating Census tracts with higher SVI scores are more likely to contain roadways with a high concentration of VRU crashes.

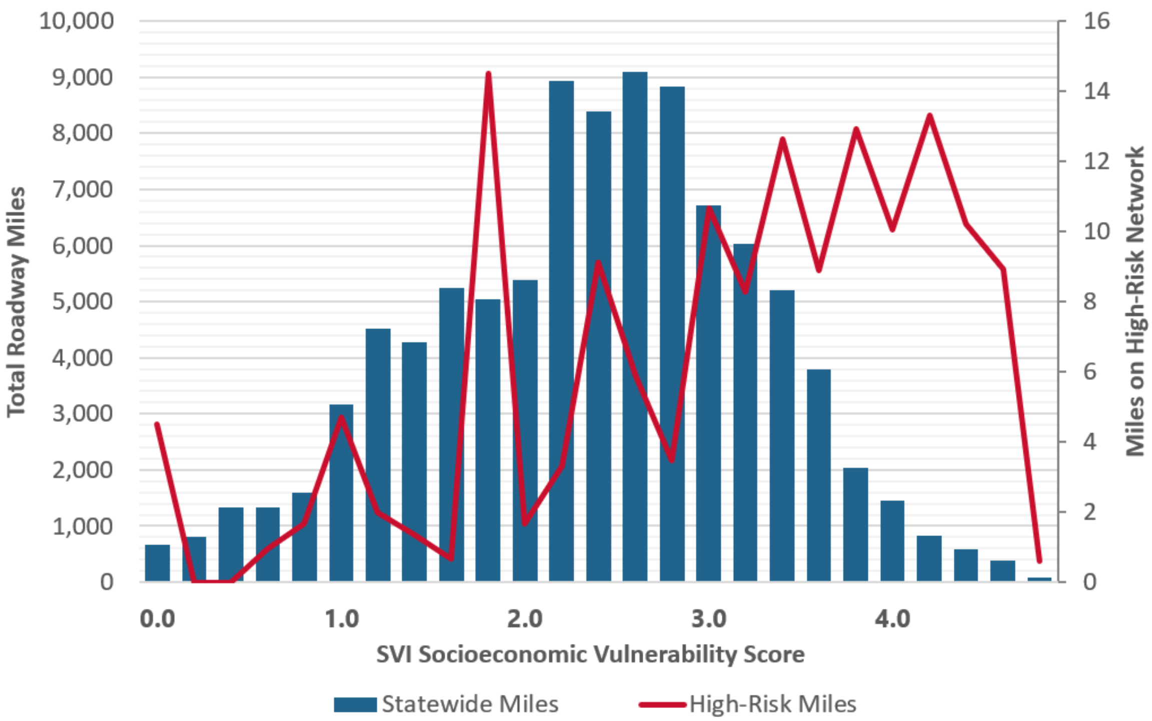

Figure 33 - Statewide Mileage and High-Risk Network Mileage by SVI Socioeconomic Vulnerability Score

Poverty and Workforce

Twenty-two percent of the households within the HRN tracts have a household income below 150% of the poverty level. Unemployment rate and VRU crash occurrence share a slight positive correlation. The distribution of high-risk facilities is consistent between various unemployment levels. The unemployment rate on high-risk roadways is not significantly elevated above the statewide mean.

SVI Theme 2 - Household Characteristics

Crash risk does not appear to be strongly correlated with the household characteristics component of the SVI score. Figure 34 shows that the HRN roadway segments are spread out across the range of SVI index scores. Some of the metrics included in this category have negative relationships, biasing the distribution towards the lower end. Others show no relationship at all.

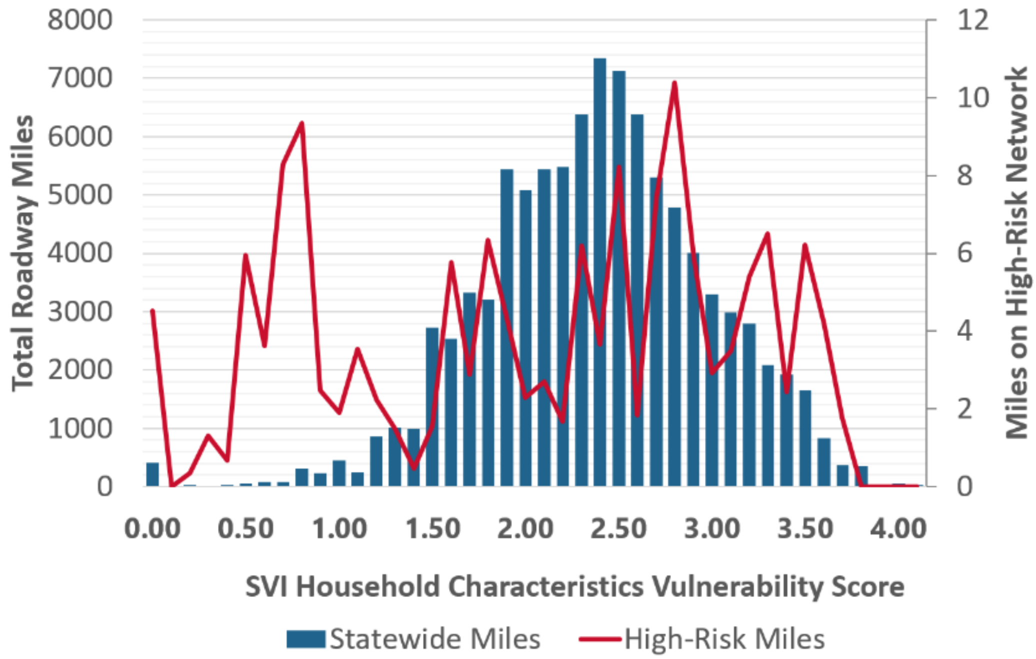

Figure 34 - Statewide Road Mileage and High-Risk Network Mileage by the Household Characteristics Component of the SVI Score

Age

Census tracts with a higher percentage of the population over age 65 are less likely to be represented on the HRN segments. The percentage of the associated Census tract population younger than 17 and older than 65 are both below the statewide mean along high-risk roadway miles. Figure 35 shows VRU-involved crashes by age group for HRN roadways. When compared with Figure 28, it is apparent that the age distribution among high-risk roadway crashes and statewide crashes is similar. One notable difference is that cyclist crashes are significantly lower for populations below 17 and above 65 years of age within the HRN. It is particularly noteworthy that cyclists below 17 are the most at-risk age bracket statewide, indicating that small children may be at particular risk in rural, residential areas.

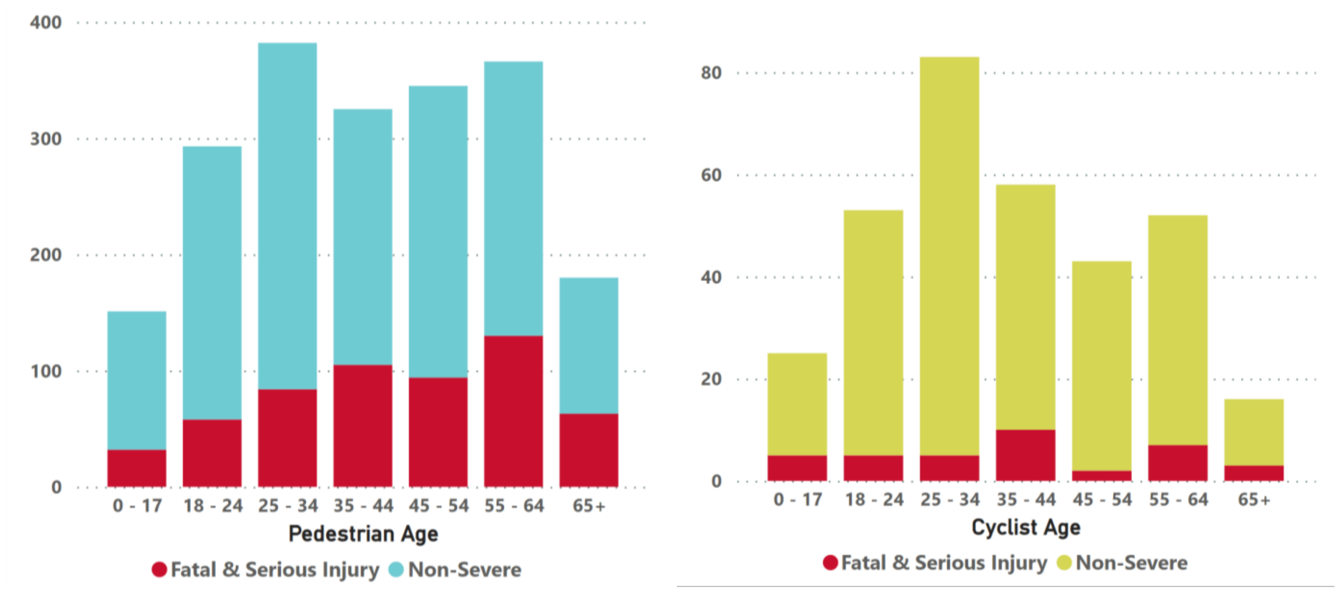

Figure 35 - VRU Crashes within the High-Risk Network by Age Group (2018-2022)

Disability

The relationship between each Census tract's percentile with regard to the prevalence of disability in the population and the occurrence of VRU crashes is slightly negative, particularly at the extreme ends of the lowest 5 percentile and upper 30 percentile. The average percentage of disabled population at high-risk locations is 13%, which is approximately 0.8 standard deviations below the mean. This comparison does not indicate that pedestrians with disabilities are at any lower risk than the rest of the population, but a high proportion of disabled residents may reduce overall exposure due to lower volume of vulnerable roadway users.

SVI Theme 3 - Race & Ethnic Minority Status

The majority minority Census tracts represent 57% percent of the HRN tracts. Majority minority Census tracts contain 41 miles of roadway in the HRN, amounting to 21% of the total HRN mileage.

The relationship between roadways in HRN tracts and the racial and ethnic component of the SVI status is shown in Figure 36. An increase in the minority population is directly correlated with an increased VRU crash risk. The average minority population percentage of high-risk roadways is 52%, compared to the statewide average of 16%. Although this is a striking difference due to the high variance of the minority data, it only represents a difference of 1.8 standard deviations above the statewide mean.

Only including urban areas, which represent most of the high-risk network, the average percent minority population by census tract is 26%. The urban high-risk network remains approximately 52%, which is approximately 1 standard deviation above the mean.

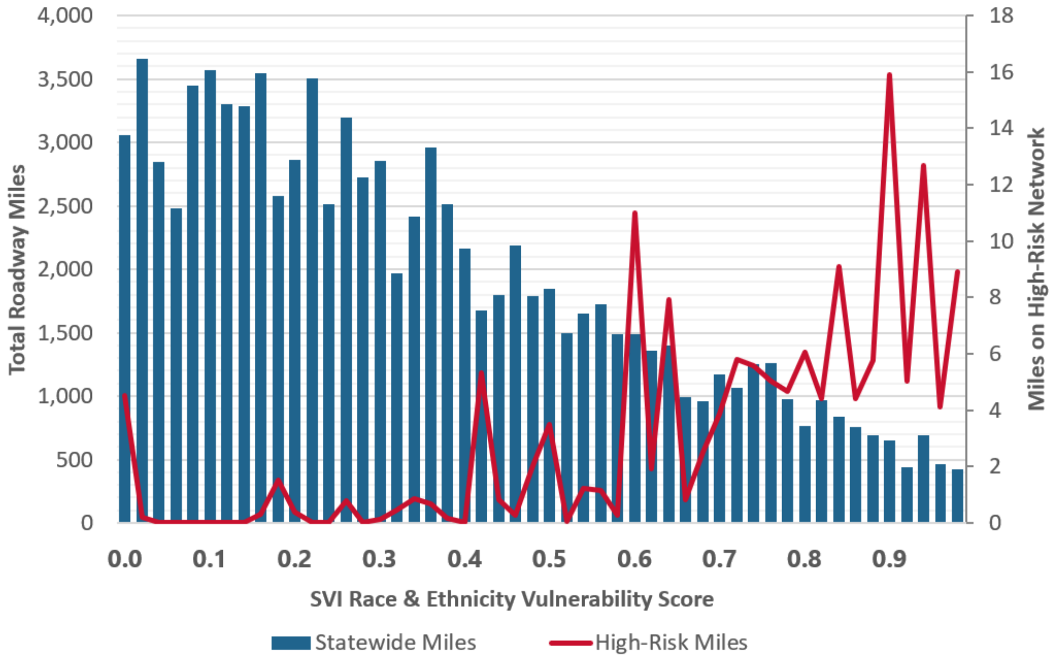

Figure 36 - Statewide Mileage and High-Risk Network Mileage by the Race and Ethnicity Component of the SVI Score

SVI Theme 4 - Housing Type & Transportation

This theme includes categories with varying relationships to crash risk. Many of the group-living characteristics correlate to an increased crash occurrence; however, the number of mobile homes in a Census tract has a negative relationship with VRU crash risk.

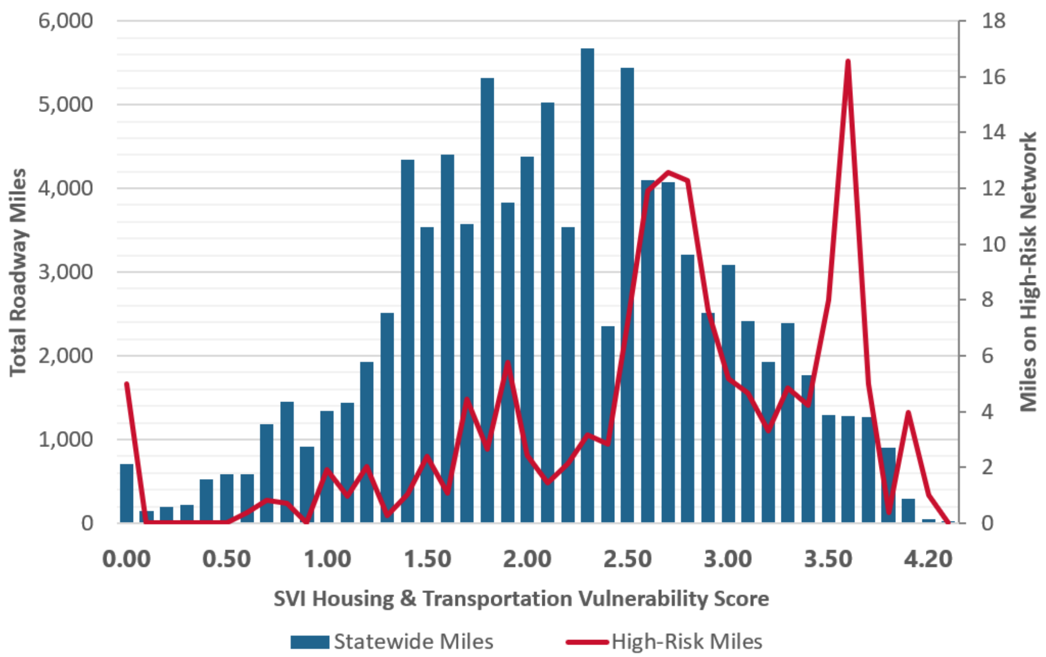

Figure 37 - Statewide Mileage and High-Risk Network Mileage by the Housing and Transportation Component of the SVI Score

Zero Vehicle Households

VRU crash risk increases as the percentage of households with zero vehicles increases. In Census tracts that include segments of the HRN, the average percentage of households with zero vehicles is 14%, compared with 5% statewide. This is 1.9 standard deviations above the mean, so it can be said that high-risk VRU roadways have a higher percentage of zero-vehicle households with 97% confidence.

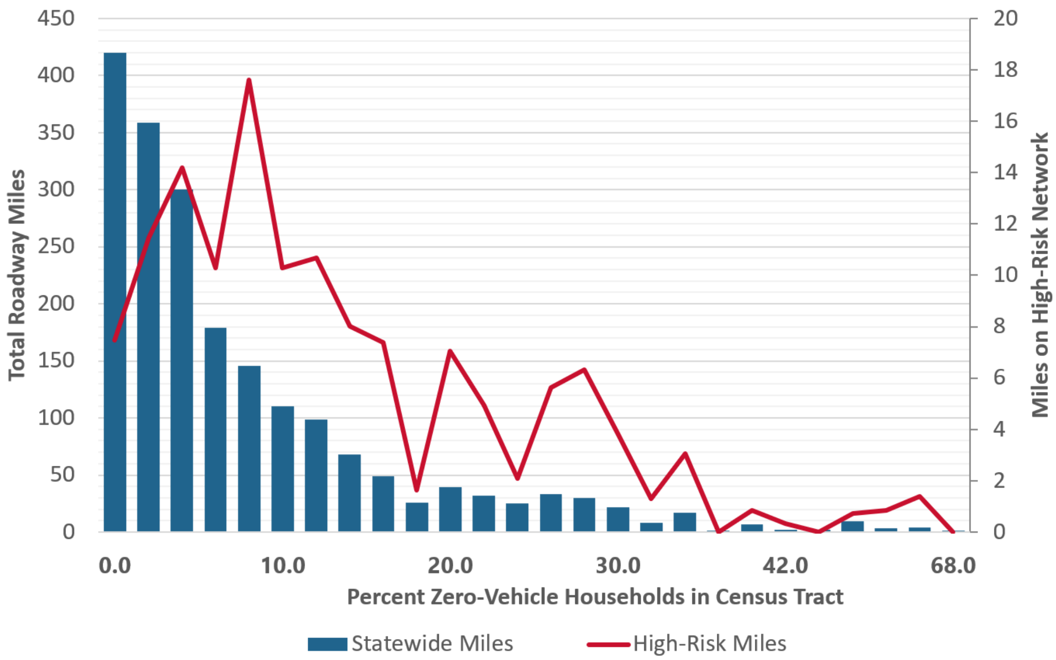

Figure 38 - High-Risk Network Shows Increased Proportion of No-Vehicle Households Compared to Statewide

Equity Conclusions and Implications

Several apparent relationships exist between social and economic equity measures and crash risk for VRUs. Multiple factors are likely involved in this correlation. Regardless of the primary cause, the correlation is visible in the data.

Predictive Model

A predictive model was trained on the aggregated crash totals to assign an expected crash value to Tennessee's roadway network. The predictive model considers roadway characteristics, land use, and demographic data as explanatory variables. The model utilizes a combination of multiple binomial and forest-based regression models to include all segments and intersections statewide, with varying degrees of data availability. Goodness-of-fit statistics are shown in Table 8 for the four split models.

Table 8 - Forest-Based Regression Model Goodness-of-Fit Statistics

Model	n	R^2	RMSE	Dispersion Parameter (φ)
State Route Intersections	36,332	0.42	0.28	0.7235
Non-State Route Intersections	168,452	0.26	0.12	0.6561
State Route Segments	25,172	0.42	0.35	0.7866
Non-State Route Segments	230,285	0.22	0.12	0.7109

Forest-based regression is a machine learning algorithm that uses many randomly generated decision trees of differing combinations of variables to assign complex relationships between explanatory variables and dependent variables. The nature of this procedure means that the relationships identified are not always linear, and coefficients are not assigned as in a linear regression model. The reported statistics for explanatory variables are referred to as importance factors, and they are quantified as the relative percentage of cases where the variable was relied on by the model during the assignment of the dependent variable. Table 9 below shows the relative importance of each variable for each of the four selected regression models.

Table 9 - Variable Importance Table for Regression Models

Variable	State Route Segments	Non-State Route Segments	State Route Intersections	Non-State Route Intersections
Roadway Characteristics				
AADT	4.05%		2.04%	
Area Type = Urban	0.16%			0.01%
Area Type = Rural	0.14%	0.02%	0.11%	
Average Crossing Width			1.27%	2.89%
Flashers Present			0.02%	0.00%
Pedestrian Signals Present = YES			7.54%	
Pedestrian Signals Present = NO			5.06%	
Curb Ramps Present = YES			0.08%	
Curb Ramps Present = NO			0.06%	
Marked Crossings			1.52%	
Crosswalk Type = Transverse			0.10%	
Crosswalk Type = Longitudinal			1.65%	
Crosswalk Type = None			0.82%	
Number of Lanes (per approach)	1.55%	7.79%	1.81%	7.35%
Number of Lanes (max approach)			0.94%	3.22%
Number of Approaches			0.75%	2.10%
Stop Controlled Approaches			0.15%	1.82%
Sidewalk	0.72%	0.98%	4.00%	9.72%
Speed Limit	0.90%		0.41%	

Continued Table 9 - Variable Importance Table for Regression Models

Variable	State Route Segments	Non-State Route Segments	State Route Intersections	Non-State Route Intersections
Roadway Characteristics continued				
Transit Density/Distance	13.50%	5.34%	6.26%	4.59%
Two-Way Left-Turn Lanes (TWLTL)	3.78%	10.19%	1.01%	2.53%
Bike Lanes	0.50%	0.93%		
Curb	0.98%	0.77%		
Median Presence	0.85%	0.89%	1.18%	0.24%
Parking Lanes	0.19%	1.55%		
Shoulder Presence	0.58%	0.38%		
Shoulder Width	1.09%	0.67%		
Signal Density	4.69%	2.05%		
Segment Length	2.73%	3.94%		
Land Use				
Distance to Nearest Church			1.25%	1.12%
Distance to Nearest Hospital			1.22%	0.83%
Distance to Nearest School	0.90%	1.34%	1.33%	1.03%
Church Density	0.31%	0.70%		
Hotel Density	4.12%	0.99%		
Light Industry Density	2.50%	1.20%	0.84%	0.97%
Multi-Family Residential Density	2.98%	4.32%	2.51%	1.93%
Office Density	3.71%	0.82%	1.86%	0.69%
Parking Structure Density	5.59%	2.11%	9.32%	6.36%
Retail Density	4.99%	4.69%	2.06%	3.79%
Single-Family Residential Density	1.63%	2.41%	1.79%	2.25%
University Building Density	0.28%	0.46%	1.15%	0.86%
Functional Classification				
Interstate	0.08%		0.00%	
Freeway or Expressway	0.01%		0.00%	
Principal Arterial	1.04%		0.05%	
Minor Arterial	0.20%	2.77%	0.04%	0.84%
Major Collector	0.00%	0.85%	0.01%	0.07%
Minor Collector		0.01%		0.01%
Local		1.58%		0.52%
Social Equity				
SVI Theme 1 - Socioeconomic Status	0.96%	1.29%	0.50%	1.04%
SVI Theme 2 - Household Characteristics	1.94%	1.96%	0.98%	2.12%
SVI Theme 3 - Race & Ethnic Minority Status	1.98%	2.55%	1.32%	0.94%
SVI Theme 4 - Housing Type & Transportation	1.09%	2.46%	1.21%	2.22%
Estimated Daytime Population	1.67%	1.31%	1.99%	0.88%
Traffic Control				
Traffic Signal			0.54%	12.23%
All-Way Stop				0.14%
Partial Stop			0.08%	0.97%
Yield			0.00%	0.00%
Uncontrolled			0.02%	0.01%
Binomial Model Prediction	**27.60%**	**30.71%**	**32.28%**	**23.73%**

Empirical Bayes

Predicted crash totals were weighted against observed values using an empirical Bayes methodology, where the weight is dependent on the dispersion of residuals in each model as well as the sample size of the crash data. This analysis results in an expected crash total for each of the segments and intersections. The weighting applied to the predicted value is calculated according to the following equation, where φ is the dispersion parameter, and X is the predicted crash number.

$$Weight - = \frac{1}{1 + {}^{X}/_{\varphi}}$$

Land Use

Land use statistics are derived from a nationwide dataset of building footprints compiled by the Federal Emergency Management Agency (FEMA). Structures are classified by primary occupancy type. Density and distance heat maps were developed for each classification. These statistics were then joined to roadway facility features. Two methods of quantifying land use and point-of-interest attributes were used. Density values are reported in units of structures per square mile that exist within a specified radius. For attributes related to points-of-interest, the distance to the nearest structure along the roadway network was computed. For segments, these statistics are calculated as an average value along the segment length. Figure 39 shows the HRN in the Nashville area overlaid on a density map of retail buildings within a 0.25-mile radius of each point.

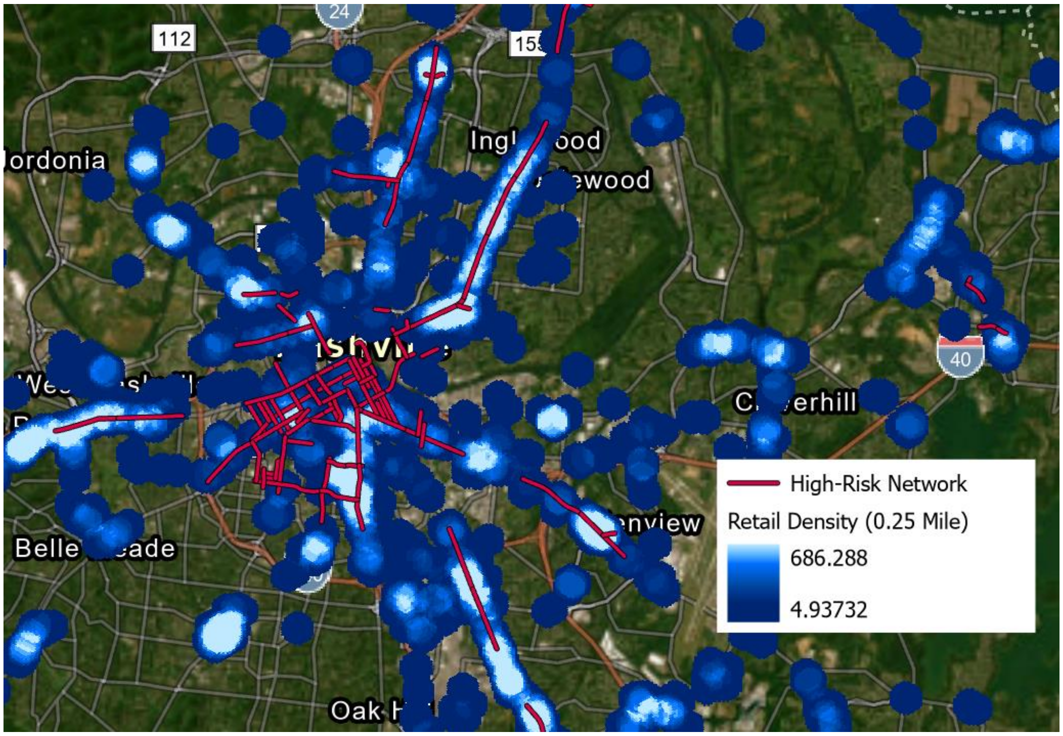

Figure 39 - Retail Density Map with High-Risk Network in Nashville, TN

Building density was found to correlate with crash occurrence in nearly every land use category. The relationships varied in strength and distance of their effect. Retail building density shared the strongest correlation to crash risk; however, its effect was greatly diminished beyond a short distance, less than a tenth of a mile. Employment-related land uses, such as office buildings and light industry, were found to have an impact at distances greater than one mile.

Stronger correlations were observed between certain land uses and intersection-related crash numbers versus segment-related ones. Residential density appears to have a stronger relationship with segment-related crash risk, whereas office density appears more strongly correlated with intersection-related crashes. This observation is reinforced by the fact that a significantly larger portion of rural crashes were away from intersections when compared to urban crashes, which are more evenly split. Scatter plots presented in Figure 40 and Figure 41 show the relationship between office density and intersection crashes observed on the left and between single-family residential density and segment-related crashes on the right. The size of the symbols corresponds to the number of locations included in each.

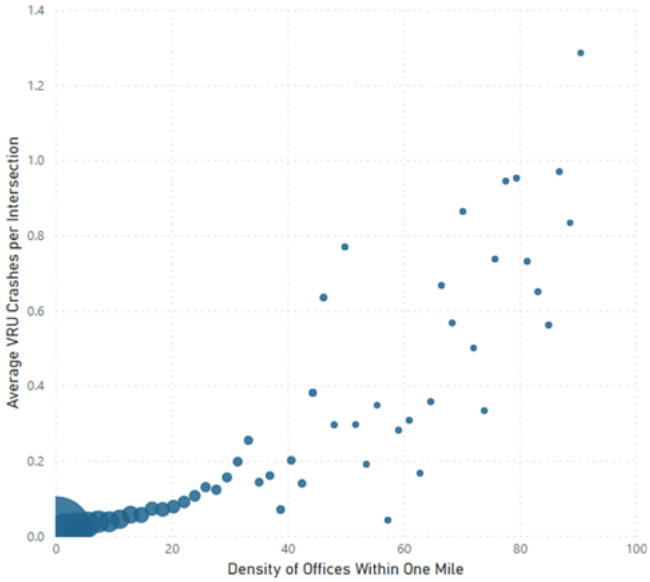

Figure 40 - Average Crashes per Intersection Versus Office Density

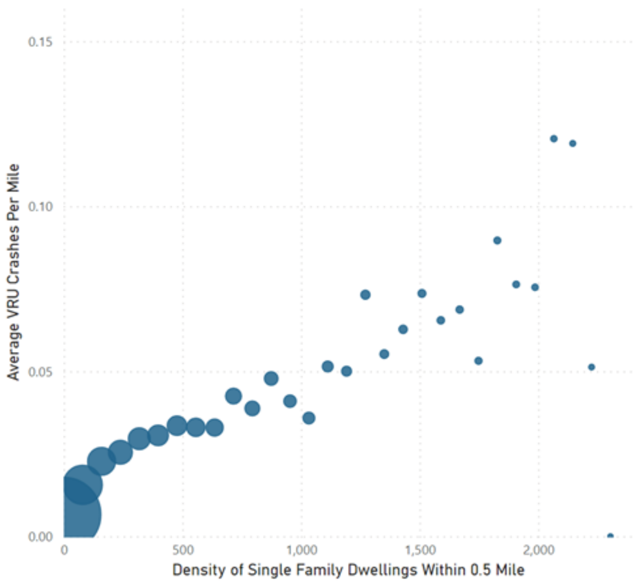

Figure 41 - Average Crashes per Mile Versus Residential Density

Major public transit corridors show a solid relationship to increased crash risk for VRUs. Transit density was among the strongest predictors among model relationships, and the trends are also visually apparent in the data.

Figure 42 shows the relationship between transit stop density and crash risk. The x-axis shows the average distance to a transit stop from any point along the segment, so segments with more transit stops on them would appear closer to zero, whereas segments with fewer stops or those adjacent to transit corridors have higher average distances. Beyond an average distance of 2,000 feet, the relationship is flat.

The average distance to a school shares a similar relationship to transit, though the average crash risk is lower and the area of effect is larger. The data in Figure 43 shows an increase in average crash risk within 2 to 3 miles of a school.

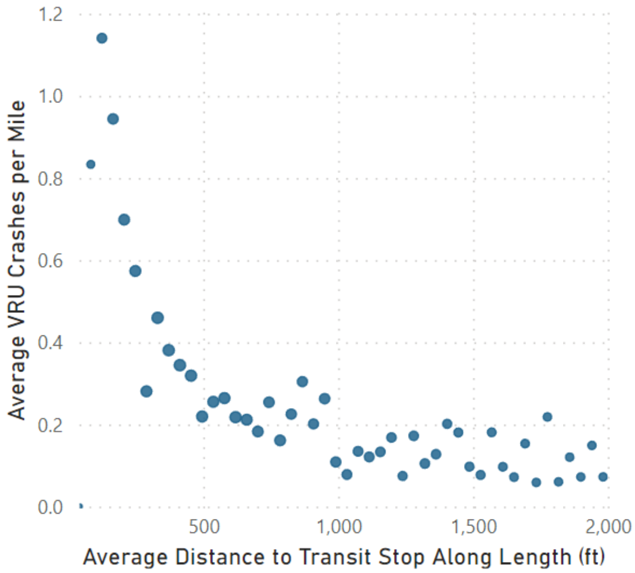

Figure 42 - Relationship Between Transit Stop Density and VRU Crash Risk

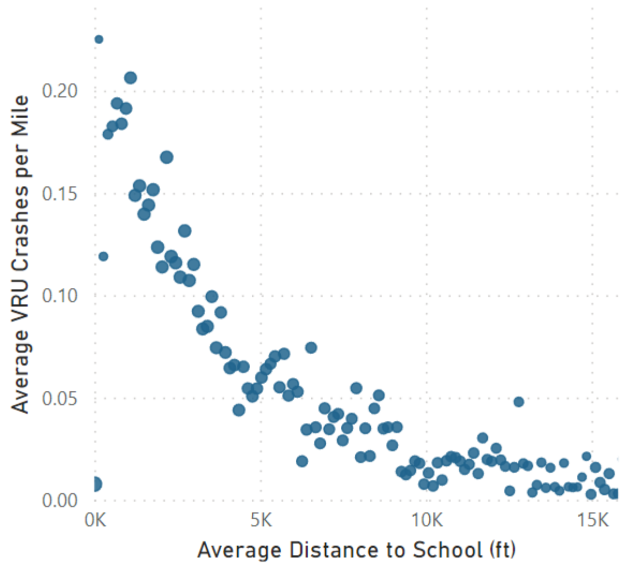

Figure 43 - Relationship Between Distance to School(s) and VRU Crash Risk

Roadway Characteristics

Two-way left-turn lanes (TWLTL) continually show up as a predictor of VRU crashes. Statewide, roadways with no TWLTL have an average VRU crash occurrence of 0.3 crashes versus 0.63 for segments with TWLTL along its entirety. This can be misleading since TWLTLs are typically only present in areas with high commercial activity and high driveway density, which are already indicators of pedestrian activity and increased crash risk. To control for this, a minimum density was applied to the data in Figure 44.

To quantify the relationship on only roadways likely to have center turn lanes, only urban, non-access-controlled roadways were included, above a density of 50 retail structures per square mile and with an AADT above 5,000 vehicles per day. Under these conditions, the average crash occurrences per mile with no TWLTL is 0.7, increasing gradually to 2.0 for segments with TWLTL along their entire length. In contrast, under these same circumstances, the percent of segment length with a raised median directly correlates to decreased crash risk.

Median type is another strong indicator of crash risk for VRUs. Figure 45 shows the likelihood of a VRU crash is higher for the roadway segments with no or partial raised medians.

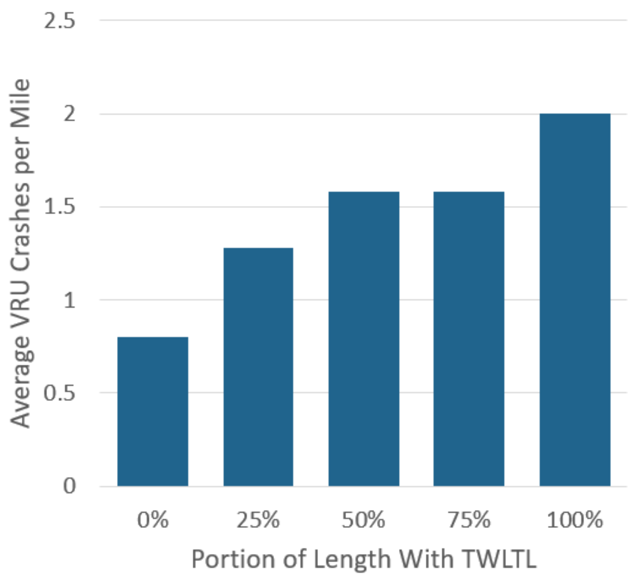

Figure 44 - VRU Crash Risk Versus Two-Way Left-Turn Lane Presence

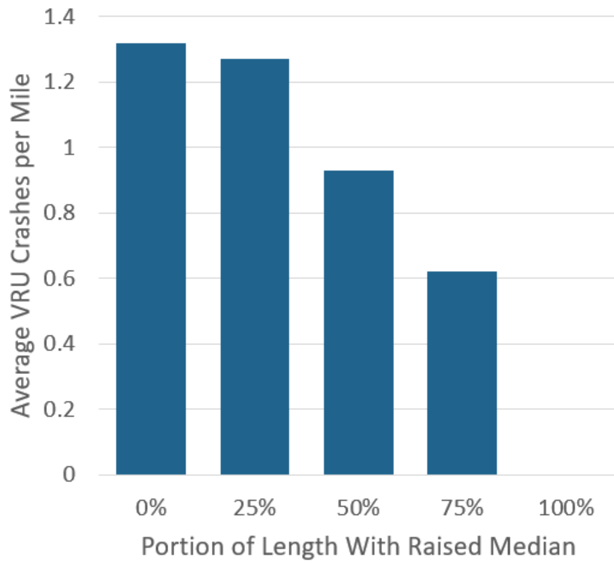

Figure 45 - VRU Crash Risk Versus Raised Median

Vehicle volume is a strong indicator of crash risk. Comprehensive traffic count data was only available for State Routes, so it is included in those models. Figure 46 and Figure 47 show the relationships between vehicle volume and crashes at intersections and along segments, respectively.

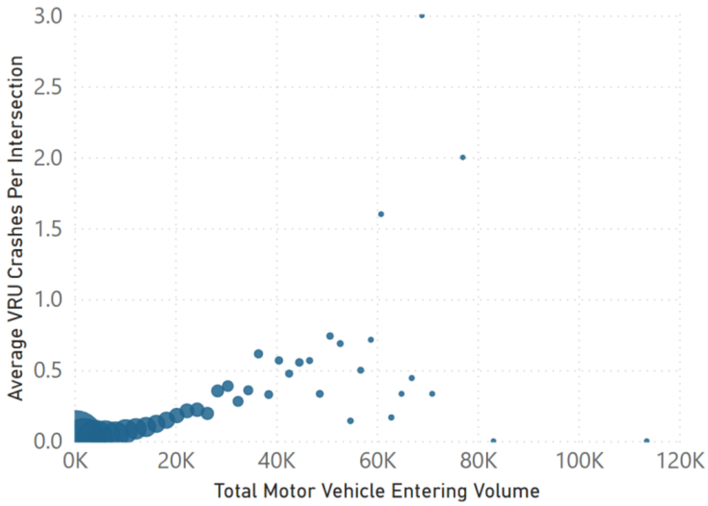

Figure 46 - Average VRU Crashes Per Intersection by Entering Vehicle Volume

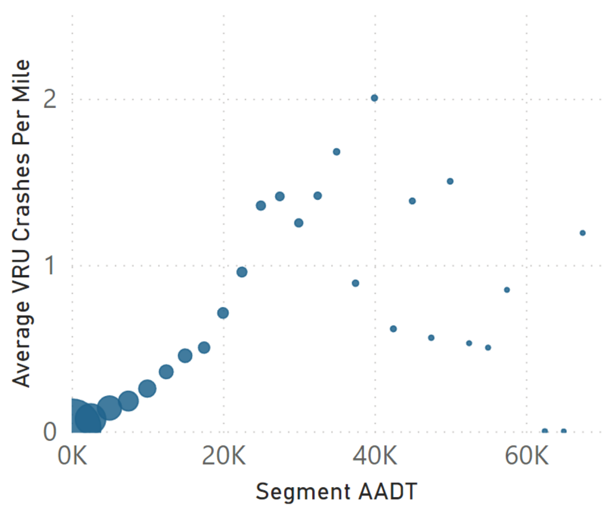

Figure 47 - Average VRU Segment Crashes Per Mile by AADT

Expected Crash Prediction Tool

After empirical-Bayes weighting, an expected 5-year crash total is produced for each roadway segment and length. The risk scores assigned to each facility account for pedestrian and cyclist demand, exposure, and high-risk roadway characteristics. They also incorporate attributes to target high-risk populations based on socioeconomic equity factors.

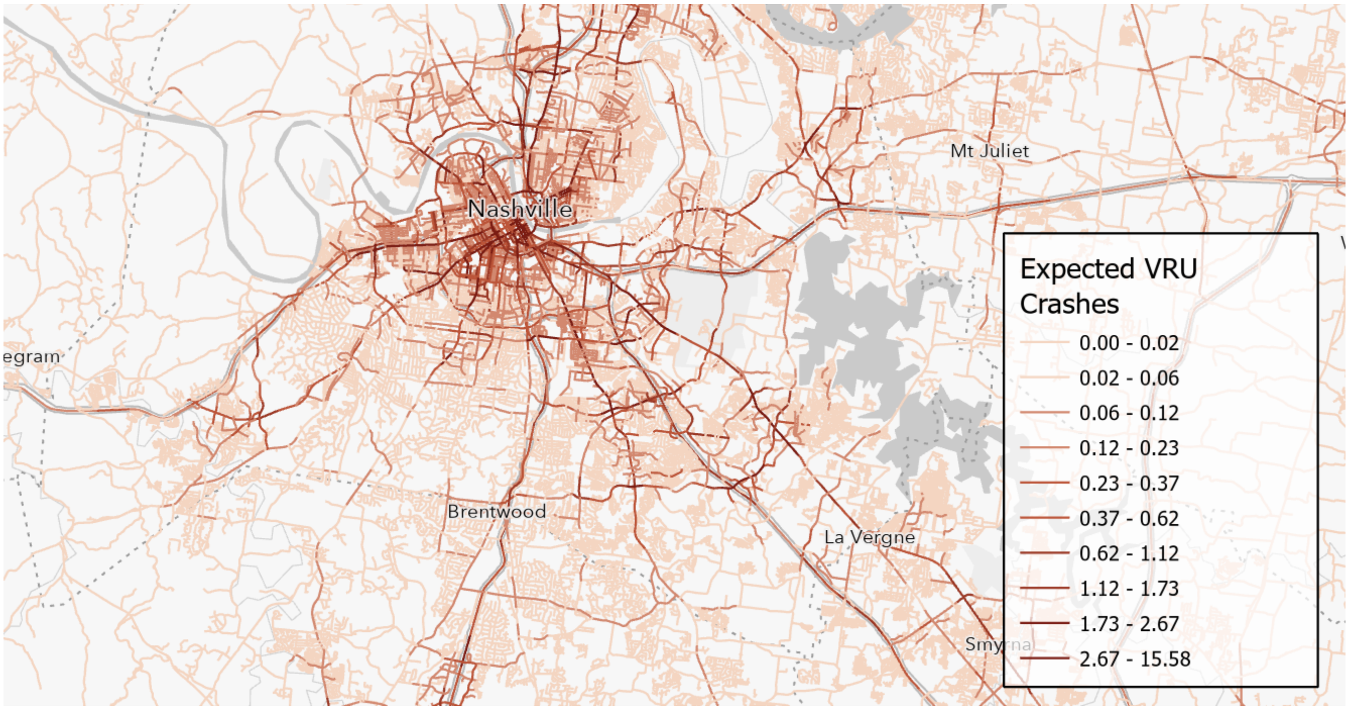

Figure 48 - Expected Crash Frequency Map of Nashville Area

The VRU Crash Risk Prediction Tool contains several statistical metrics that may be useful in varying methods of safety evaluation and network screening. They include the following:

- **Observed Crashes** is the total number of crashes reported at each location over the 5-year study period.
- **Predicted Crashes** is the raw output of the crash prediction regression model. This is essentially an average crash rate for each facility type statewide, controlling for all of the model variables.
- **Expected Crashes** is the result of the Empirical-Bayes analysis, which weights observed crashes and predicted crashes.
- **Crash Residual** is the difference between observed and predicted crashes. This is the number of crashes that occurred over the 5-year period above (below, if negative) the total predicted by the model.
- **Crashes Above Critical** is the number of observed crashes above the 99% confidence interval of residual values. The average and standard deviation of residuals is computed for every combination of urban or rural roadway and each functional classification. Comparing the residual for each individual roadway segment or intersection to similar facilities provides a measure of the statistical confidence that the given location has a crash total elevated above the model average, and that the difference is not attributable to random variance in the data.

It is recommended that expected crashes be the focus when evaluating or prioritizing locations based strictly on VRU safety risk for blanket application of countermeasure programs. This can include network-wide strategy-based programs, such as modernizing pedestrian signals, implementing access management, replacing two-way left-turn lanes with raised medians, and similar efforts to update facilities to current standards.

Within safety audit programs, such as the Pedestrian Road Safety Initiative, it is recommended that crash residual measures are used to prioritize locations. Observed crash totals significantly above the predicted average indicate that safety is being impacted due to characteristics or situations that are not accounted for in the predictive model. These are the locations where a team of experts is needed to evaluate the unique circumstances that are creating safety hazards. The predictive model accounts for adjacent land use trends, roadway characteristics, area demographics, and VRU trip generators, but it cannot predict isolated scenarios such as network bottlenecks, sight distance restrictions, or other unique location-specific safety concerns. The expected crash prediction statewide is illustrated in Figure 49.

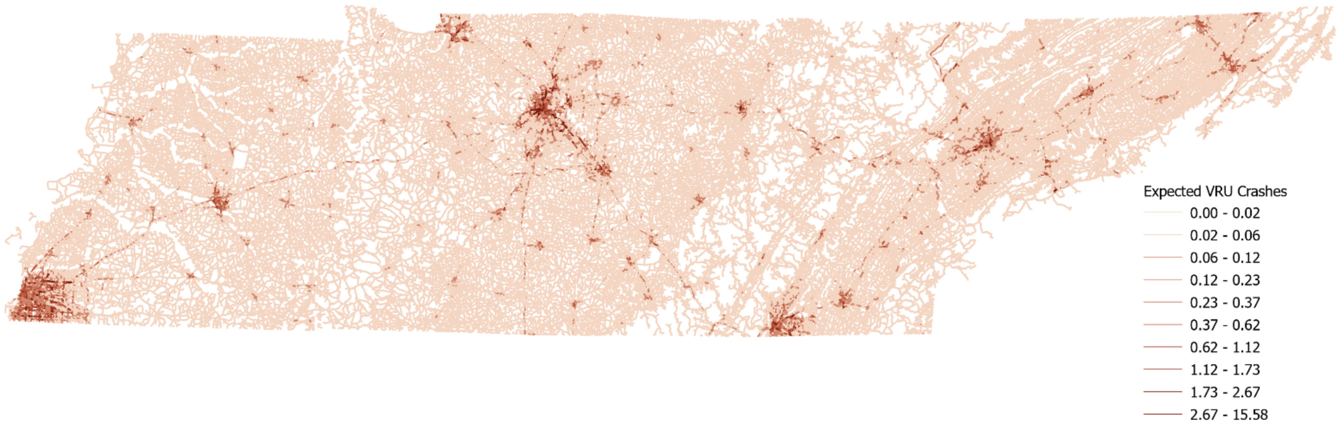

Figure 49 - Expected Crash Prediction for Every Tennessee Roadway Segment

The following describes 5 of the highest expected segment crash totals in the state. Four of the five locations that were flagged by expected crash totals have existing PRSIs or studies in-progress. Several common trends exist along the segments. They are all located in urban areas with relatively high commercial density. All five are along transit routes, with several including multiple overlapping bus routes. All of the segments except the Parkway in Gatlinburg are multi-lane arterials, with center left-turn lanes along at least a portion of each.

Segment:	**8th Avenue / Lafayette Street (SR-1)**					**Nashville**	
Observed Crashes: 58				**Expected Crashes:**	**51.3**		
Segment:	**24**	**Intersection:**	**34**	**Segment:**	**20.5**	**Intersection:**	**30.8**
Pedestrians:	**53**	**Cyclists:**	**5**				
This 1.5-mile-long urban arterial segment stretches from Broadway to the southeast. It is a 7-lane cross-section, including the center TWLTL, carrying approximately 16,000 vehicles per day, with several signalized intersections along it. Additionally, as it traverses the grid network at a diagonal, there are several non-standard intersections with severe skew angles and numerous approaches intersecting in proximity. Ten separate WeGo transit routes either provide service along this route or cross a portion of the route, providing a transfer opportunity.							

Segment:	Gallatin Pike (SR-6)					Nashville	
Total Crashes:	**47**			**Expected Crashes:**	**34.5**		
Segment:	**19**	**Intersection:**	**28**	**Segment:**	**15.8**	**Intersection:**	**18.7**
Pedestrians:	**43**	**Cyclists:**	**4**				

Gallatin Pike between Lakewood Drive and Madison Street is a 7-lane urban arterial, with center turn lane. Several signalized intersections with other major routes exist along this 1-mile stretch of roadway. It is situated in a dense commercial district, with large shopping centers on one side of the highway, and low-income, multi-family housing on the other. WeGo Routes 56, 76 and 79 overlap along this section of Gallatin Pike, competing with an average daily vehicle volume of nearly 29,000 vehicles per day.

Segment:	Dickerson Pike (SR-11)					Nashville	
Total Crashes:	**16**			**Expected Crashes:**	**12.3**		
Segment:	**11**	**Intersection:**	**5**	**Segment:**	**8.9**	**Intersection:**	**3.4**
Pedestrians:	**16**	**Cyclists:**	**0**				

This 0.5-mile segment of Dickerson Pike, stretching from Hart Lane to Broadmoor Drive, is a dense commercial corridor. Retail lines both sides of the roadway, with high driveway density. Approximately 21,000 vehicles travel through per day. Large residential areas exist nearby, particularly with several multi-family housing complexes towards the south end of the segment. WeGo Route 23 provides transit service along the route, with 9 stops within this half of a mile. Maplewood Comprehensive High School is less than a half-mile east from the north terminus.

Segment:	Parkway (US-441)					Gatlinburg	
Total Crashes:	**23**			**Expected Crashes:**	**15.2**		
Segment:	**11**	**Intersection:**	**12**	**Segment:**	**9.3**	**Intersection:**	**5.9**
Pedestrians:	**23**	**Cyclists:**	**0**				

The Parkway through Gatlinburg is a heavily trafficked, 2-lane tourist corridor, with an average daily volume of approximately 11,000 vehicles. It is classified as a rural minor arterial. Retail, dining, and entertainment exist along both sides of the entire stretch of this 0.75-mile road segment. The Gatlinburg Trolley provides transit service. The speed limit in this area is 25 miles per hour.

Segment:	Nolensville Pike (SR-11)					Nashville	
Total Crashes:	**31**			**Expected Crashes:**	**25.0**		
Segment:	**19**	**Intersection:**	**12**	**Segment:**	**16.0**	**Intersection:**	**9.0**
Pedestrians:	**28**	**Cyclists:**	**3**				
This one-mile segment is an urban, 5-lane arterial with a center turn lane. It has buffered bike lanes and sidewalks along both sides. The land use in the immediate area is dense commercial, with residential adjacent, and several multi-family living complexes within a quarter mile. TriStar Southern Hills Medical Center is on the east side of the south terminus. The Nashville Zoo and several middle and high schools also exist within one mile. Transit stops exist along the route, which carries 42,000 vehicles per day, and has a speed limit of 40 miles per hour.							

Multimodal Priority Tool 2.0

The Tennessee VRU Safety Assessment has resulted in an expected VRU crash screening tool designed to facilitate a deep dive into the characteristics of high-risk areas. This tool, rooted in the predictive model, offers a comprehensive look at Tennessee's transportation infrastructure and land use to determine systemically what each road segment and intersection should expect for VRU crashes. TDOT can harness the capabilities of this screening tool to pinpoint areas where VRUs are most at risk.

By incorporating the insights, the screening tool provides into the newest version of the Multimodal Priority Tool, TDOT can systematically add another layer of data to identify VRU areas of concern. TDOT uses the Mobility Priority Tool to identify the most dangerous locations for each round of PSRI projects, then begins conversations with local partners to select project sites.

Consultation

Stakeholder engagement is a critical component of any VRU Safety Assessment, as it brings together diverse perspectives to inform and enrich the program's overall effectiveness. The input and insights from community members, local and regional agencies, transportation planners, and VRU advocacy groups provide a comprehensive view of the unique challenges and opportunities that exist within an area. This collaborative approach ensures that the assessment is not a top-down exercise but is rooted in the real-world experiences and needs of those it seeks to protect.

Engaging stakeholders allows for identifying locally relevant risk factors, evaluating current measures, and formulating practical, community-endorsed strategies. The collaborative process facilitates buy-in, increases the likelihood of successful implementation, and enhances accountability among the parties involved. Furthermore, stakeholder participation helps to ensure that the Safe System Approach is tailored to community-specific conditions and is equitable, addressing the needs of underserved communities and ensuring that all road users can benefit from improved safety measures.

TDOT’s approach to stakeholder engagement ensured the VRU Safety Assessment contained essential local context and broad-based support, making it more robust, actionable, and likely to achieve its goal of reducing VRU fatalities and injuries.

Before the VRU Safety Assessment started, a 15-month stakeholder engagement period was completed for the SATP. During this time, TDOT attended MPO & RPO Board Meetings, actively participated in safety performance target setting, and hosted monthly MPO and RPO calls with coordinators covering various topics, including safety topics. This engagement built a strong foundation allowing the VRU Safety Assessment to move forward in a more focused manner. The following sections describe the consultation objectives, methods, and findings.

Objectives of VRU Assessment Stakeholder Consultation

1. Inclusive Participation: Ensure stakeholders from various sectors, including local and regional transportation agencies and VRU advocacy groups, are actively involved.
2. Information Gathering: Use stakeholder input to identify problem areas, vulnerable populations, high-risk behaviors, and existing infrastructure issues contributing to VRU incidents.
3. Solution Ideation: Facilitate discussions to generate viable safety countermeasures and strategies tailored to local conditions.

Stakeholder Organizations Involved

- Bike Walk Tennessee
- Bike Walk Knoxville
- Chattanooga-Hamilton County RPA
- City of Chattanooga
- Chattanooga TPO
- City of Knoxville
- City of Memphis
- Clarksville MPO
- Greater Nashville Regional Council
- Johnson City MTPO
- Kingsport Area Transit Service
- Kingsport MTPO
- Knoxville TPO
- Lakeway Area MTPO
- Memphis MPO
- Metro Nashville-Davidson County
- Nashville DOT

Methods of Engagement

Survey

An online survey was utilized to gather input from key stakeholder groups such as MPOs, advocacy groups, and local municipalities. TDOT invited stakeholders to participate in the survey on October 6, 2023, and asked respondents to complete it by October 20, 2023. Respondents were asked to provide feedback on a variety of topics related to VRU crashes, safety, and trends within their local communities. The survey also explored methods by which local jurisdictions are addressing VRUs, such as safety measures, planning efforts, and educational strategies. The full survey and results are included in the Appendix.

A total of 12 stakeholders representing seven geographic areas within Tennessee responded to the survey. Figure 50 contains the responses from the stakeholders on their communities' major contributing factors for VRU crashes. Distraction was the number one response, with the following tie for the second highest responses: driver compliance, lack of non-motorized facilities, and motorist speeding.

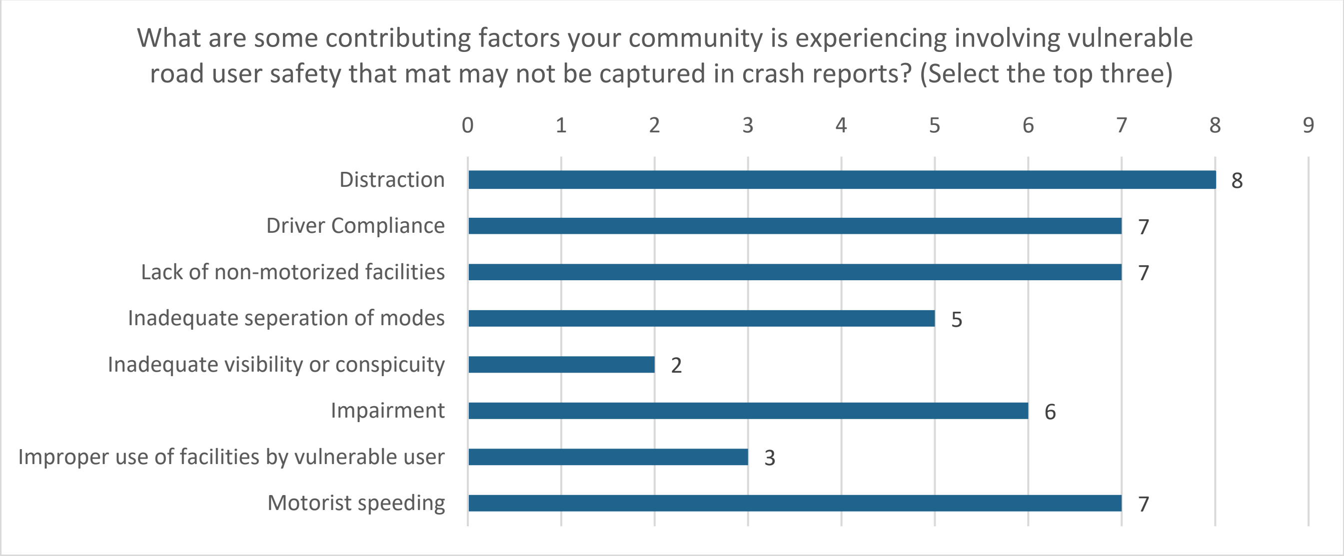

Figure 50 - Question and Responses from VRU Safety Survey Sent to Stakeholders

To better understand the age and availability of each community's Local Safety Plans, the stakeholders were asked for the status of their plans, the age, and a hyperlink to each plan. Table 10 contains the number of stakeholders that responded to whether their community has a completed plan and the age of the most recent plan. One item discovered is several participating jurisdictions have prepared or are preparing Vision Zero Implementation Plans that involve extensive outreach to disadvantaged communities. Overall, reviewing these Local Safety Plans allowed the VRU Assessment to identify countermeasures and strategies that are based on local needs and applicable to their current plans.

Table 10 - Tally of Stakeholder Responses for Local Safety Plan Completion and Age

Local Safety Plans	2018 or before	2019	2020	2021	2022	2023	Underway
ADA Transition Plan	4	5	2	2	-	-	1
Bicycle & Pedestrian Plan	7	1	2	-	1	-	-
Local Road Safety Plan	1	-	-	-	2	1	1
Safe Routes to School	6	-	-	-	-	-	1
Vision Zero	-	-	-	-	1	2	2
Walkable Community Plan	1	-	2	-	-	-	1

The stakeholders were also asked what VRU safety measures have been recently added to corridor and intersection/midblock crossing projects. Table 11 contains the response tally for what countermeasures have been recently deployed. This feedback aided in the development of the assessment's proposed countermeasures.

Table 11 - Tally Stakeholder Responses for Recently Deployed Countermeasures

Countermeasures Along Corridors	Survey Responses
Shared use path	11
Standard bicycle lanes	10
Walkways	9
Separated or protected bicycle lanes	8
Midblock medians	8
Buffered bicycle lanes	7
Other bicycle lanes or advisory shoulders	7
Pedestrian-scale lighting	6
Speed cushings	5
Speed tables	5
Lower speed limits	4
Traffic calming chicanes	4
Quick build solutions	1

Countermeasures At Crossing	Survey Responses
High visibility crosswalk markings	11
Median and pedestrian refuge island	9
Roundabouts	8
Curb extensions	7
Rectangular rapid flashing beacons	7
No right on red in pedestrian areas	6
Leading pedestrian intervals	5
Bike boxes	4
Pedestrian Hybrid beacons (HAWKS)	4
Raised crosswalks	4
Tighter curb radii at corners	3
Raised intersections	2
Bicycle signals	2
Two-stage turn queue bicycle boxes	1
Easements and landscaping	1
Quick build solutions	1

Workshop

The workshop included an overview of the VRU assessment, its purpose, methodology, initial findings, and potential safety countermeasures. During the workshop, participants discussed their observations about VRU safety, locally used safety countermeasures, and TDOT's ongoing Pedestrian Road Safety Initiative (PRSI). The complete presentation and minutes are included in the Appendix.

Twenty-four attended the workshop, including sixteen stakeholders from local governments, public agencies, and community organizations. All were active in the planned workshop discussion and gave valuable feedback on what each community was experiencing concerning VRU safety.

High-Risk Network

The six local governments with the highest VRU crash risk were invited to the Workshop to discuss the High-Risk Network in their communities. The top six include Nashville, Memphis, Chattanooga, Knoxville, Murfreesboro, and Clarksville. Based on the reported crash data, the stakeholders all supported the highlighted roadway segments as their highest areas of concern.

A discussion was also held on what each stakeholder identified as risk factors in their communities; some identified include the built environment, proximity to transit and schools, proximity to vulnerable populations, congestion, 4-5-lane roadways, and sparse traffic signals.

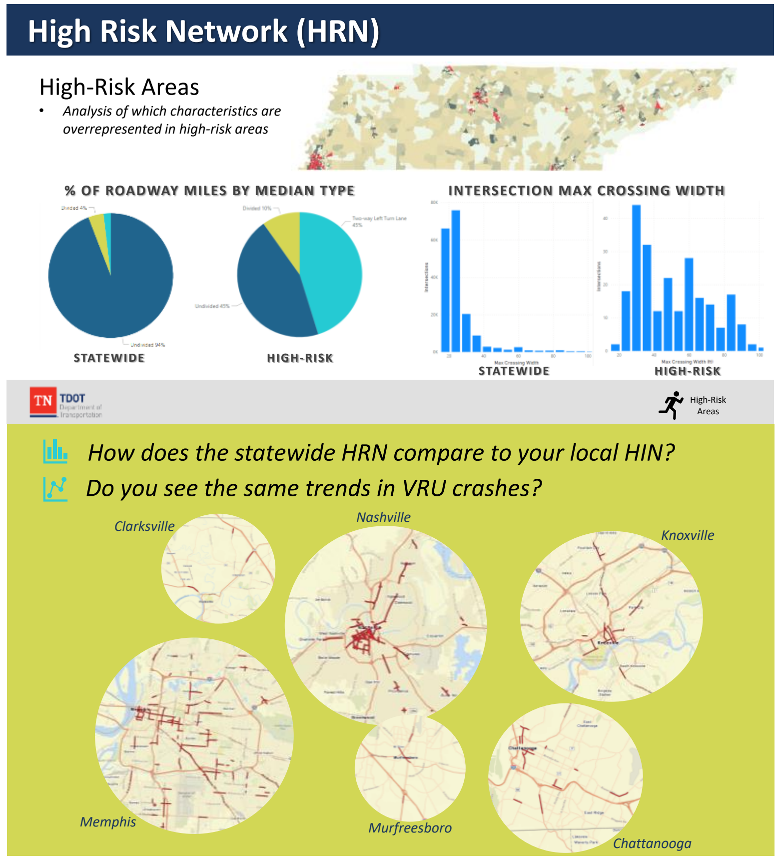

Figure 51 - VRU Workshop Presentation Slides on the High-Risk Network

The survey and workshop feedback are summarized in the following sections.

Safety Concerns

Insights gained from the stakeholder consultation process include the following:

- Speed reduction was identified as a significant factor in improving VRU safety in both the workshop and survey. Respondents noted that countermeasures to reduce speed are needed as an alternative to lower posted speed limits.
- Distracted drivers, lack of driver compliance, and the lack of non-motorized facilities were ranked as other top contributing factors to VRU safety, which crash reports may not adequately reflect.
- Both the workshop and survey indicated that there is a desire for increased coordination with TDOT on project selection for the Pedestrian Road Safety Initiative (PRSI) projects.
- Standard bicycle lanes, shared-use paths, and walkways were the major VRU safety measures added to recent corridor projects.
- Recent intersection or mid-block projects at the local level included high visibility crosswalk markings, median and pedestrian refuges, and roundabouts.
- Community support was identified as lacking for standard bicycle lanes and lower speed limits.

- A wide range of intersection safety measures was indicated as lacking community support, such as raised crosswalks, roundabouts, prohibiting right-on-red turns, bicycle boxes, and tighter curb radii.

Challenges and Limitations

- Available right-of-way is a significant challenge in retrofitting an area for VRU safety. Along fully developed streets, acquiring additional right-of-way for VRU facilities, such as sidewalks or other safety countermeasures, can be costly and disrupt established land uses.
- Multiple survey respondents mentioned funding for VRU safety improvements as a hurdle to project implementation, particularly funding at a level that has a substantial impact.
- The lack of reliable pedestrian volume data and land use data presents challenges in assessing needs on a scale to identify precise areas for targeted improvements.
- Public opinion regarding the implementation of VRU safety measures is mixed. Most street users are traveling in private motor vehicles, and any perceived disruption is usually met with resistance.
- Workshop participants were skeptical about TDOT’s willingness to use traffic calming measures to reduce travel speed in order to decrease VRU crashes.

Potential Solutions

- Hold future stakeholder meetings/workshops to address the specific challenges identified, including assisting local municipalities with using a standard methodology for analyzing VRU risk.
- More investigation of the VRU population to refine the understanding of the common demographic factors and built environments associated with those involved in a VRU crash. Direct sampling and quantitative analysis of those involved in VRU crashes, including the vehicular drivers, can provide greater insight into the factors involved in VRU safety.
- When gauging public support for safety countermeasures, ensure the preferences of VRUs are considered.
- Low-cost pilot projects to improve VRU safety, such as temporary barriers for new or widened walking paths, can be implemented in the area for a given amount of time. Analysis of their effectiveness by drivers and VRUs should be made with successful projects being scaled up to permanent improvements.
- Continued education on VRU safety and the benefits of multimodal transportation can help ease resistance to safety countermeasures. Dense areas with notable volumes of VRU traffic can be designated as awareness areas through signage and a public information campaign.
- Data collection and analysis are not a substitute for local observation. Agencies responsible for VRU safety should observe and note areas where VRUs struggle and identify interventions to address those struggles, even if initial measures are modest. Small local measures can have a large impact on vulnerable populations.

The stakeholder engagement process in has proven to be a pivotal component, enriching the assessment's effectiveness and ensuring that it is deeply rooted in real-world experiences and community needs. This inclusive approach has facilitated the identification of locally relevant risk factors, assessment of existing measures, and the formulation of practical, community-endorsed strategies. Importantly, it has promoted buy-in, increased the likelihood of successful implementation, and enhanced accountability among all parties involved. Furthermore, this stakeholder engagement has enabled the Safe System Approach to be tailored to the specific conditions of the community, ensuring equity and addressing the needs of underserved populations.

VRU Safety Priority Areas and Strategies

Priority areas form the cornerstone of this report, derived from the analysis of VRU safety data in conjunction with invaluable stakeholder feedback. Five distinct categories emerged as critical avenues to direct project and program prioritization:

VRU Crossing Safety

This area prioritizes designing infrastructure that ensures that VRUs can cross roadways safely, employing specific countermeasures to minimize potential hazards.

Safe and Accessible Roadways

Priority is placed on making roads more navigable and secure for VRUs. Design modifications and countermeasures in this area are pivotal in creating an inclusive transportation environment.

Vehicle Speed Reduction

As the title suggests, this category is geared towards design improvements that reduce average vehicle speeds, a prime factor in VRU-involved crashes. Targeted countermeasures in this area directly address the dangers posed by high-speed vehicular traffic.

VRU Daily Needs

This priority area holistically addresses the daily requirements of VRUs. While the first three categories lean heavily on design improvements and countermeasures, this section prioritizes the actual day-to-day needs and experiences of VRUs, ensuring that infrastructure and policies align with their genuine requirements.

System Longevity

The future is constantly in flux, and this priority area is all about preparedness. It concentrates on ensuring the sustainability and long-term viability of TDOT's VRU safety initiatives. This encompasses continuous data analysis, the incorporation of emerging technologies, and anticipating the evolution of VRU needs and challenges.

Reflecting TDOT's commitment to improving road safety for VRUs, the priority areas have been selected as components of an overall Safe System Approach recommended by FHWA. This approach ensures that the strategies chosen to form a holistic approach to VRU safety, addressing both the likelihood of human error and the design characteristics of the road environment that influence human behavior. While these priority areas remain adaptive to emerging VRU challenges, they provide a sturdy framework for implementing meaningful safety enhancements. The Program of Strategies proposed in this report for each priority area reflects Safe System principles, thereby promising a comprehensive and forward-thinking approach to VRU safety.

Program of Strategies

Tennessee's VRU Safety Assessment is strengthened by a program designed to tackle and anticipate the challenges faced by VRUs directly. Recognizing that a one-size-fits-all methodology is insufficient, a multi-layered program of strategies was crafted to address the challenges of VRU safety. These strategies delve into three critical dimensions: VRU safety improvements and projects, the daily needs of the VRU, and program development and growth.

VRU safety improvements and projects form the strategy's backbone by being the primary focus of the first three strategies. The overall improvement and project focus are broken down into the first three priority areas, ensuring roads and pathways are constructed with the safety of all users in mind.

However, the physical infrastructure is just the first part of the equation. Addressing user behavior is vital, as it plays an instrumental role in preventing VRU crashes and mishaps. By adhering to the principles of the Safe System Approach, the Program of Strategies aims not just to react to incidents but to proactively strive for an environment where fatalities and serious injuries are eliminated. It is a vision where the system, including infrastructure and user behavior, inherently prioritizes safety.

Lastly, how projects are developed and implemented sets the stage for long-term, sustainable safety solutions. It is important to actively seek input through stakeholder consultations to ensure these strategies resonate on the ground and are effective in real-world scenarios. These dialogues provided invaluable insights, allowing for tailored strategies to meet community-specific needs. Additionally, TDOT ensures a comprehensive and cohesive approach by anchoring the strategy development on established priority areas and recommended countermeasures. In essence, TDOT's Strategy Development is a synergistic blend of expert insights, community feedback, and best practice recommendations, converging towards a singular goal: a safer Tennessee.

The following summarizes strategies that correspond with the above priority areas:

- Strategy 1 – Prioritize VRU Roadway Crossings
- Strategy 2 – Implement Corridor Improvements Along Prioritized VRU Segments
- Strategy 3 – Manage Vehicle Speeds in Locations with High VRU Activity
- Strategy 4 – Support Safety Improvements to Address VRU Behaviors
- Strategy 5 - Commit to the Continuous Evaluation and Evolution of VRU Projects

Strategies and Actions

Strategies and actions organize the Program of Strategies. Strategies represent the broad approaches TDOT will undertake to further the objectives and goals of the VRU Safety Assessment. They are the overarching guiding principles that inform the direction and priorities in this essential mission. These strategies are not merely abstract ideas; they have been conceived to ensure that the Safety Assessment's objectives are met and exceeded.

Complementing these strategies are Actions. Actions describe the specific means, methods, and mechanisms through which each strategy will be realized on the ground. These are the tangible steps TDOT will take to transform the strategic vision into actual, on-the-ground impact.

The Program of Strategies is summarized below in Tables 13-17. Each table contains the following explanatory material:

- **Stage** represents a broad categorization of the present phase of each action:
  - Future- slated for upcoming implementation
  - Planning- blueprinting and goal setting for the action
  - Active- active execution of the action
  - Ongoing- continuous maintenance or improvement
- **SSA Elements**:
  1. Safe Road Users
  2. Safe Vehicles
  3. Safe Speeds
  4. Safe Roads
  5. Post-Crash Care
- **Related Plan Action**:
  - SHSP actions are in reference to the *Vulnerable Road Users Emphasis Area* in the 2020-2024 plan. [18]
  - SATP actions are in reference to the *Implementation Plan* found at the end of Technical Memorandum #3 of the 2021 plan.[19]

Each strategy's table is segmented into columns that detail the *Action*, the current *Stag*e of that action, the related *Safe System Approach (SSA) Elements*, and the *Related Plan Actions* from both the Strategic Highway Safety Plan (SHSP) and the Statewide Active Transportation Plan (SATP) plans. This organized structure ensures that every stakeholder can easily comprehend and trace the flow from strategy to specific action. Moreover, aligning the program actions with those in the SHSP and SATP plans further reinforces the approach's unity of purpose and cohesion, ensuring that our efforts harmonize with established road safety priorities.

PRIORITY AREA 1 - VRU Crossing Safety

VRU CROSSING SAFETY SUBAREAS

- Midblock Crossings
- Intersection Crossing
- Lighting and Crossing Placement
- Signal Phases and Timing

In Tennessee, every intersection is a legal crosswalk (TCA § 55-8-101); as such, pedestrians are legally permitted to cross any street at any intersection whether the crossing is marked or not, and motorists are required to yield. Pedestrians are not required to use a crosswalk (unless they are between adjacent signalized intersections or local ordinances have restricted their crossing), and they must yield to vehicles on the roadway before doing so.

[18] TDOT, Tennessee Strategic Highway Safety Plan (SHSP), 2020, https://www.tn.gov/content/dam/tn/tdot/strategic/SHSP-2020.pdf

[19] TDOT, Tennessee Statewide Active Transportation Plan (SATP), 2021, https://www.tn.gov/content/dam/tn/tdot/multimodaltransportation/TDOT_SATP_Plan%20Document_Final_2021_07_23.pdf *(Technical Memorandum is available on request.)*

Midblock Crossings

One of the primary concerns for pedestrian safety is crossing roadways, especially at locations that are not governed by traffic signals or other controls. At the forefront of addressing these concerns is the implementation of marked crosswalks at midblock locations.

High-visibility, continental marked crosswalks serve as a key countermeasure for uncontrolled crossing locations in areas where adjacent land uses generate pedestrian traffic. The main purpose of midblock crossings, as described by the Manual on Uniform Traffic Control Devices (MUTCD), is to establish pedestrian crossings at locations other than intersections legally. Continental crosswalks are sufficient countermeasures until motor vehicle speeds rise above 30 MPH, there is more than one lane in a single direction, or the AADT volume is above 9,000.

Image 2 - Memphis, TN Midblock Crossing with Continental Crosswalks, Rectangular Rapid Flashing Beacon, Pedestrian Refuge and In-Street Sign

A marked crosswalk is typically paired with other evidence-based safety strategies to optimize its effectiveness, including *crosswalk lighting, in-street pedestrian signage, advance yield/stop markings, curb extensions and parking restrictions*. Uncontrolled multi-lane crossings generally have higher speeds and a greater number of people driving, walking, and biking. These crossings require extra elements to foster pedestrian safety, such as *raised crosswalks, pedestrian refuge islands, rectangular rapid flashing beacons (RRFB), and Pedestrian Hybrid Beacons (PHB).*

CONTINENTAL CROSSWALKS COMPLEMENTARY COUNTERMEASURES

- PHB or RRFB (uncontrolled only)
- Advance STOP or YIELD sign and pavement striping
- Pedestrian Refuge Island
- Curb Ramp Extensions
- Raised Crosswalk
- In-street Pedestrian Crossing Sign
- ADA Compliant Curb Ramps
- Lighting
- No parking within 25 feet of the crosswalk

Table 12 provides design guidance for crosswalk countermeasures by road type, vehicle AADT, and posted speed limit. All existing marked crossings should breviewed to identify if current guidelines are not met. An engineer should review all crossing locations and designs to ensure that recommended treatment is appropriate and that ramps are Americans with Disabilities Act (ADA)-compliant.

Table 12 - Crosswalk Countermeasure Candidates by Roadway Features[20]

ROADWAY CONFIGURATION	VEHICLE AADT and POSTED SPEED LIMIT								
	Vehicle AADT < 9,000			9,000 < AADT < 15,000			Vehicle AADT > 15,000		
	≤ 30 MPH	35 MPH	40 + MPH	≤ 30 MPH	35 MPH	40 + MPH	≤ 30 MPH	35 MPH	40 + MPH
2 LANES	⚫	⚫	🟡🟠	⚫	🔵	🟡🟠	⚫	🟡	🟠
3 LANES WITH RAISED MEDIAN	⚫	🔵	🟡🟠	⚫	🔵	🟡🟠	⚫	🟡🟠	🟠
3 LANES W/O RAISED MEDIAN	⚫	🔵	🟠	🔵	🟡🟠	🟠	🟡	🟠	🟠
4+ LANES WITH RAISED MEDIAN	🔵	🔵	🟠	🔵🟡	🟡🟠	🟠	🟡🟠	🟠	🟠
4+ LANES W/O RAISED MEDIAN	🔵	🔵🟡	🟠	🔵🟡	🟡🟠	🟠	🟡🟠	🟠	🟠

⚫ Marked Crosswalk and possible advance warning sign/striping
🔵 Marked Crosswalk and advanced warning sign/striping with possible pedestrian refuge island or curb extension
🟡 Marked Crosswalks with advance warning signs/striping and Rectangular Rapid-Flashing Beacons (RRFB)
🟠 Marked Crosswalk and Pedestrian Hybrid Beacon (PHB) with possible pedestrian refuge island or curb extension

Intersection Crossings

To optimize safety at controlled intersections, it is imperative to integrate design and operational countermeasures that address the challenges faced by VRUs. As seen in Figure 16, signal-controlled intersections have the highest average crash rates, followed by roundabouts, then all-way stops. Other intersection types (e.g., partial stop, yield, and uncontrolled) have relatively low crash rates. The following infrastructure improvement countermeasures are proven to reduce VRU crossing crashes at intersections:

Image 3 - Nashville Youth Design Team installing bulb-outs to shorten crossing distances on Dickerson Pike, Nashville[21]

Accessible Pedestrian Signals (APS) at traffic lights are required by ADA and are crucial for fostering inclusivity and equity in urban settings. Designed with tactile, visual, and auditory cues, they aid individuals with sensory impairments in safely crossing intersections. By reducing ambiguities and potential conflicts between pedestrians and vehicles, APSs decrease pedestrian-related crashes by helping navigate city streets safely and confidently.

Green pavements in bike lanes at urban intersections enhance safety by providing clear demarcation for cyclists' spaces. This vibrant color serves as a visual alert for motorists, indicating areas where

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[20] Table was developed by using information from FHWA. Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE). http://www.pedbikesafe.org/PEDSAFE/; FHWA. *Manual on Uniform Traffic Control Devices*. 2009 Edition. (Revised 2012); FHWA. Crash Modification Factors (CMF) Clearinghouse. http://www.cmfclearinghouse.org/ ; and FHWA. Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (dot.gov)
[21] Civic Design Center, *The Journey to Complete Streets on Dickerson*, https://www.civicdesigncenter.org/all-projects-blog/dickerson-complete-street-infrastructure

cyclists may be crossing or have designated lanes. By minimizing potential conflict points between vehicles and cyclists, green pavement improves visibility and conditions drivers to expect and respect cyclists. The outcome is a streamlined traffic flow, fewer collisions involving cyclists, and a safer environment for all road users.

Protected intersections, designed with unique infrastructure elements, prioritize safety for cyclists and pedestrians by physically separating them from vehicular movements. Features such as corner islands, forward queuing areas, and recessed crossings reduce turning speeds and enhance visibility, allowing motorists more time to yield. Implementing these intersections requires detailed design, including truck aprons to manage speeds and ADA-compliant APS for inclusivity. Clear right-of-way protocols at conflict points, alongside supplementary measures like "No Turn on Red" restrictions and parking limitations further safety goals, creating safer and more accessible urban spaces for all.

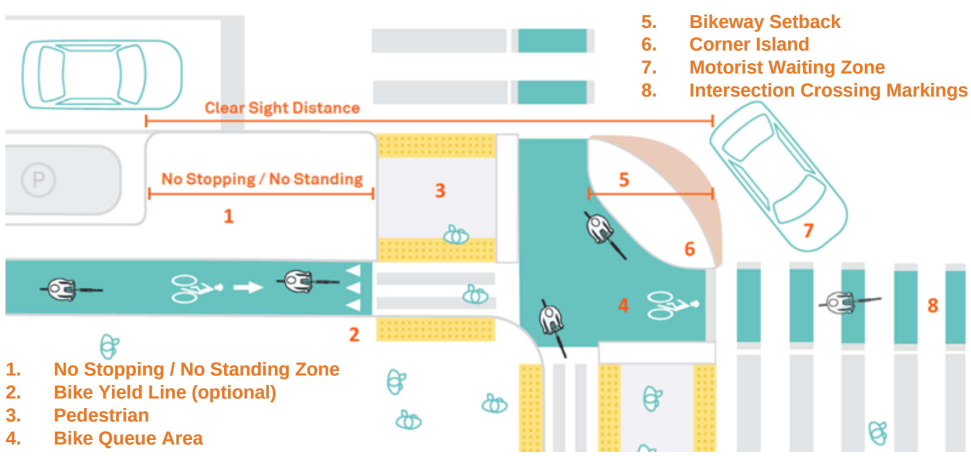

Image 4 - Protected Intersection Diagram from NACTO[22]

Transitioning from two-way or all-way stops to implementing **roundabouts** offers substantial benefits for VRUs. Roundabouts inherently promote reduced vehicle speeds due to their circular design, enhancing the safety of pedestrians and cyclists. Unlike traditional intersections, where multiple conflict points exist, roundabouts simplify these interactions by ensuring a consistent flow of traffic in one direction. This reduces the potential for severe T-bone and head-on collisions. Additionally, for pedestrians, crossing distances are typically shorter at roundabout approaches, and they only need to assess traffic from one direction at a time, further decreasing the risk of crashes. For cyclists, roundabouts can feature dedicated cycle lanes, ensuring they are safely segregated from motor vehicle traffic.[23] Overall, introducing roundabouts in place of traditional stop-controlled intersections prioritizes VRU safety by reducing conflict points, slowing down traffic, and providing clearer, more manageable crossing opportunities.

[22] National Association of City Transportation Officials (NACTO), Don't Give Up at the Intersection Guide, https://nacto.org/publication/dont-give-up-at-the-intersection/protected-intersections/
[23] TDOT, *Instructional Bulletin No. 22-10*, Section 10 – Roundabout Design, https://www.tn.gov/content/dam/tn/tdot/roadway-design/documents/instructional-bulletins/2022/IB_22_10.pdf

As illustrated in Figure 52, the incorporation of medians in intersection approaches leads to a notable decrease in the average VRU crashes per signalized intersection. This is particularly evident for intersections with crossing widths exceeding 60 feet. Medians, particularly raised ones, play a two-fold role. First, they act as physical barriers, compelling vehicular traffic to adhere to the designated paths and thus reducing potential conflict points with VRUs.

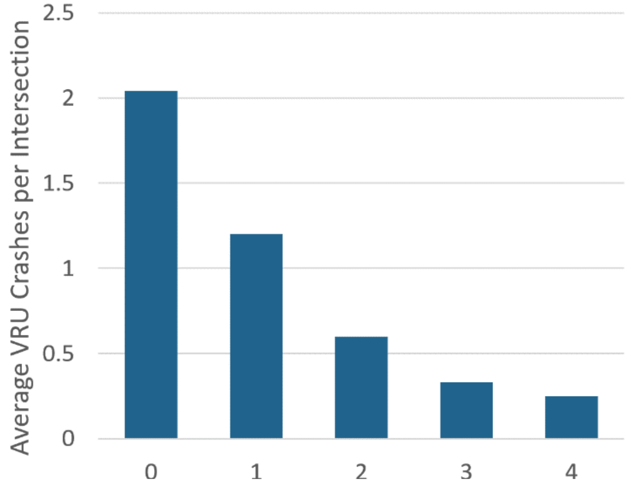

Figure 52 - Average VRU Crashes per Signalized Intersection with Crossing Width over 60 Feet by the number of Approaches with Median (2018-2022)

Moreover, for pedestrians, these raised medians provide a refuge, breaking their crossing into segments. This allows pedestrians to tackle one direction of traffic at a time, offering a pause, especially in wide intersections, reducing their exposure to potential crashes. The ability to stop and assess traffic halfway can be crucial for the elderly, children, or those with mobility challenges. As the data suggests, intersections that employ more approaches with medians experience fewer VRU crashes, emphasizing the importance of their widespread adoption in road safety design.

Lighting and Crossing Placement

Pedestrian Lighting serves as a critical countermeasure in ensuring the safety of VRUs at mid-block crossings, at intersections, and along roadway segments. Properly scaled illumination enhances visibility, enabling drivers to detect and recognize VRUs from a distance, especially during nighttime and low-light conditions. At mid-block crossings, where motorists might not always anticipate pedestrians, effective lighting is paramount to signal the possible presence of crossing pedestrians. Along the roadway, consistent and strategically placed lighting illuminates the path of cyclists and other VRUs, reducing the likelihood of side or rear-end collisions. The exact placement of lights is crucial, ensuring there are no blind spots or overly darkened areas, and consistent illumination helps in preventing sudden glare or sharp shadows that can be disorienting. By considering the positioning and illumination levels of lights, municipalities can significantly elevate the safety of VRUs, offering them a more secure and visible presence on the roads.

Determining the optimal placement and intensity of lighting ensures not only the safety but also the aesthetic and functional aspects of a location. The VRU activity level in a particular area often dictates the required level of illumination. In bustling downtown areas, where pedestrian and vehicular activity peaks during nighttime hours, higher levels of illuminance are essential to guarantee visibility and safety.

Conversely, in serene residential areas or parks, where the level of activity is comparatively lower during nighttime, lighting can be more subdued, focusing on ambiance while still ensuring safety. The main objective is to provide adequate lighting for residents or visitors without causing light pollution or disturbances. Transit zones, such as bus stops or train stations, require moderate to high illuminance, providing safety and visibility for passengers during their commutes, especially during early morning or late evening hours.

School zones and educational institutions necessitate tailored lighting solutions, with brighter lights during early morning or late afternoon hours when students are most likely to commute. In contrast, rural areas, often characterized by sparse activity, require lower average illuminance strategically placed at intersections, crucial landmarks, or points of interest. The placement and intensity of lighting must be judiciously determined based on the level of activity and the specific requirements of each zone, ensuring a harmonious blend of safety, functionality, and aesthetics.

Midblock Crossing Placement

Determining the optimal placement of crossings is vital for ensuring the transportation network's safety and efficiency.[24] Depending on their primary function and type of VRU activity, the following different areas necessitate varying crossing spacing considerations.

- **Transit-heavy areas** crossing should be in proximity to bus stops or stations, catering to the influx of passengers moving between transit points and their destinations.
- **Parking zones**, particularly in urban settings, require crossings near entrances or exits to provide safe pathways for drivers transitioning to pedestrians.
- **School zones** are another critical area; crossings must be strategically placed to provide students the shortest and safest paths, often involving additional signage or signals.
- **Downtown regions**, frequent crossings cater to the high pedestrian volumes, ensuring fluid movement without compromising safety.
- **Rural areas**, characterized by longer distances and lower pedestrian volumes, may require less frequent but strategically placed crossings, especially near any local amenities or junctions.
- **Urban regions**, dense with both vehicular and pedestrian traffic, demand a fine-tuned balance to accommodate the needs of VRUs.

The spacing of crossings must be tailored to each area's unique characteristics and needs, reflecting the dynamics of VRU activity and vehicular activity. and ensuring safety for all.

Traffic Signal Phasing and Timing

The VRU Safety Assessment found that approximately 23% of crashes involving VRU occur at signalized intersections, representing roughly half of all intersection-related VRU crashes. Analysis of driver's pre-crash action indicates that 6% of crashes at signalized intersections involve drivers making an unsafe right turn and 14% making an unsafe left turn. Altogether, 41% of all VRU crashes at signalized intersections involve turning vehicles. Protecting crossing VRUs from automobile turning phases can help decrease these right and left turn conflicts.

Effective countermeasures at signalized intersections can significantly enhance VRUs safety by organizing their movements distinctly from vehicle turning movements. The aim is to reduce potential conflict points and enhance predictability for all road users. Below is an overview of potential signal phasing and timing countermeasures for vehicle turning movements:

- **Protected Left Turns** - vehicles intending to turn left are given a dedicated green left-turn signal. During this phase, pedestrians are not allowed to cross, eliminating conflict between left-turning vehicles and crossing pedestrians. If space constraints do not allow for a dedicated left-turn pocket, prohibiting left turns might be a feasible solution.

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[24] NCHRP 17-115 (Pending), *Guide for Marked Crosswalk Design, Spacing, Placement, and Safety*, https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5344

- **Protected Right Turns** - vehicles are restricted from making a right turn during the pedestrian phase. Instead, a dedicated right-turn signal is given, during which pedestrians are held from crossing. Supplementing this with a “NO TURN ON RED” sign further ensures crossing pedestrians' safety by eliminating ambiguity.
- **All Pedestrian Phases** - This measure halts all vehicular movement, granting pedestrians an exclusive phase to cross the intersection in any desired direction, including diagonally. By allowing pedestrians to occupy the intersection without any vehicular interference, their safety and visibility are heightened.
- **Leading Pedestrian & Bike Interval** –
  - Leading pedestrian Intervals allow pedestrians to receive a head-start of 3-10 seconds when entering the intersection before vehicle traffic can move. This advance time ensures that pedestrians establish their presence within the crosswalk, making them more noticeable to turning vehicles.
  - Leading bike intervals (LBI) can accompany the LPI. Bike signal heads may provide LBIs; bike-symbol signals are considered experimental under MUTCD Interim Approval 16.22.

STRATEGY 1 - Prioritize VRU Roadway Crossings

This strategy supports the overarching need to assess the most dangerous path of VRUs and focus on safety, comfort, and increasing the number of VRU crossing locations. The safety assessment revealed 92% of all VRU crashes and 87% of all severe crashes occur in urban locations. Within these urban settings, crashes are evenly distributed between intersections and roadway segments; however, regarding severe incidents, 53% happen on urban segments and 34% at urban intersections. This indicates a heightened risk associated with urban roadway segments and a need to target midblock crossings.

Table 13 - Index of Strategy 1 Actions

ACTION	STAGE	SSA ELEMENT	RELATED PLAN ACTION
1.1 Continually expand and target safety improvements at midblock and controlled crossings prioritized in the VRU Safety Screening Tool.	Planning	Safe Roads	SHSP- 1.1, 1.4 SATP- A.1.1, A.1.2
1.2 Plan placement of crossings and lighting to ensure safety and comfort for VRUs.	Future	Safe Roads	
1.3 Explore a quick-build program pilot to separate VRU crossing paths from vehicle turning paths through the phase and timing of traffic signals.	Planning	Safe Roads	SATP- A.1.3, A.2.2

PRIORITY AREA 2 - Safe and Accessible Roadways

SAFE & ACCESSIBLE ROADWAYS SUBAREAS

- Urban Areas
- Rural Areas
- Corridor-Wide Roadway Improvements

As Tennessee grows and transportation demand shifts, there is a pressing need to revisit, reimagine, and revamp the roadway infrastructure. This section provides comprehensive strategies for urban and rural settings. From dedicated bike lanes to strategic road diets, it is important to explore context-appropriate countermeasures that enhance safety and foster a more inclusive and sustainable mobility landscape.

The dichotomy between rural and urban environments presents distinct transportation challenges and necessitates tailored solutions. Urban areas, with their dense populations, often grapple with heavy traffic congestion, a myriad of transportation modes, and the need for efficient pedestrian and bicycle systems. Their infrastructural planning must accommodate high volumes of VRUs and seamlessly integrate various mobility forms. Conversely, rural regions, characterized by vast landscapes and scattered populations, face challenges like longer travel distances and limited public transportation options. Here, the focus might lean towards enhancing connectivity, ensuring road safety in areas with higher speed limits, and providing safe pathways for the occasional pedestrian or cyclist. Recognizing and addressing these unique demands is crucial. A one-size-fits-all approach risks overlooking specific local needs, underscoring the importance of a nuanced, location-specific strategy in transportation planning.

Urban Areas

Ensuring smooth pedestrian and cyclist mobility in urban landscapes hinges upon establishing comprehensive and connected infrastructures. A primary consideration is the strategic linking of sidewalks and bike lanes to areas of high activity. This not only includes commercial hubs, marketplaces, and recreational spots but also transit stops. Such connections streamline VRU flow, ensuring that individuals can transition seamlessly from walking or biking to public transport, promoting sustainable transportation modes.

Connected sidewalks stand as the pillar of urban pedestrian mobility. Beyond the evident provision of an all-weather surface, sidewalks establish a clear separation between vehicular and pedestrian realms, significantly enhancing safety. Their presence ensures that pedestrians are not relegated to dangerous alternatives such as walking on roads or shoulders — a situation responsible for a substantial number of "walking along roadway" crashes. In fact, introducing dedicated walkways separated from travel lanes could mitigate up to 88% of these incidents.[25]

Further accentuating sidewalk needs is the application of functional road classifications. On arterials and major collectors — roads with significant traffic volumes — it is standard practice to provide sidewalks on both sides of the roadway unless there are physical limitations. This dual placement accounts for varying pedestrian origins and destinations, ensuring comprehensive accessibility on minor collectors and local streets. Sidewalks on both sides of the roadway are still appropriate, with exceptions for specific scenarios like short dead-end streets with

[25] U.S. Department of Transportation, Federal Highway Administration, *An Analysis of Factors Contributing to "Walking Along Roadway" Crashes: Research Study and Guidelines for Sidewalks and Walkways*, FHWA-RD-01-101 (Washington D.C., 2001).

limited residential prospects or access points. In their universality and design, sidewalks reflect the essence of urban planning — prioritizing safety, inclusivity, and seamless mobility.

In locations with motor vehicle traffic exceeding 6,000 vehicles per day and speeds surpassing 25 mph, **protected bike lanes** emerge as a highly beneficial solution.[26] They are often hailed as the pinnacle of bicycle infrastructure; protected bike lanes offer a robust buffer between cyclists and the moving vehicular traffic. This buffer materializes through physical barriers such as raised curbs, bollards, or strategically positioned parking lanes. The benefits of these lanes are multifaceted: they reduce injury rates by keeping bikes and vehicles separate and stimulate an uptick in the number of people choosing bicycles over cars, thereby fostering a more sustainable transportation ecosystem.

When considering protected bike lanes, addressing and preempting potential safety concerns is essential. Despite the undeniable advantages of protected lanes, intersections remain a hotspot for potential collisions between cyclists and motorists. The design of these lanes often means that cyclists are not within the immediate line of sight of turning vehicles, leading to an increased risk at intersections. Hence, while protected bike lanes minimize the usual threats posed by vehicles overtaking cyclists on the road, comprehensive solutions must be devised to counteract the specific risks at intersections to maximize cyclist safety.[27]

Rural Areas

While scenic and less congested, rural roads often pose unique challenges to road safety due to their inherent design and the lack of investment in infrastructure for VRUs. To address the safety concerns, some possible countermeasures include implementing *rumble strips to alert inattentive drivers, paving road shoulders to offer a safe space for pedestrians and cyclists, installing appropriate signage to warn of upcoming intersections or pedestrian crossings, and incorporating traffic calming measures like speed humps or chicanes*. Together, these interventions can make rural roads safer and more connected for all users.

Adding **paved shoulders** to roadways in rural areas stands out as a significant safety enhancement, especially for cyclists. When these shoulders remain unpaved, they are prone to becoming uneven, especially after bouts of rain, resulting in muddy or impassable terrains that can endanger cyclists.

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[26] NACTO, *Choosing an All Ages & Abilities Bicycle Facility*, https://nacto.org/publication/urban-bikeway-design-guide/designing-ages-abilities-new/choosing-ages-abilities-bicycle-facility/

[27] Florida Department of Transportation, *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects* (Tallahassee, FL, 2005). http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SF/FDOT_BD015_04_rpt.pdf.

Figure 53 illustrates the correlation between a road segment's average shoulder width (in feet) and the average VRU crashes per mile along all road segments. Notably, there is a sharp decline in VRU crashes as the shoulder width increases, with 10 feet emerging as the optimum width for safety. This suggests that a 10-foot shoulder offers an ideal buffer space for cyclists or motorist exiting their vehicles, effectively reducing the risk of crashes. In contrast, segments with no shoulder pose the highest risk because VRUs, without a shoulder, must travel in the roadway, making them more susceptible to crashes. Interestingly, the trend begins to reverse after the 10-foot mark, seeing a gradual rise in collisions. One plausible explanation could be that larger shoulder widths might induce a false sense of security among road users, especially those exiting vehicles, reducing vigilance and increasing the risk of crashes.

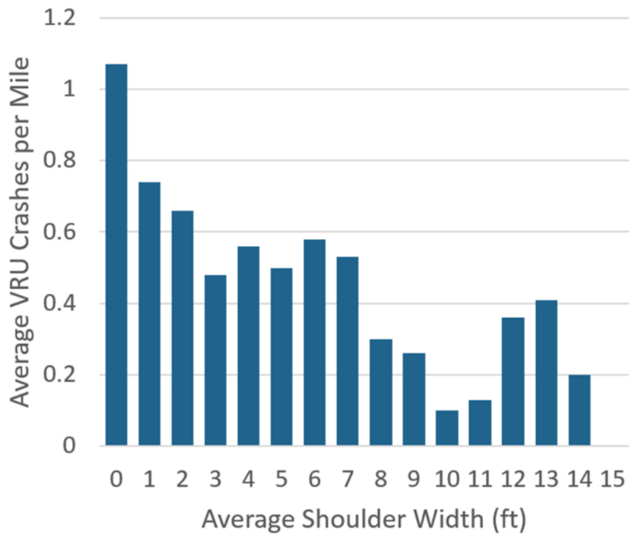

Figure 53 - Average VRU Crashes per Mile by Average Segment Shoulder Width on roadways between 10,000 and 30,000 AADT (2018-2022)

A paved shoulder reduces the risk of VRU-involved crashes. An evident advantage is the 71 % reduction seen in "walking along roadway" crashes.[28] The unpredictability of unpaved shoulders is a key contributor to crashes. Paved shoulders can dramatically reduce such incidents by offering a consistent and stable surface. This stability is especially crucial for cyclists, who often must navigate the challenges of loose gravel, ruts, or mud on unpaved shoulders. A paved surface provides cyclists with a smoother riding experience and a more predictable one, free from these hazards.

For motorists, these paved shoulders enhance road safety as well. They provide a reliable space for emergency stops or pull-overs, a necessity for mechanical failures or other unforeseen circumstances. Additionally, from a maintenance perspective, paved shoulders are more resilient. They simplify operations like debris clearance and, in winter, provide a more effective space for snow storage. However, while the benefits are clear, there are challenges, particularly in rural settings. The acquisition of the required right-of-way for expansion or paving might pose logistical issues. Furthermore, the design of the cross-slope, the gradient of the road and its shoulder demands careful attention to prevent problems like water retention.

Corridor-Wide Improvements

Embracing methodologies such as road diets and the Complete Streets approach offer heightened safety and cost-effective and efficient avenues for urban development. Rather than undergoing extensive overhauls or new infrastructural projects, these strategies capitalize on reconfiguring existing roadways to better serve all users.

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[28] Florida Department of Transportation, *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects* (Tallahassee, FL, 2005). http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SF/FDOT_BD015_04_rpt.pdf.

Road diets, particularly the transformation from four lanes to three, emerge as an effective strategy to enhance the safety of VRUs along transportation corridors. A standard road diet at its core involves converting a four-lane, undivided roadway into two through lanes with accompanying turn lanes at driveways and roads. This restructuring not only provides left-turning drivers with a designated space to await a safe turning gap but also creates an opportunity to repurpose the reclaimed space for several enhancements, such as pedestrian refuge islands, enhanced visibility crosswalks, widened sidewalks, bicycle or transit lanes, and on-street parking, to name a few. Figure 54 indicates a clear upward trend in the VRU crashes as the number of through lanes increases for arterial roads and below with an AADT between 10,000 and 20,000. This data underscores the value of implementing road diets, as reducing the number of through lanes can potentially decrease the risk of VRU crashes, enhancing overall road safety.

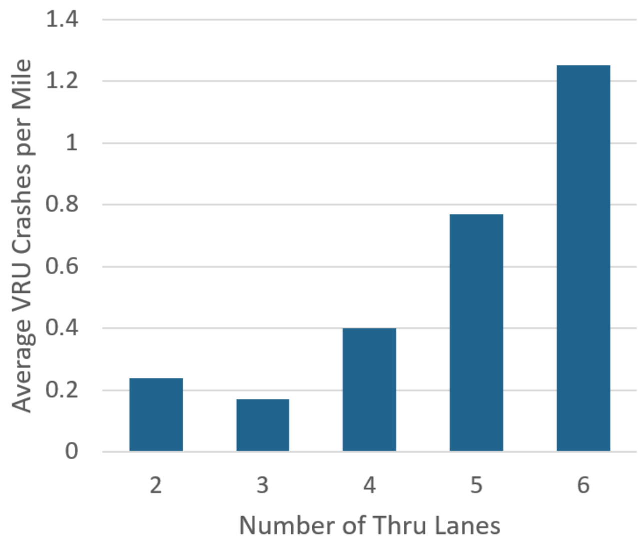

Figure 54 - Average VRU Crashes per Mile by Number of Thru Lanes for Classification of Arterial and below and AADT between 10,000 and 20,000 (2018-2022)

Such transformations play a pivotal role in addressing the inherent challenges posed by multilane roads. Pedestrians, for instance, find it challenging to cross multilane roads due to their vast widths combined with potentially high vehicle speeds. Road diets tactically reduce these crossing distances, consequently minimizing the exposure of pedestrians to vehicular traffic. Additionally, reducing vehicle speeds and optimizing sight distances for left-turning vehicles dramatically decreases the chance of rear-end collisions. It is not just about the safety of pedestrians and cyclists; road diets holistically enhance the flow of traffic and streamline vehicle movements, especially with the inclusion of features like raised medians and left-turn bays. When integrated with existing reconstruction or overlay projects, road diets can be implemented cost-effectively, offering safety benefits at a fraction of the cost of a stand-alone project. Road diets do not just reshape roads; they redefine urban mobility, making streets safer, more efficient, and inclusive for all users.

The concept of **Complete Streets** represents a paradigm shift in urban planning and transportation design, centering the safety and convenience of all road users, especially VRUs. At its core, a complete street is adaptable and context-sensitive, ensuring that the design is tailored to balance the needs of pedestrians, cyclists, motorists, and public transport users alike, whether in bustling urban centers or serene rural locales. This encompasses an array of features, from pedestrian-friendly sidewalks and bicycle lanes to strategically placed crosswalks, raised crosswalks, audible pedestrian signals, and more. The multi-faceted design not only facilitates safer roadways by clearly demarcating spaces for diverse uses but also fosters a heightened awareness among users about the shared nature of the streets.

Furthermore, the benefits of complete streets go beyond safety. They actively promote healthy living by encouraging walking and cycling, reducing reliance on cars, and consequently mitigating traffic congestion. This not only translates to healthier communities but also more vibrant, interconnected urban spaces. For agencies like TDOT, integrating complete streets principles into state route resurfacing projects can be both strategic and cost-effective. By identifying potential complete streets networks early in the planning phase, TDOT can seamlessly incorporate these designs into initial projects, avoiding the financial and logistical challenges of later retrofits. Such a proactive approach can transform state routes into holistic transportation networks, enhancing safety, promoting health, and elevating Tennessee's residents' overall quality of life.

Raised medians provide a refuge for pedestrians, allowing them to break their crossing into two stages. This is particularly valuable on multi-lane roads where the width of the roadway and the volume of fast-moving vehicles can be intimidating and dangerous for pedestrians. By breaking up the crossing, pedestrians only need to judge and negotiate traffic from one direction at a time. This drastically reduces the exposure risk, giving pedestrians a safer environment, especially on roads with high traffic volumes or multiple lanes.

Moreover, these medians deter unsafe mid-block vehicle turns, a common cause of crashes involving VRUs. By restricting such turns, raised medians ensure that vehicles adhere to designated turning points, reducing unpredictable vehicular movements that can endanger pedestrians and cyclists. Furthermore, raised medians can be landscaped with trees or shrubs, not only beautifying the urban space but also creating a visual cue for motorists, signaling them to be more cautious. This passive form of traffic calming can further deter speeding and enhance the safety of the road for all users.

STRATEGY 2 - Implement Corridor Improvements Along Prioritized VRU Segments

Strategy 2, centered around improving the connectivity and safety of VRU infrastructure along prioritized segments, showcases a holistic commitment to creating safer roadways tailored to the unique needs of VRUs. By implementing targeted safety measures, especially in areas prioritized in the VRU Safety Screening Tool, TDOT can proactively address potential hotspots. Introducing a quick-build program underscores the urgency and adaptability of this strategy, leveraging innovative solutions to carve out dedicated space for cyclists, ensuring their safety and promoting sustainable transportation modes.

Furthermore, incorporating the 'Road Diet' countermeasure signifies a forward-thinking approach, reimagining road space utilization to prioritize safety above all. It is not just about retrofitting but about updating the very procedures and thresholds used to define safe spaces. Including Complete Streets Design in state route resurfacing projects further cements the dedication to creating roads that are not just thoroughfares for vehicles but inclusive spaces that cater to every road user's needs. In sum, Strategy 2 embodies a comprehensive, well-thought-out approach, targeting both the immediate and long-term safety of VRUs.

Table 14 - Index of Strategy 2 Actions

ACTION	STAGE	SSA ELEMENT	RELATED PLAN ACTION
2.1 Continually expand and target safety improvements along roadways prioritized in the VRU Safety Screening Tool.	Ongoing	Safe Roads	SHSP- 1.1, 1.4 SATP- A.1.1, A.1.2
2.2 Explore a quick-build program for deploying innovative solutions to dedicate space to cyclists.	Planning	Safer Road Users, Safe Roads	SATP- A.2.2, D.1.1
2.3 Implement the 'Road Diet' countermeasure, focusing on optimizing road space and prioritizing safety. This action also entails updating existing procedures and thresholds to contemporary standards.	Active	Safe Roads	SATP- A.1.3, A.2.2
2.4 Incorporate Complete Streets Design into State Route resurfacing projects.	Future	Safe Roads	SATP- A 1.4, A 2.1

PRIORITY AREA 3 - Speed Management

There is a direct relationship between the speed of a vehicle and the likelihood of a VRU fatality in a crash. As shown in Figure 55, nine out of 10 pedestrians will likely survive if hit by a vehicle traveling 23 MPH. In comparison, only 1 in 10 pedestrians will likely survive if hit by a vehicle traveling 58 MPH. Speed management can accommodate VRU injury severity in three ways: reducing impact forces, providing additional time for a driver to stop, and providing improved visibility at a lower speed.

SPEED MANAGEMENT SUBAREAS

- Geometric Improvements
- Signal Progression
- Posted Speed Limits Reduction
- Traffic Calming

Figure 55 - Relationship of Vehicle Speed and Risk of Death of Vulnerable Road User[29]

[29] USDOT Pedestrian Safety Action Plan: https://highways.dot.gov/sites/fhwa.dot.gov/files/2020-11/FHWA_PedSafety_ActionPlan_Nov2020.pdf

Figure 56 provides a striking visualization of the correlation between posted speed limits and the severity ratio of VRU crashes in Tennessee. The overarching trend is clear: higher speed limits correlate with more severe VRU crashes. The significance of this relationship cannot be overstated. Speed is a primary determinant of crash survivability. At higher speeds, both the likelihood of a crash occurring and the subsequent severity of injuries in the event of a crash increase exponentially. This graph serves as a compelling reminder of the dire consequences of higher speeds. It underscores the need for effective speed management to protect the most at-risk road users, especially in areas with high VRU activity. Note: the sample size of crashes at 60 MPH is only six crashes, resulting in a drop in the severity ratio.

Other studies have shown a driver traveling at 30 MPH who hits a pedestrian has a 45% chance of killing or seriously injuring them, and at 20 MPH, that percentage drops to 5 percent.[30] While the trend in Tennessee shows a lower chance of killing or seriously injuring VRUs at 30 MPH, the chance of a severe crash at 20 mph is 17% (15 percent greater than otherwise reported). At 35 MPH, the Tennessee severity steadily grows from 24% to 45% at 50 MPH and 73% at 70 MPH.

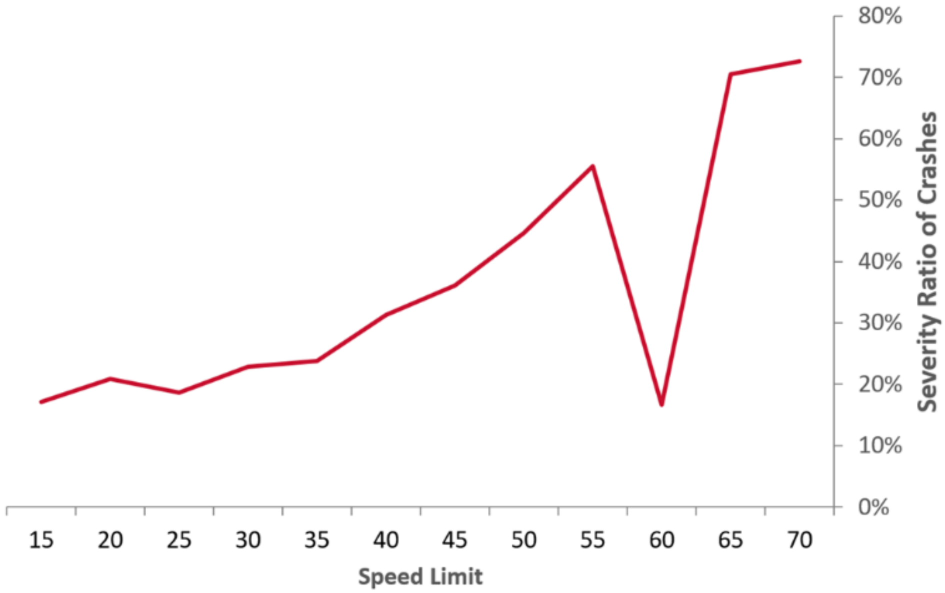

Figure 56 - Total VRU Crash Severity Ratio by Posted Speed Limit (2018-2022)

Geometric Improvements

Geometric improvements in road design play a key role in moderating vehicle speeds and augmenting the safety of VRUs. It can influence drivers' behavior by incorporating design elements such as tighter radii at corners, lane width reductions, and the introduction of roundabouts (see the Intersection section for more details), encouraging slower speeds and heightened awareness. These modifications make crossings less daunting for VRUs and reduce the likelihood and severity of crashes.

Tighter curb radii at intersections significantly mitigate the risks pedestrians face from right-turning vehicles. By reducing the curve, turning speeds for vehicles are lowered, improving the safety of

[30] *Reducing the speed limit to 20 mph in urban areas*: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1127572/

crossing zones for pedestrians. A shortened radius also reduces the pedestrian crossing distance, enhancing the visibility and reaction time between motorists and pedestrians.

Quick-build projects can employ cost-effective materials to adjust existing curbs. However, it is important to consider the impact of such measures on large vehicles. Radii between 2 and 5 feet can be effective without adverse effects, especially when additional space from parking or bike lanes is considered.

Tighter curb radii offer a dual benefit: they bolster pedestrian safety by reducing crossing distances and slowing vehicle turns and potentially optimizing signal timing for smoother intersection flow.

Lane width plays an indispensable role in street design, striking a balance between various road users, including motorists, buses, bikes, and parked cars. Historically, wider lanes ranging from 11–13 feet were favored, as they offered a cushion against potential sideswipes in high-speed environments. However, newer research challenges this perspective, emphasizing that narrower lanes promote slower driving speeds and reduce the severity of potential crashes.[31] [32] The correlation between lane width and vehicle speed is influenced by numerous factors, from traffic volume to the driver's age.

Narrower streets carry several inherent advantages. Apart from encouraging a reduction in driving speed, they slash pedestrian crossing distances, result in shorter signal cycles, and even lead to environmental benefits like reduced stormwater runoff. Moreover, they demand less construction material, marking them as economically efficient. When considering multi-lane roads frequented by larger vehicles such as trucks or buses, the wider lanes, if necessary, should ideally be positioned as the outer lanes. The inner lanes should maintain the narrowest feasible width.

A 10-foot lane width in urban settings is often ideal, balancing safety and operational efficiency. On routes designated explicitly for trucks or public transit, an 11-foot lane might be necessary in each direction. However, in unique scenarios, lanes as narrow as 9-9.5 feet can be effective through lanes, especially when paired with a dedicated turn lane.[33]

Signal Progression

In bustling downtown areas with closely spaced signals, coordinated **signal progression** enhances more than just speed regulation; it significantly aids the movement of cyclists. Employing short cycle lengths and strategic signal progressions makes traffic flow smoother, leading to increased safety. For cyclists, this coordination can be epitomized by a "green wave"[34] - a signal timing technique that, when adhering to a certain speed, allows them to continually hit green lights without halting. This not only smoothens the cyclist's journey but also facilitates the transit movement within the corridor and tempers the speed of motorists. Adding leading bike intervals and protected-permissive bike signals further innovates urban bike traffic, offering an added adaptability dimension.

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[31] Theo Petrisch, "*The Truth about Lane Widths*," The Pedestrian and Bicycle Information Center, http://www.bicyclinginfo.org/library/details.cfm?id=4348.

[32] Previous research has shown various estimates of relationship between lane width and travel speed. One account estimated that each additional foot of lane width related to a 2.9 mph increase in driver speed. Source: Kay Fitzpatrick, Paul Carlson, Marcus Brewer, and Mark Wooldridge, "*Design Factors That Affect Driver Speed on Suburban Arterials*": Transportation Research Record 1751 (2000):18–25.

[33] Ingrid Potts, Douglas W. Harwood, and Karen R. Richard, "*Relationship of Lane Width to Safety on Urban and Suburban Arterials*," (TRB 86th Annual Meeting, Washington, D.C., January 21–25, 2007).

[34] http://www.pedbikesafe.org/bikesafe/countermeasures_detail.cfm?CM_NUM=35

While these methodologies offer advantages, urban planners and practitioners need to evaluate the associated risks and efficiencies judiciously. Analyzing the signal timing across intersections and corridors provides a comprehensive view of the current traffic scenario. Equally crucial is understanding the prevailing risks at intersections and gauging the behavioral response of street users to signals. Such multifaceted insights form the bedrock of informed decisions, ensuring that the signal progressions optimize safety and fluidity for cyclists at intersections.

Posted Speed Limit Reduction

Reducing speed limits is more than just a matter of altering signposts; it is a deliberate strategy aimed at enhancing road safety for both motorists and VRUs. While instituting lower speed limits is a recognized strategy for moderating road speeds, evidence indicates that such reductions only lead to marginal decreases in actual travel speeds. For every 5-mph drop in speed limits, average road speeds generally dip by just 1-2 mph. Yet, these marginal decreases can be critical. A mere 3 mph reduction from a baseline average speed of 30 mph can result in a 27% decrease in injury crashes and a 49% decrease in fatal crashes.[35] However, for the reductions to be genuinely effective, they must be implemented alongside comprehensive public awareness campaigns, enhanced law enforcement, and strategic engineering interventions like road diets or traffic calming measures. Such multifaceted strategies curb speeding and reshape public perception, fostering a culture where road safety is paramount.

Beyond the technical aspects of reduced speed limits, it is essential to introduce these changes as part of a larger, visible transformation in targeted zones. For instance, designating certain areas, like downtown locales, as pedestrian-friendly zones can magnify the effects of lowered speed limits. Such areas, marked by unique signage, landscaping, or streetscaping, can serve as potent reminders of the altered road conditions. Initiatives like Vision Zero, adopted by several Tennessee cities, have synergized speed limit reductions with other safety measures for maximum effect. Ultimately, while changing speed limits is affordable and straightforward, its real impact is magnified when combined with broader road safety strategies and community involvement.

Traffic Calming

Traffic calming is a vital approach aiming to slow down or reduce vehicular traffic, ensuring safer streets and neighborhoods. Traffic calming is a top priority on local and collector-level streets prioritized by the VRU Safety Screening Tool. Integrating traffic calming measures into existing pedestrian-focused initiatives like Safe Routes to School, the Multimodal Access Grant Program, and the Pedestrian Road Safety Initiative reinforces pedestrian safety and contributes to more walkable, livable urban spaces. To realize the full benefits of these programs, it is important to include equity considerations during project selection so that they are implemented equitably throughout the city.

TDOT possesses the resources and reach to amplify these efforts at a statewide level significantly. Local partners have expressed interest in implementing traffic calming measures with TDOT. TDOT can bolster this collaboration by leveraging Highway Safety Improvement Program (HSIP) funds. Investing in traffic calming partnerships would help advance a more cohesive statewide strategy for pedestrian safety.

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[35] NHTSA, *Countermeasures That Work: A Highway Safety Countermeasure Guide*, for State Highway Safety Offices Tenth Edition, 2020, https://www.nhtsa.gov/sites/nhtsa.gov/files/2021-09/Countermeasures-10th_080621_v5_tag.pdf .

> *"Speed is at the heart of a forgiving road transport system. It transcends all aspects of safety: without speed there can be no movement, but with speed comes kinetic energy and with kinetic energy and human error come crashes, injuries, and even deaths."*
>
> *-Organization for Economic Co-operation and Development*

STRATEGY 3 - Manage Vehicle Speeds in Locations with High VRU Activity

Strategy 3 emphasizes the pivotal role of managing vehicle speeds, particularly in areas characterized by high VRU activity. Recognizing that speed is often a crucial factor in the severity of crashes, this strategy delves deep into formulating measures that prioritize the well-being of Vulnerable Road Users (VRUs). By persistently working on infrastructure enhancements prioritized in the VRU Safety Screening Tool, the focus remains firmly on creating environments that organically encourage safer vehicle speeds. A significant stride in this direction is the exploration of safer, consistent, and more enforceable speed limits, especially on arterials and collectors within the High Crash Network. These efforts suggest a keen understanding of the varied dynamics of different road types and their unique needs.

Further solidifying this comprehensive approach is the idea of partnering with local entities. By exploring a joint program, the strategy seeks to leverage the expertise and reach of local agencies and jurisdictions in traffic calming endeavors, coupled with robust educational initiatives. Collectively, Strategy 3 presents a multifaceted approach to speed management, placing VRU safety at its core.

Table 15 - Index of Strategy 3 Actions

ACTION	STAGE	SSA ELEMENT	RELATED PLAN ACTION
3.1 Continually expand and target safety improvements of infrastructure to better manage vehicle speeds prioritized in the VRU Safety Screening Tool.	Ongoing	Safe Speeds, Safe Roads	SATP- A.2.2
3.2 Explore safe, consistent, and enforceable speed limits on arterials and collectors prioritized in the VRU Safety Screening Tool.	Future	Safe Speeds	
3.3 Explore a joint program to assist local agencies and jurisdictions with traffic calming efforts and education.	Future	Safe Road Users, Safe Speeds	

PRIORITY AREA 4 - VRU Daily Needs

VRU DAILY NEEDS

- Transit Riders
- School Zones
- Work Zones
- Equity

Transit

Figure 41 illustrates a correlation between transit stop density and VRU crash risk. As the average distance to a transit stop from any point along the segment increases to 2,000 feet, the average VRU crashes per mile diminishes. Beyond 2,000 feet, the relationship plateaus. This highlights the concentration of VRU crashes in areas of higher transit density or in proximity to transit stops.

The findings underscore the pressing need to scrutinize the surroundings of transit stops, focusing on VRU safety. These areas, acting as convergence points for various modes of transportation (pedestrians, cyclists, and vehicular traffic) and road crossings by VRUs, are frequently required in multi-lane, high AADT environments. Without well-thought-out infrastructure, these zones can become hotspots for VRU crashes.

Acknowledging this correlation, TDOT extends sidewalks up to the curb at transit stops during resurfacing projects where the surface is present. However, ongoing collaboration between TDOT and transit agencies operating on state routes would facilitate the exchange of crucial data, insights, and expertise, paving the way for impactful safety improvements. Regular consultations and joint safety audits with transit agencies can help identify potential VRU hazards and context-appropriate mitigation. This could range from reengineering crosswalks, ensuring adequate lighting, and deploying signage that accentuates pedestrian priority to establishing clear and safe waiting zones for transit users.

The data presents an unequivocal case for a proactive and collaborative approach toward ensuring VRU safety around transit-dense areas. As urban landscapes evolve and public transit becomes an even more integral part of the transport ecosystem, prioritizing VRU safety around these hubs is not just a responsibility but imperative for building sustainable cities.

School Zones

Figure 42 illustrates the correlation between the proximity to schools and the occurrence of VRU crashes per mile. The crash rate increases in areas closer to schools, gradually declining as the distance widens. Such a trend, while concerning, is not unexpected. Schools inherently attract a confluence of various road users - walking and cycling students, parents' vehicles, school buses, and even public transport. This mix, combined with the intrinsic dynamism during school hours - bus halts, impatient parents in drop-off zones, and young, unpredictable pedestrians - amplifies the risks.

Several elements contribute to this heightened crash occurrence in proximity to schools. Apart from the sheer volume of pedestrians and cyclists, other factors come into play. There is the recurring deceleration and acceleration of buses, vehicles navigating the chaos during peak drop-off and pick-up windows, and potential distractions for drivers (navigating through congestion) and students (mobile phones, peer interactions). The proximity to residential areas further compounds this, introducing more VRUs.

Acknowledging this conspicuous trend, TDOTs identifies the location of crosswalks within a designated buffer of schools and assesses the need for upgrades, like the installation of Rectangular Rapid Flash Beacons or Pedestrian Hybrid Beacons, exemplify a targeted approach to mitigate risks. Yet, as urban dynamics evolve and our understanding of VRU safety matures, there's room for further refinement. By employing the VRU Safety Screening Tool, TDOT can gain a more granulated understanding of risk-prone crosswalks. Prioritizing these, especially during summer maintenance windows before the school year recommences, optimizes resource allocation and ensures that students return to an even safer commute environment.

In sum, the data serves as both an affirmation of the known risks around school zones and a clarion call for relentless innovation in ensuring the safety of the future generations. Through a blend of data-driven insights, technological tools, and timely interventions, TDOT is poised to make significant strides in safeguarding the school-going populations.

Work Zones

Addressing VRU crashes within work zones presents a unique challenge, primarily due to the transient nature of these zones and their often-dynamic configurations. Unlike fixed locations such as schools or transit stops, work zones come and go, constantly altering the road landscape and traffic patterns. TDOT’s coordination with law enforcement and “Work with Us” public information campaigns increase worker safety, but work zone conditions are inherently highly hazardous.

A significant hurdle in understanding and addressing the scale of VRU crashes in work zones is the inconsistency or lack of detailed reporting within police crash reports. Without specific categorization or annotation denoting a crash's occurrence within a work zone, the circumstances surrounding work zone crashes can be obscured. As it stands, this ambiguity hinders targeted interventions and makes it challenging to devise effective countermeasures. Working with law enforcement agencies to develop enhanced reporting protocols would facilitate the development of a compilation of data for use in shaping future safety practices- influencing roadway worker training and informing public awareness campaigns.

TDOT has invested in an updated Work Zone Field Manual, which emphasizes worker safety within work zones. While this enhances safety for TDOT workers, some workers deployed by local agencies statewide may not have such guidance. Reaching out to local partners to share work zone safety guidance couple be an opportunity to expand the use of TDOT safety protocols broadly.

Equity

Equity in transportation planning is paramount. It ensures that all communities, regardless of socio-economic status or racial or ethnic background, have equal access to safe and efficient transportation. For TDOT, this means ensuring that priority areas, especially those concerning VRU safety, are assessed with an unwavering commitment to equity.

Historically, marginalized communities often endure the most transportation inequities, from being disproportionately impacted by road safety issues to having limited access to quality transit options. Recognizing and addressing these imbalances is vital in creating a transportation system that truly serves all.

TDOT's initiative to integrate a 'communities of concern' overlay within the Multimodal Planning Tool is a commendable first step. Doing so ensures that these communities' specific needs and vulnerabilities are not just recognized but prioritized. However, integrating these tools is just the beginning.

For TDOT to champion equity in all its endeavors:

- Continuous Stakeholder Engagement: Regularly engage with communities, especially those historically underrepresented in transportation decision-making. Their feedback will provide invaluable insights into local needs and concerns.
- Training & Education: Ensure that all TDOT staff, especially those in decision-making roles, receive training on the importance of equity in transportation planning. A well-informed team is more likely to make equity-centric decisions.
- Regular Reviews: Periodically review and update the 'communities of concern' overlay or identify an equity overlay to better fit VRU crash analysis, ensuring it accurately reflects the evolving dynamics of the regions it serves.
- Transparent Reporting: Publish regular reports detailing how equity considerations have influenced transportation decisions. This not only holds TDOT accountable but also reinforces its commitment to equity.
- Collaboration: Work closely with other state and local agencies, non-governmental organizations, and community groups focusing on equity. Their expertise can guide TDOT's efforts and foster a sense of ownership in projects.

While tools and data are instrumental, the underlying commitment to equity will determine TDOT's success. By institutionalizing equity as a core principle, TDOT can ensure that safety improvements benefit all communities, fostering a more inclusive and just transportation landscape.

STRATEGY 4. Support Safety Improvements to Address VRU Behaviors

Strategy 4 is deeply rooted in a proactive, collaborative approach to advancing the safety and well-being of VRUs in daily life contexts. This strategy is central to recognizing that effective communication and joint action are paramount. Actions 4.1 to 4.3 depend on effective communication between TDOT and the local partners. By consistently reviewing transit stops along resurfacing projects, there is a reinforced commitment to ensure that each stop within the project is accessible. Similarly, by examining school zones, this strategy emphasizes the creation of safer crossings and corridors, a move that primarily benefits Tennessee's younger VRUs. The meticulous review of work zones and interstate crash patterns further exemplifies a commitment to identify and mitigate risks preemptively.

The heart of Strategy 4 lies in its emphasis on inclusivity. Every review and assessment ensures that priority areas are seen through an equity lens, guaranteeing that every community, regardless of socio-economic status, benefits from these safety improvements. However, the keystone of this strategy is its emphasis on fostering a collaborative environment.

Through continuous dialogue and partnership between local transportation agencies, public stakeholders, and TDOT, Strategy 4 champions a shared vision: to collaboratively eliminate all VRU fatalities and serious injuries on Tennessee roads.

Table 16 - Index of Strategy 4 Actions

ACTION	STAGE	SSA ELEMENT	RELATED PLAN ACTION
4.1 Regularly review facilities for transit riders, focusing on the safety and accessibility of stops and crossings.	Implementing	Safe Road Users	SHSP- 3.1 SATP- D.1.5
4.2 Regularly review school zones by focusing on safer crossings and corridors to protect younger VRUs.	Future	Safe Road Users	
4.3 Regularly review potential hazards and patterns of work zone and interstate crashes to devise preventive measures.	Future	Safe Road Users, Safe Roads, Post Crash Care	
4.4 Ensure prioritized VRU locations are assessed with an equity lens, ensuring all communities benefit from safety improvements.	Implementing	Safe Road Users	SATP- B.1.1

PRIORITY AREA 5 - System Longevity

In the complex tapestry of Tennessee's transportation landscape, the concept of 'system' goes beyond mere roads and bridges; it encompasses the intricate interplay of infrastructure, planning, programs, and strategies. The System Longevity Priority Area encapsulates this comprehensive vision, recognizing that the durability and effectiveness of the transportation framework are linked to the safety and welfare of VRUs. Laying the groundwork for longevity entails evolving and updating plans, innovating within programs, and ensuring infrastructure remains state-of-the-art. It's a commitment to a holistic approach, wherein every facet of the transportation matrix is harmonized to provide endurance.

SYSTEM LONGEVITY

- Coordination
- Project Prioritization
- Continued Evaluation
- Improved Data
- Research & Implementation

Coordination

By actively coordinating with local agencies, jurisdictions, and its regions, TDOT fosters a collaborative environment to bolster safety initiatives, facilitate project execution, streamline grant management, and spark innovative funding solutions. Local engagement ensures that all stakeholders have the necessary tools and resources to prioritize and enhance VRU safety, creating a unified front against the challenges that VRUs face daily.

Moreover, TDOT has been instrumental in encouraging local entities to tap into resources like the Department's Multimodal Access Grant. This competitive grant is dedicated to advancing bike and pedestrian improvements on state routes and represents an excellent opportunity for municipalities to accelerate their VRU safety projects. TDOT also guides cities in submitting projects to the 3-year plan and assists them in accessing Highway

Safety Improvement Program (HSIP) funds. Continuous coordination helps cities locate funding for VRU projects and streamlines the process, making it more accessible for all involved parties.

Project Prioritization

Under the support of the Pedestrian Road Safety Initiative's (PRSI), TDOT is shifting toward a more comprehensive approach to active transportation projects. Rather than viewing safety in isolation, TDOT recognizes that the intersections of accessibility, mobility, equity, economic development, land-use, and climate change are crucial elements in sculpting a transportation network that serves all Tennesseans effectively and responsibly. In this light, projects embodying these multifaceted considerations will be prioritized, ensuring that roads are safer for VRUs and creating an inclusive, sustainable, and vibrant transport ecosystem aligned with both present needs and future challenges.

Furthermore, the formula-based Federal Highway Administration (FHWA) funding solidifies TDOT's commitment to this initiative. This funding mechanism ensures a consistent allocation of resources to projects that align with the PRSI's vision. By leveraging FHWA's support, TDOT is better positioned to drive impactful change across the state, fostering connected, resilient, and forward-thinking communities.

Continued Evaluation

Continuously monitoring and evaluating the performance of the statewide transportation system is crucial in ensuring that the safety of VRU remains a paramount concern. A transportation system that does not adapt or respond to changing conditions risks being outpaced by emerging challenges. By focusing on areas prioritized in the VRU Safety Screening Tool, TDOT can identify and address danger zones proactively. Implementing measures such as a mid-year update ensures timely assessments and the ability to adjust as required. A dynamic response system is also established by emphasizing specific crash severities like fatal crashes and meticulously tracking high-risk locations monthly. This approach ensures immediate attention can be allocated to areas most in need, upholding that every life matters and ensuring VRU safety remains an ever-present priority in the transportation blueprint.

Improved Data

Committing to regular and comprehensive statewide data collection efforts is paramount to ensuring that strategies are grounded and informed by tangible insights. A robust data-driven foundation allows TDOT to objectively assess the efficacy of the current approaches' effectiveness. It provides the foresight needed to anticipate challenges and tailor strategies for maximum impact. Furthermore, collaboration with first responders and hospitals is indispensable. Such partnerships can shed light on underrepresented or unreported incidents, helping to identify overlooked crash-prone locations, modes of transportation, and the actual severity of incidents. A comprehensive and collaborative approach to data collection ensures that the safety strategies are complete, precise, and continuously refined for the betterment of all residents.

Research & Implementation

In an ever-evolving world, staying abreast of innovative research and harnessing the power of new technologies is paramount for achieving optimal results in any sector. Particularly in the realm of transportation and road safety, emerging technologies like passive pedestrian detection systems, automated enforcement mechanisms, enhanced intersection communication, and considerations related to vehicle size present transformative opportunities. Leveraging these innovations can significantly improve safety measures, especially for VRUs, by predicting potential risks, automating responses, and fostering enhanced communication between vehicles and infrastructure. By actively investing in research, TDOT can be reactive to current challenges and proactively prepare for future demands, ensuring a safer and more efficient transportation environment for all.

To turn this vision into reality, it becomes imperative to continually monitor and evaluate new VRU countermeasures, tools, and technologies. Furthermore, to maximize the benefits these technologies can offer, it is crucial to accelerate their adoption and integration into existing systems. Doing so can pave the way for a safer, more responsive, and technologically advanced transportation ecosystem across the state.

Recent TDOT Funded
Active Transportation Research

- Applying Induced Travel Study in Urban Areas in Tennessee with the University of Memphis
- Feasibility of Real-Time Infrastructure-Driven Intervention for Improving Pedestrian Safety with the University of Tennessee, Chattanooga
- Addressing Traffic Safety to Reduce Pedestrian Injuries and Fatalities in Tennessee with the University of Tennessee, Knoxville

STRATEGY 5. Commit to the Continuous Evaluation and Evolution of VRU Projects

Central to this strategy is a sustained commitment to collaboration, involving intra-agency coordination and forging productive partnerships with local entities, jurisdictions, and TDOT regions. This joint effort aims to bolster the effectiveness and reach of VRU safety projects, streamlining grant management and unlocking creative funding avenues. The Pedestrian Road Safety Initiative (PSRI) emerges as a touchstone, championing projects that encapsulate a broad spectrum of concerns — from safety and accessibility to economic growth and environmental stewardship.

At the heart of Strategy 5 is the principle of continuous improvement. By regularly monitoring the statewide transportation system's performance and ensuring consistent, data-driven evaluations, the strategy ensures that VRU safety remains an unwavering priority. Furthermore, the commitment to research and stay abreast of emerging VRU countermeasures, tools, and technologies ensures that the strategy remains future-ready, adaptive, and aligned with the best practices worldwide.

Table 17 - Index of Strategy 5 Actions

ACTION	STAGE	SSA ELEMENT	RELATED PLAN ACTION
5.1 Continued coordination with local agencies, jurisdictions, and TDOT Regions to support VRU safety initiatives, projects, grant management, and creative funding.	Implementing	Safe Road Users, Safe Roads	SHSP- VRU 1.3 SATP- B.3, C.3.1, D.2.3
5.2 Under the Pedestrian Road Safety Initiative (PRSI), prioritize projects that holistically focus on safety, accessibility, mobility, equity, economic development, land use, and climate change considerations.	Ongoing	Safe Roads	SHSP- VRU 1.6 SATP- D.2.1
5.3 Continuously monitor and evaluate the performance of the statewide transportation system, ensuring that VRU safety remains at the forefront.	Ongoing	All	SHSP- 1.2, 5.3 SATP- C.1.1
5.4 Commit to regular and comprehensive statewide data collection efforts, providing a data-driven foundation for future strategies.	Implementing	All	SATP-C.1.2
5.5 Actively research and monitor new VRU countermeasures, tools, and technologies.	Implementing	All	SHSP- 5.2, 5.4
5.6 Accelerate advanced technologies and best practices to deploy useful VRU technologies statewide.	Future	All	

Summary of Countermeasures

Countermeasures are strategic interventions aimed at improving the safety and efficiency of the transportation network. Spanning various strategies, they can include infrastructural changes, policy adjustments, and educational campaigns. These countermeasures are designed to address specific safety concerns and are often based on detailed analysis and best practices from previous implementations.

VRU's applicable countermeasures are pivotal in enhancing safety and fostering an inclusive roadway environment. VRUs often face disproportionate road risks due to their inherent lack of protection. Implementing specialized countermeasures tailored to their needs helps mitigate these risks by addressing specific challenges at transit stops, school zones, intersections, or midblock locations. Using a combination of infrastructural changes, technological solutions, and road safety studies, these countermeasures aim to create safer roadways that cater to all users, ensuring that the mobility needs of VRUs are recognized and prioritized.

Guidance and Standards

Sources of information for countermeasures and their Crash Reduction Factors (CRF) are obtained from research studies, transportation safety agencies, and institutions like the Federal Highway Administration (FHWA). These entities often publish guidelines and repositories, such as the Highway Safety Manual detailing various countermeasures and their associated CRFs. By drawing upon this collective knowledge and combining it with localized data, transportation planners and engineers can make informed decisions, tailoring their approach to the unique needs of the Tennessee communities. The following resources were key in to determine the countermeasure recommendations.

Federal

- FHWA’s Systemic Safety Project Selection Tool (SSPT)
- FHWA’s Proven Safety Countermeasures, Pedestrian and Bicycle Crash Analysis Tool (PBCAT)[36]
- FHWA’s Toolbox of Pedestrian Countermeasures and Their Potential Effectiveness[37]
- FHWA’s Crash Modification Factors Clearing House[38]
- FHWA’s Safe Transportation for Every Pedestrian (STEP) Studio[39]
- FHWA’s Pedestrian Safety Guide and Countermeasure Selection System[40]

State

- TDOT’s Multimodal Design Guidelines[41]

Other

- National Association of City Transportation Official’s (NATCO) *Urban Street Guide*[42]

[36] https://highways.dot.gov/safety/proven-safety-countermeasures
[37] https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa18041.pdf
[38] https://www.cmfclearinghouse.org/
[39] https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/step_studio.pdf
[40] http://www.pedbikesafe.org/PEDSAFE/
[41] https://www.tn.gov/tdot/roadway-design/design-standards/design-guidelines.html
[42] https://nacto.org/publication/urban-street-design-guide/

- National Highway Traffic Safety Administration's (NHTSA) Countermeasures that Work[43]

Countermeasures Table

A menu of potential countermeasures for VRU crashes is summarized in Table 18. The countermeasures are organized by possible treatment area. Each countermeasure includes a description and the following explanatory material:

- **Crash Reduction Factor (CRF)** is the pedestrian crash reduction value in percentage, unless otherwise specified. CRFs play an integral role in the selection of these countermeasures. CRFs provide a percentage estimate of the potential reduction in future crashes if a specific countermeasure is implemented. By analyzing the historical impact of similar strategies, CRFs offer a data-driven approach to improving safety conditions. For instance, if a particular countermeasure has a CRF of 20%, it indicates that its implementation could result in a 20% reduction in pedestrian crash types.
- **Crash Modification Factor (CMF) ID** is the identification number of the CMF in the CMF Clearinghouse. Other references may also be included from prior listed literature. Most references are a hyperlink for easy access to additional information.
- **Planning-Level Cost Estimate** is broken down into the following price ranges:

$	< $10,000
$ $	$10,000 - 100,000
$ $ $	$100,000 - $500,000
$ $ $ $	> $500,000

- **Time Estimate** that is broken down into the following ranges:

🕓	< 6 months
🕓🕓	6 months - 1 year
🕓🕓🕓	1 year - 3 years
🕓🕓🕓🕓	> 3 years

- Addition information may be included in reference to the countermeasure's ideal conditions including the number of travel lanes or Average Annual Daily Traffic (AADT).

[43] https://www.nhtsa.gov/book/countermeasures/countermeasures-work

Table 18 - Potential Countermeasure Summary

TREATMENT	COUNTERMEASURE		
Crossing Improvements	FHWA Proven **Install High Visibility Continental Marked Crosswalk**		
	Continental crosswalk striping is characterized by its high-visibility broad white bands, enhancing pedestrian safety at both intersection and midblock crossings. Implementing this striping style at all existing and future warranted crosswalks is highly recommended. For detailed specifications and best practices, consult Section 3B.18 and 2C.50 of the MUTCD.		
	Intersection CRF - 40% CMF ID 4123	Midblock CRF - 16% CMF ID 11181	
	$ |	2-3 Lanes Ideal	1,000 < AADT < 9,000
	FHWA Proven **Crosswalk Visibility Enhancements**		
	This group of countermeasures includes improved lighting, advanced or in-street warning signage, pavement markings, and geometric design elements. Features may be combined to indicate optimal crossing locations and help reinforce the driver's requirement to yield the right-of-way to VRUs at crossing locations. For multi-lane roadway crossings where vehicle AADTs exceed 10,000, a marked crosswalk alone is typically insufficient.		
	CRF – 23% to 48% Tech Sheet		
	$-$$| -	3+ Lanes Ideal	AADTs > 10,000
	FHWA Proven **Pedestrian Refuge**		
	Often raised and situated at midblock or intersection locations, it provides a haven for VRUs crossing streets. These center islands allow individuals to navigate one direction of traffic at a time, pausing if needed before proceeding. Their design and minimum widths are guided by the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)" to ensure accessibility for all.		
	CRF - 32% NCHRP 17-56 STEP		
	$-$$ |	2-3+ Lanes Ideal	AADT > 5,000
	Raised Crosswalk		
	Gives pedestrians a typical 3- to 7-second head start before vehicles in the parallel direction are given the green signal indication. LPIs can help reduce conflicts between pedestrians and left- or right-turning vehicles.		
	CRF - 13% to 59% CMF ID 1993 MUTCD 4E.06		
	$-$$ |	Vulnerable Populations	High Ped Volumes
	FHWA Proven **Lighting**		
	Lighting enhances VRU safety at mid-block crossings and along roadways by improving visibility during nighttime and low-light conditions. Strategic placement and consistent illumination levels ensure drivers can detect and recognize pedestrians and cyclists without blind spots or glare disruptions.		
	Street CRF - 12% CMF ID 4462 PEDSAFE	Install Lighting on Unlit Road CRF - 70% CMF2873	
	$$ |	Place lights in advance of Midblock Crossings	

Continued Table 18 - Potential Countermeasure Summary

TREATMENT	COUNTERMEASURE		
Midblock Crossing Improvement	**Rectangular Rapid Flash Beacon (RRFB)** (FHWA Proven)		
	User-activated amber LEDs designed to enhance VRU safety at unsignalized intersections or midblock crosswalks. Using a distinct irregular flash pattern akin to police vehicle flashers, RRFBs create a "gateway effect" that boosts their visibility and efficacy, especially when visible from both traffic directions. Evidence suggests that when placed on medians or refuge islands, particularly on multi-lane roads, RRFBs achieve higher levels of vehicle yielding, especially at nighttime.		
	CRF - 47% CMF ID 9024 MUTCD Section 2C.50		
	$$ | 🕒🕒	4+ Lanes Ideal	Posted Speed < 40 MPH
	Pedestrian Hybrid Beacon (PHB) (FHWA Proven)		
	Devices designed for marked crosswalks to enhance pedestrian safety. Their installation varies: on a four-lane road with a median, they can be side-mounted, but without a median or wider roads, they should be overhead, with specific guidance for incandescent versus LED signal heads. The MUTCD mandates "CROSSWALK STOP ON RED" signs adjacent to PHBs and suggests stop lines be placed at least 40 feet before the signal; consult Section 4F.		
	PHB CRF - 55% CMF ID 9020	PHB + Advanced Warning CRF - 57% NCHRP 17-56	
	$$ | 🕒🕒	4+ Lanes Ideal	Posted Speed > 40 MPH
Intersection Crossing Improvement	**Update Pedestrian Signals**		
	Replace "Walk/Don't Walk" signals with countdown signal heads and/or provide audible and tactile signals, ensuring safe and equitable pedestrian crossings for individuals with visual impairments.		
	Replace w/ Countdown Signal CRF - 25% CMF ID 1409	Install New Ped Signal CRF - 70% CMF ID 5272	
	$$ | 🕒🕒	Vulnerable Populations	High Ped Volumes
	Green Bike Lane		
	These lanes utilize vibrant green pavement to delineate and enhance the visibility of cycling paths, particularly in conflict zones and intersections.		
	NACTO		
	$ | 🕒🕒	Increases cyclist comfort	Multimodal Nature Corridor
	Protected Intersection		
	Prioritizes safety by physically separating vehicle and bicycle traffic, incorporating specialized features like corner islands and forward queuing areas to reduce potential conflicts.		
	NACTO		
	$-$$ | 🕒🕒-🕒🕒🕒	Common with Bike Lanes	Could use Interim Material
	Roundabout (FHWA Proven)		
	Converting signalized intersections to modern roundabouts enhances VRU safety by reducing conflict points and slowing down vehicular traffic, thus creating a safer environment for pedestrians and cyclists.		
	CRF - 73% CMF ID 1634		
	$$$ | 🕒🕒🕒	Lowers Vehicle Speeds	High Bike Volumes

Continued Table 18 - Potential Countermeasure Summary

<table>
<tr><th>TREATMENT</th><th colspan="3">COUNTERMEASURE</th></tr>
<tr><td rowspan="23">Separation of VRU and Vehicle at Traffic Signal</td><td colspan="3">Traffic Phase and Timing</td></tr>
<tr><td colspan="3">FHWA Proven Leading Pedestrian Interval (LPI)</td></tr>
<tr><td colspan="3">Gives pedestrians a typical 3- to 7-second head start before vehicles in the parallel direction are given the green signal indication. LPIs can help reduce conflicts between pedestrians and left- or right-turning vehicles.</td></tr>
<tr><td colspan="3">CRF - 13% to 59% <u>CMF ID 9918</u> <u>CMF ID 1993</u> MUTCD 4E.06</td></tr>
<tr><td>$ |</td><td>Vulnerable Populations</td><td>High Turning Volumes</td></tr>
<tr><td colspan="3">Protected Left Turns</td></tr>
<tr><td colspan="3">Protected (or prohibited) left turns refer to dedicated signal phases or restrictions that allow vehicles to make left turns without conflicting with oncoming traffic or pedestrians. This measure substantially enhances VRU safety, minimizing potential collision points and ensuring safer crossings for pedestrians and cyclists.</td></tr>
<tr><td colspan="3">CRF - 6% <u>CMF ID 9899</u></td></tr>
<tr><td>$ |</td><td colspan="2">Turn Conflicts</td></tr>
<tr><td colspan="3">Protected Right Turns</td></tr>
<tr><td colspan="3">Right-Turn-on-Red (RTOR) restrictions are critical in ensuring pedestrian safety, especially in areas with high pedestrian volumes or exclusive pedestrian phases. R TOR has often inadvertently compromised pedestrian safety, as drivers, engrossed in watching traffic from their left, may overlook pedestrians approaching from the right or block pedestrian pathways while waiting for a gap in traffic. Implementing RTOR restrictions and measures like leading pedestrian intervals can mitigate potential conflicts and enhance safety at intersections.</td></tr>
<tr><td colspan="2">Prohibit RTOR CRF - Equation
<u>CMF ID 5194</u></td><td>Permit RTOR CRF - (-)69%
<u>CMF ID 4579</u></td></tr>
<tr><td>$ |</td><td>Turn Conflicts</td><td>School Crossings</td></tr>
<tr><td colspan="3">Exclusive Pedestrian Phase</td></tr>
<tr><td colspan="3">Also known as Barnes Dance and Pedestrian Scramble, it is a special phase added to the regular two-phase permissive signal timing, which stops vehicle traffic in all directions and allows pedestrians to cross in any fashion, including diagonally.</td></tr>
<tr><td colspan="3">CRF - 51% <u>CMF ID 4117</u></td></tr>
<tr><td>$ |</td><td>Vulnerable Populations</td><td>High Ped Volumes</td></tr>
<tr><td colspan="3">Increase Pedestrian Crossing Time</td></tr>
<tr><td colspan="3">Increasing pedestrian crossing time by extending signal phases ensures that pedestrians, especially those who may require a longer duration, such as the elderly or disabled, can cross streets safely and comfortably. This measure fosters a more inclusive and safer urban environment for all road users by accommodating a broader range of pedestrian speeds.</td></tr>
<tr><td colspan="3">CRF - 51% <u>CMF ID 5252</u></td></tr>
<tr><td>$ |</td><td>Vulnerable Populations</td><td>W/out Increase in Phase Length</td></tr>
<tr><td rowspan="4">Geometric Improvements</td><td colspan="3">FHWA Proven Raised Median</td></tr>
<tr><td colspan="3">By providing refuge, controlling vehicular movement, and acting as a visual cue, they play a pivotal role in reducing VRU crashes and making roads safer for everyone.</td></tr>
<tr><td colspan="3">CRF - 39% <u>CMF ID 3034</u></td></tr>
<tr><td>$$ |</td><td>Consider Pedestrian Refuge</td><td>High Volume, High Speeds</td></tr>
</table>

Continued Table 18 - Potential Countermeasure Summary

Geometric Improvements cont.	**Road Diet (Roadway Reconfiguration)** (FHWA Proven)		
	Narrow roadway from four lanes to three lanes (two through lanes with center turn lanes at driveways and side streets).		
	Urban CRF - 19% CMF ID 5554	Rural CRF - 17% CMF ID 2841	
	$$$$ |	4 Lanes Ideal	Limit TWLTL
	Lane Width Reduction		
	Reducing lane widths can effectively slow vehicular traffic and create a safer environment for all road users. Narrower lanes, often integrated with road diets or complete street designs, can also free up space for other amenities such as bike lanes, sidewalks, or greenery, enhancing the overall street experience.		
	12 ft to 10 ft CRF - 42% CMF ID 7827	12 ft to 11 ft CRF - 24% CMF ID 7825	
	$$-$$$ |	Great for Adding Bike Lanes	Lowers Vehicle Speeds
	Separated Bike Lane (SBL) (FHWA Proven)		
	SBLs provide a bicycle lane that is separated from the adjacent motor vehicle lanes by including both a buffer and a vertical element between the motor vehicle lanes and the bicycle lane.		
	CRF - 18-56% Tech Study		
	$$-$$$|	Multiple Barrier Types	Possible Quick Build
Along Roadway Improvements	**Sidewalk** (FHWA Proven)		
	Sidewalks provide a dedicated and safe space for pedestrians, separating them from vehicular traffic and enhancing mobility in urban and suburban areas. Their presence promotes walking as a sustainable mode of transportation and contributes to the overall safety and livability of communities.		
	CRF - 40% CMF ID 11246 CMF ID 136		
	$$-$$$ |	Both Sides of Road is Ideal	High Ped Activity
	Paved Shoulder		
	Paved shoulders significantly enhance the safety and mobility of vulnerable road users, offering cyclists and pedestrians a delineated space in areas without dedicated pathways. Providing this buffer from vehicular traffic reduces the potential for VRU-involved collisions and fosters a safer roadway environment.		
	2 Foot Shoulder with Resurfacing CRF - 31% CMF ID 10288		
	$$-$$$ |	10 feet is Ideal	
	Safe Routes to School Program		
	Safe Routes to School (SRTS) programs prioritize the safety of vulnerable road users, especially children, by promoting safer walking and bicycling paths to educational institutions. By addressing infrastructure challenges and fostering educational initiatives, SRTS ensures that young pedestrians and cyclists have secure and efficient pathways, reducing their risk of traffic-related incidents.		
	CRF - 16% CMF ID 2204		
	$$ |	Sidewalk Upgrades	Intersection Crossings

Continued Table 18 - Potential Countermeasure Summary

Speed Management	FHWA Proven	**Appropriate Speed Limit**	
	Setting appropriate speed limits in areas with high VRU activity is crucial, as it directly influences the severity of potential crashes. Lower speed limits significantly reduce the risk of fatal and severe injuries to vulnerable road users, ensuring a safer coexistence of vehicles and pedestrians in these zones.		
	Fact Sheet NCHRP 20 MPH Urban Area Study		
	$ | ◷	High Pedestrian Volumes	
		Progressive Signal Timing	
	Progressive signal timing coordinates traffic signals along a corridor to ensure a sequence of green lights, facilitating smoother traffic flow and reducing stop-and-go conditions. This method improves vehicular efficiency and reduces emissions and can enhance safety by minimizing sudden stops and potential conflict points.		
	NACTO		
	$ | ◷	Urban Areas	Closely Spaced Signals
		Traffic Calming	
	Traffic calming employs various design measures to slow down vehicular traffic, ensuring safer and more pedestrian-friendly streets. These interventions, such as speed humps, chicanes, and bulb-outs, prioritize pedestrian safety, and reduced vehicular speeds, can enhance the overall quality of the local environment.		
	CRF - 6% - 50% CMF IDs - 138, 129, 131, 132 CMFs for Numerous Traffic Calming Improvements		
	$-$$ | ◷◷	Local Streets Ideal	