ATSSA

SAFER ROADS SAVE LIVES

SUCCESSFUL SAFETY SOLUTIONS

PREPARED UNDER CONTRACT BY ARORA AND ASSOCIATES, P.C.

American Traffic Safety Services Association • ATSSA.com

This case study booklet is based on a topic originally discussed during ATSSA's Circle of Innovation event held during ATSSA's Annual Convention & Traffic Expo.

American Traffic Safety Services Association (ATSSA) Publication
Prepared under contract by Arora and Associates, P.C.

Table of Contents

Overview

Over the past two decades, significant advancements have been made in the state of practice for roadway safety. This has been a result of changes in federal legislation and dedicated safety funding, collaboration across disciplines, evolving research and technology, and implementation of successful safety solutions.

State Strategic Highway Safety Plans (SHSP) have been updated multiple times and are now more robust, reflecting expanded use of effective safety countermeasures, established performance targets, and zero-based fatality goals supporting initiatives such as Towards Zero Deaths (TZD), Vision Zero, and Road to Zero Coalition.

The importance of addressing fatal and serious injury crashes on local roadways is recognized. Municipalities, counties or regions face unique issues specific to their area. Local roads safety plans (LRSP) are being developed to address these issues. LRSPs support state SHSP implementation efforts. Priority emphasis areas include roadway departure, intersections, and pedestrians, and in some cases work zones.

Roadway departure crashes continue to represent a significant number of the fatalities occurring in the United States (U.S.), in particular on rural, two-lane roadways. While wrong way driving (WWD) continues to be a challenge, a lot more is known about how to detect and mitigate these incidents. Pedestrian fatalities and serious injuries have continued to increase. Work zones present unique conditions. In consideration of these issues, transportation agencies have analyzed data to understand contributing factors, are developing action plans, and implementing strategies, in many cases, systemically.

Research has been performed to evaluate estimated crash reductions due to installation of a variety of safety countermeasures including wider pavement markings, rumble strips, signing, traffic signal modifications, and roadside safety devices. Furthermore, it has also provided a better understanding of how the interactions between road users, the vehicle, and the roadway influence the effectiveness of safety countermeasures. Federal Highway Administration's (FHWA) experimental feature process has also provided an avenue to evaluate new technology. These efforts are particularly important as advanced technology emerges.

This publication includes 16 case studies in the following areas that align with implementation of state SHSP and reflect successful safety solutions aimed at reducing fatalities and serious injuries on all public roadways:

- Local Roads Safety Plans (LRSP)
- Roadway Departure
- Wrong Way Driving
- Pedestrians
- Work Zones

Acknowledgements

This report was developed by Arora and Associates, P.C. (ARORA) under contract with the American Traffic Safety Services Association (ATSSA). ARORA undertook a synthesis of existing technical literature and research and interviewed representatives from several transportation agencies to develop the case studies included in this publication. ATSSA would like to recognize the principal researcher Priscilla Tobias, P.E., RSP (Manager, Illinois Operations, ARORA) for her work on this report.

In addition, we acknowledge the participation, support, contributions, and input from the representatives of the state and local transportation agencies. Finally, we express our gratitude to the following individuals who served on the expert panel and provided technical reviews and valuable feedback throughout the development of this publication.

Will Burney
Vice President, U.S. Guardrail Sales
Trinity Highway Products, LLC

Paul Carlson, Ph.D., P.E.
Chief Technology Officer
Road Infrastructure

Scott Chapman
Senior Global Marketing Manager
Avery Dennison

Eric Greyson
Global Technical Leader - Road Markings
Dow

Tim Hancock
Sales Director
Eastern Metal Signs & Safety

Scott Heydt
Director of Marketing, NY/NJ Sales Manager
Horizon Signal

Reed Leidle
Vice President
Safety Signs, LLC

Eric Perry, P.E.
Director of Innovation and Technical Services
American Traffic Safety Services Association (ATSSA)

Brian Watson
Regional Sales Manager
Horizon Signal

Introduction

Roadway safety is a complex multi-faceted issue that involves the consideration of human behavior, vehicle type, roadway design, operations, and maintenance. Understanding the interaction between the various types of road users as well as their interaction with the roadway itself is important to identifying opportunities to improve safety performance. Over the past two decades, significant advancements have been made in the state of practice for roadway safety due to a combination of factors including improved data analyses, evolving research and technology, increased implementation of evidence-based safety countermeasures, collaboration with stakeholders, and leveraging of limited resources. These efforts have resulted in reductions in traffic related fatalities and serious injuries, but the collective transportation body recognizes more needs to be done to eliminate serious injuries and deaths on our nation's roadways.

With the passage of Safe, Accountable, Flexible, Efficient Transportation Equality Act: A Legacy for Users (SAFETEA-LU), the Highway Safety Improvement Program (HSIP) was established as a new core federal-aid funding program with a focus on achieving significant reductions in traffic fatalities and serious injuries on all public roads. This provided the dedicated funding to focus efforts specifically at identifying crash trends and contributing factors and implementing effective safety countermeasures. States were required to develop strategic highway safety plans (SHSP). These state SHSPs provide a data-driven framework, establish safety goals, and identify key emphasis areas and multi-discipline safety strategies to aid in achieving these reductions. Implementation of state SHSPs is supported in part by the HSIP. Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing America's Surface Transportation (FAST) Act further increased the emphasis on safety by establishing requirements for safety performance measures and targets. These pieces of federal legislation, research providing a better understanding of the effectiveness of various safety countermeasures in reducing the frequency and severity of crashes, and policies established to implement these strategies systemically have been instrumental in advancing safety. State SHSPs have matured since the first ones were developed. They now include prioritized emphasis areas such as roadway departure, intersections, and pedestrians; expanded use of effective safety countermeasures; established performance targets, and zero-based fatality goals supporting initiatives such as Towards Zero Deaths (TZD), Vision Zero, and Road to Zero Coalition.

The importance of addressing fatal and serious injury traffic crashes on local roadways is recognized. Municipalities, counties or regions face unique issues specific to their area. Local roads safety plans (LRSP) are considered an FHWA Proven Safety Countermeasure and are being developed to address these issues and further support state SHSP implementation efforts. LRSPs further define the traffic safety issues and identify strategies specific to the locality. These plans are developed in collaboration with local agencies and safety stakeholders and include local roadways, both rural and urban facilities, at a minimum, but may include roadways outside of their jurisdiction, even state routes. Most notable is one size does not fit all and implementation is the key to success. State transportation agencies are making resources available to assist in the development and implementation of LRSPs.

Because roadway departure crashes continue to be one of the most over-represented fatal and serious injury crash types on all public roads, it is an emphasis area in most state SHSPs and LRSPs. Three key principles to reducing roadway departure crashes are 1) keeping motorists in their lane of travel, considered the most effective, 2) providing for safe recovery if a vehicle leaves its lane of travel, and 3) if a vehicle leaves the roadway, reducing the potential severity of the crash by using crashworthy roadside safety devices.

Providing guidance with low cost safety countermeasures such as wider pavement markings, improved delineation and signing, and rumble strips are extremely effective steps at reducing the frequency and severity of roadway departure crashes (Figure 1). Research has shown that

Figure 1. Better guidance with pavement markings and rumble strips (Courtesy of Missouri Department of Transportation)

wider pavement markings and rumble strips are extremely effective low-cost safety countermeasures. Wider pavement markings also provide improved performance of machine vision (MV) systems that provide automated driving features.

Roadside barriers are designed to shield obstacles or features along the roadway and reduce the severity of a crash should a vehicle leave the lane of travel. These devices are developed by manufacturers and tested under standardized conditions. Roadside safety devices are installed in conditions that vary widely from the sterile conditions of crash testing. Because of that, transportation agencies are encouraged to perform in-service evaluations of these devices. That provides for a better understanding of the devices' performance, helps to identify potential design, installation, and maintenances issues that may exist, and allows for improvement by all stakeholders. A collaborative process between transportation agencies and industry partners is providing avenues to improve upon these safety devices.

Because crashes can result from a number of contributing factors, transportation agencies are pursuing strategic approaches where multiple strategies are implemented systemically, based on supporting crash analysis. This is particularly advantageous on rural roads where fatal and serious injury crashes due to roadway departure may be sporadic. Safety corridors can be another means to further address this challenge and provide for a more proactive approach to safety. A safety corridor is a designated section of highway in which a multi-discipline safety approach is implemented to leverage resources and the impact of potential crash reduction.

Wrong way driving (WWD) crashes are another type of roadway departure crash and typically occur on freeways. These types of crashes continue to be a challenge for transportation agencies as they occur infrequently but typically result in fatalities. While many states have installed additional signing and pavement markings to provide better guidance, further data analysis and research have helped agencies better understand the contributing factors. Advance technology such as Light-emittling Diode (LED) Highlighted WWD Signs and vehicle detection have been implemented to further mitigate these types of incidents.

Another area that has become a priority for state and local transportation agencies is pedestrian safety. While walking is an attractive and easy mode of transportation, unfortunately, pedestrian fatalities continue to significantly increase annually. Agencies have performed systemic safety analysis to better understand where and why these crashes are occurring and have used these results to develop pedestrian safety action plans and implement a variety of safety countermeasures that are effective at reducing pedestrian related crashes. Based on analysis of more than 12,000 fatal and injury crashes, the City of San Diego is implementing leading pedestrian interval (LPI) and electronic blank-out turn restriction signs at more than 300 intersections within the city.

While work zone crashes represent a small number of the total fatal and serious injury crashes, work zones introduce unique traffic conditions that can be complex because of changing conditions and speeds, and, therefore, require more cognitive awareness by the driver. Transportation agencies across the nation have work zone activities in place, potentially at all times of the day, as they repair and maintain their roadways. Because of this, some agencies have included work zone safety as an SHSP emphasis. Transportation agencies are assessing their work zones to identify trends and are implementing unique safety countermeasures to influence driver behavior and improve work zone safety. Queue detection and temporary rumble strips alert drivers as they approach the work zone, allowing them to slow down. Presence lighting highlights an active work zone area and alerts motorists to the presence of workers during nighttime operations. Driveway assistance devices (DAD) can better direct traffic entering a one-lane work zone from a driveway or sideroad.

This publication reflects multiple case studies that encompass state SHSP emphasis areas. Many of the successful safety solutions documented are considered as FHWA's Proven Safety Countermeasures and are shown to reduce fatal and serious injury crashes based on research. Transportation agencies recognize the impact that implementation of these effective safety countermeasures can have on the safety performance of state and local roadways. They are using data to support advanced implementation and are pursuing modifications if they help advance implementation. Furthermore, collaboration between transportation agencies, researchers, and industry officials has provided an atmosphere of growth and sharing of lessons learned.

1. Local Roads Safety Plans (LRSP)

State SHSPs are developed by state transportation agencies in collaboration with multi-discipline stakeholders to identify safety needs and guide investment decisions. These plans provide a data-driven framework for establishing goals and identifying key emphasis areas and integrated safety strategies to achieve reductions in traffic-related fatalities and serious injuries on all public roads. Implementation is supported in part by the HSIP. State SHSPs have evolved and become more robust with improved data analysis, collaboration across disciplines with increased stakeholder participation, and established performance targets. In fact, many states have established zero-based fatality goals and support initiatives such as Toward Zero Deaths (TZD), Vision Zero, and Road to Zero Coalition.

Crash trends may vary widely across the state depending on the region and factors such as land use (rural and urban), topography, population, and demographics. Different issues may require different approaches, strategies and resources. Engaging local safety stakeholders is important to have a better understanding of the needs and challenges that exist in an area and to tailor strategies to address specific issues. Furthermore, metropolitan planning organizations (MPOs) have also established safety performance targets to support the state target.

A significant number of fatal and serious injury traffic crashes occur on local roadways. These include both rural and urban facilities. State transportation agencies have recognized that they need to strategically direct resources to the local level to achieve larger reductions of fatalities and serious injuries within a state. LRSPs can help support implementation of the state SHSP as they further define the traffic safety issues in a municipality, county or region, and identify strategies specific to the locality. These plans are developed in collaboration with local agencies and safety stakeholders following a similar process as the state SHSP (Figure 2), and include local roadways as a minimum, but may include roadways outside of their jurisdiction, even state routes. LRSPs developed in coordination with MPOs may include safety performance targets. These plans may also support Vision Zero efforts. Most notable is one size does not fit all. In addition, these plans can reflect local processes, needs, and issues, and the key to success is implementation. State transportation agencies are beginning to require a LRSP be in place for a local agency to obtain HSIP funding.

1.1 Washington State

Washington State adopted Target Zero with a goal of reducing fatalities and serious injuries to zero by 2030. To assist in achieving this goal, the Washington State Department of Transportation (WSDOT) established the County Safety Program to provide funding for projects that reduce fatal and serious injury crashes on county roads using infrastructure improvements and implementation of safety countermeasures. Projects are identified through each county's LRSP, which identifies and prioritizes projects based on the top crash types in the county. Projects can be improvements at specific intersections or mid-block locations, on corridors throughout a county, or countywide systemic implementation.

Figure 2. LRSP Development Process
(Source: Federal Highway Administration (FHWA), Local Road Safety Plans)

WSDOT began requiring the use of LRSP in 2014 from counties that wished to apply for HSIP funds. Since that time, 35 of 39 counties have developed a LRSP and most of those agencies have updated their plans for subsequent rounds of funding. The state provides each agency with crash data tools to help support LRSP development, including a data summary and comparison data for identifying priorities. Training has also been provided statewide to help counties in taking the data summaries and preparing a LRSP. The counties have been required to develop their own plans either with county staff or by hiring a consultant. Due to the success of the program, both in identifying safety priorities and in a better statewide trend for fatal and serious injury crashes (Figure 3) compared to other facility types, this program has expanded to include cities as well. There are currently 23 city LRSPs in Washington State as well. WSDOT recommends each LRSP include the following:

- Data analysis to identify priorities
- Identified risk factors (based on fatal/serious injury crash locations)
- Prioritized roadway network (based on presence of risk factors)
- Prioritized projects (specific countermeasures and locations in priority order based on analysis)

Since 2013, county projects have received HSIP funding aligning with SHSP emphasis areas as illustrated in Table 1.

Contact Information:

Matthew Enders, P.E., Technical Services Manager, Local Programs, WSDOT, Matthew.Enders@wsdot.wa.gov

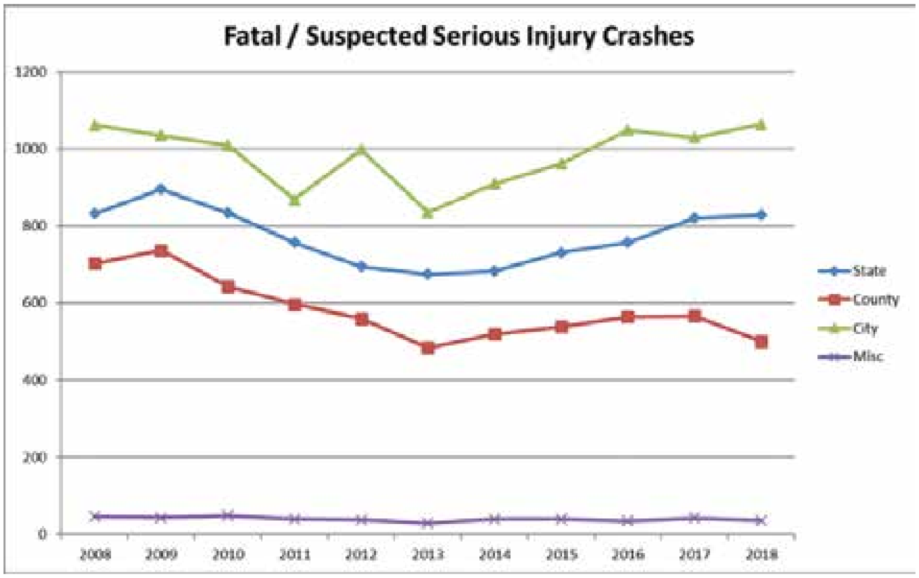

Figure 3. Washington State Fatal and Serious Injury Crashes (Courtesy of WSDOT)

Table 1. Project Type by SHSP Emphasis Areas and Funding Allocation (Data Courtesy of: WSDOT)

Roadway Departure (74%)	Intersections (22%)	Other (5%)
• Guardrail (27%) • High Friction Surface Treatment (HFST) (16%) • Signing (11%) • Clear Zone Improvements (4%) • Slope Flattening (3%)	• Roundabouts (12%) • Traffic Signals (4%) • Signal Operations and Visibility (3%) • Signing (1%)	• Pedestrians (2%) • Data Improvements (2%) • Speeding (1%)

1.2 Michigan

Michigan is a TZD state, which translates to eliminating traffic-related fatalities and serious injuries on all public roads. Because a significant number of the fatal and serious injury crashes in Michigan occur on the local roadway system, local stakeholder involvement was important during the development of the Michigan SHSP. In particular, it was noted that the different regions within the state had distinct issues and concerns specific to their area. Furthermore, while Michigan has seen reductions in fatal and serious injury crashes on the local roadways, Michigan Department of Transportation (MDOT) believed that one way to advance local safety efforts would be to develop regional safety plans. There are 14 State Planning and Development Regions (SPDR) encompassing the 83 counties in the state. MDOT worked with the SPDR to develop LRSPs for each region. Each LRSP is unique to the region. As an example, the Southeast Michigan Council of Government (SEMCOG) established a Road Safety Task Force comprised of elected officials, local governments, transportation professionals, and a wide range of additional safety stakeholders to provide input into key elements of the SEMCOG Traffic Safety Plan (Figure 4). The plan establishes safety performance targets, identifies several high priority emphasis areas based on data, details the distribution of crashes across counties, maps prioritized intersections and roadway segments, and recommends multi-discipline safety strategies.

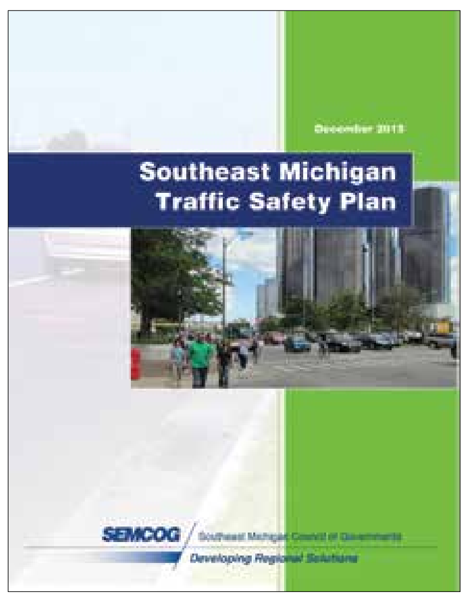

Figure 4. SEMCOG Traffic Safety Plan (Courtesy of MDOT)

LRSP implementation is accomplished in part by MDOT's highly successful Local Safety Initiative (LSI). MDOT established LSI as a free service to help local agencies improve local road safety. To participate in the program, local agencies voluntarily enroll (email MDOT-zerodeaths@michigan.gov).

LSI helps local agencies identify safety issues and emphasizes low cost safety improvements. LSI provides the following services:[1]

- Complete crash analysis of local agency's roadway system
- Identify intersection and roadway segment locations of concern, including heat maps
- Perform field reviews of the locations with the local agency representative
- Perform an engineering study or other types of analysis, as needed
- Identify potential improvements and safety countermeasures, many of which are low cost
- Conduct follow-up reviews including before-and-after analysis

Currently, MDOT supports the day-to-day LSI activities with in-house staff who perform the crash analysis and field reviews. The crash analysis identifies those locations of interest, crash types and trends. The field reviews further assist in diagnosing the safety issues and selecting the appropriate safety countermeasures. Field reviews are typically performed in the spring and summer and reports are generated thereafter. In the last two years, 36 crash analyses were completed with 28 field reviews requested and completed. Some of the low-cost safety countermeasures recommended include:

- Horizontal rumble strips approaching the intersection
- Upgrading chevrons and curve signing
- Adding reflective sheeting to signposts
- Doubling up stop signs
- Adding additional "Cross Traffic Does Not Stop" signs
- Investigating signal timing
- Replacing pavement markings

In addition, MDOT provides the local agencies information regarding FHWA's top eight "Proven Safety Countermeasures" (Figure 5) and the MDOT LSI staff contact for additional assistance. Projects identified through LSI are eligible for funding through MDOT's Local Agency Programs and receive additional bonus application points. The most recent call for projects resulted in more than 130 project applications.

Contact Information:
Stephen Shaughnessy, P.E., MDOT Safety Programs Unit Manager, Shaughnessys@michigan.gov

Figure 5. MDOT's "Common Safety Countermeasures for Local Agencies" (Courtesy of MDOT)

1.3 California

California is a very diverse state with more than 500 local agencies and 18 MPOs. California Department of Transportation (Caltrans) established the Systemic Safety Analysis Report Program (SSARP)[2] in 2016 to support local agencies' systemic safety analysis efforts. The SSARP is a state funded program that allows a local agency to trade local HSIP federal funds for State Highway Account (SHA) funds. The objective behind this exchange of funding is to eliminate administrative challenges that exist with the use of federal funds. Ultimately, the intent is to have a local agency's SSARP analysis results lead to potential projects for HSIP funding.

The SSARP has been successful at addressing safety on local roadways. To further advance the California SHSP, Caltrans is encouraging local agencies to collaborate, build partnerships, and develop a LRSP. Similar to a state SHSP, a LRSP provides a framework for identifying, analyzing and prioritizing roadway safety improvements. However, the LRSP is on a smaller scale and specific to a municipality, county or region. Caltrans has held two highly successful peer exchanges (northern and southern California) and is accomplishing further outreach to local agencies through a series of webinars. In addition, Caltrans is providing seed money to support LRSP development as well as providing focused one-day training classes.

The local agencies can choose to have their plan focus on the municipality or reflect the county or MPO region. For example, the Metropolitan Transportation Commission (MTC) for the San Francisco Bay Area is currently working on developing a regional LRSP. As part of a pilot LRSP development program, Trinity, Marin, Yolo, Nevada, and Humboldt counties volunteered to be part of the pilot and all have had their plans completed and approved (Figure 6). On a separate effort, Santa Barbara County developed a county LRSP as well.

Caltrans provides services to assist the local agencies in developing HSIP project applications. This service includes evaluating the results of safety analysis, selecting appropriate safety countermeasures, and performing a benefit-cost analysis. Linking LRSPs to local HSIP funding is now emphasized. A LRSP is highly recommended for agencies applying for the 2020 HSIP Call for Projects but will be required for the 2022 cycle. Systemic Safety Analysis Report (SSAR) or Vision Zero Action Plan would be considered equivalent to a LRSP for purposes of HSIP project applications. Any local agency requesting HSIP for a safety improvement will be required to demonstrate that the project supports implementation of the agency's local safety plan.

Contact Information:

Robert W. Peterson, P.E., Office Chief, Federal Programs, HQ Local Assistance, Caltrans, robert.peterson@dot.ca.gov

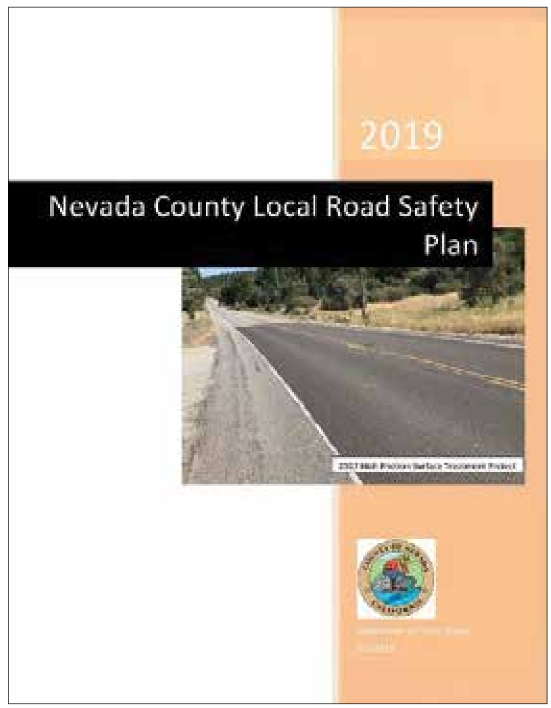

Figure 6. Nevada County, California LRSP (Courtesy of Caltrans)

1.4 Ohio

Ohio is a large state with rural and urban areas with 70 percent of the roadway miles being locally owned. Ohio Department of Transportation (ODOT) has initiated its Local Safety Assistance (LSA) program to further engage locals in the efforts to reduce traffic- related fatalities and serious injuries on local roadways (Figure 7). This program provides free technical assistance and consultant support to local agencies and MPOs to advance three FHWA "Proven Safety Countermeasures", one of which is the development of LRSP. Assistance is requested through https://ODOT.formstack.com/forms/local_safety_assistance_request.

ODOT is following the SHSP process to develop County and regional safety plans, ODOT's version of the LRSP. These mini-SHSPs document priority emphasis areas and how safety partners across the region will come together to address these issues. The LRSP includes an action plan with a localized roadmap (Figure 8) and improvements that can be used to reduce fatalities and serious injuries across a region's roadway network. This allows the local agencies to target and justify investments. Efforts started with counties and MPOs that have a high number of fatalities as well as those that have been longstanding safety champions. So far, Ohio has initiated nine regional or county safety plans.

Once a LRSP is completed, ODOT's goal is to immediately move these priorities into the implementation process. This is accomplished through additional technical assistance that aligns directly with the Ohio SHSP. This includes performing safety studies, road safety audits (RSAs), and systemic safety analysis. From these efforts, short- and long-term countermeasures are identified to address specific crash types and trends. ODOT looks at these to identify opportunities to implement larger scale systemic safety projects. At least 23 safety studies or RSAs and three systemic safety improvement analyses have been performed to date.

The results of these efforts can lead to abbreviated ($500,000 or less) or formal higher dollar safety applications for HSIP funds. Abbreviated safety applications can be submitted year-round for non-complex safety improvements. More complex improvements require formal safety applications and are submitted in April and September of each year. Funding is available for all phases of project development. So far, Ohio has funded four projects from the effort.

Contact Information:

Jordan Whisler, AICP, Local Safety & Active Transportation Manager, Office of Program Management, ODOT, Jordan.Whisler@dot.ohio.gov

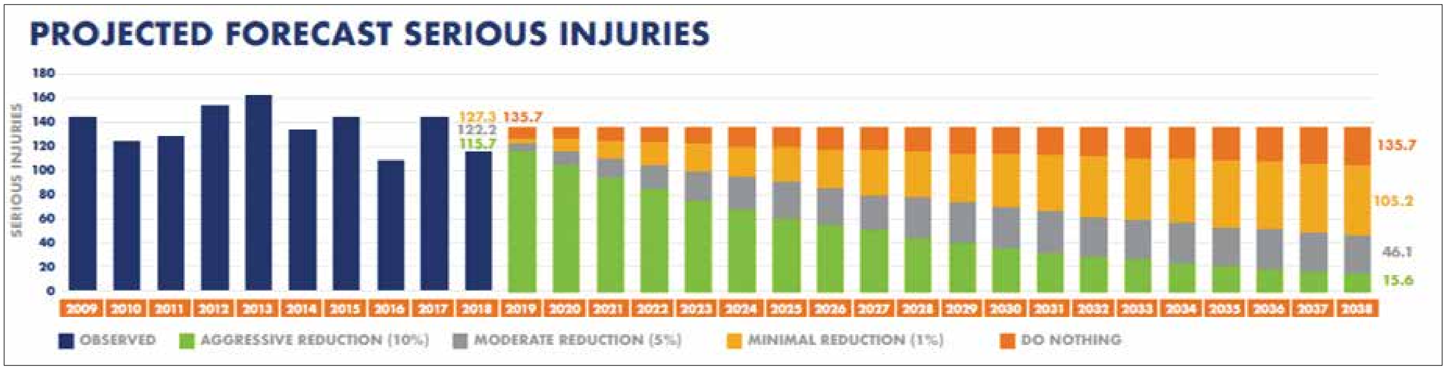

Figure 7. LRSP Projected Forecast of Serious Injuries (Courtesy of ODOT)

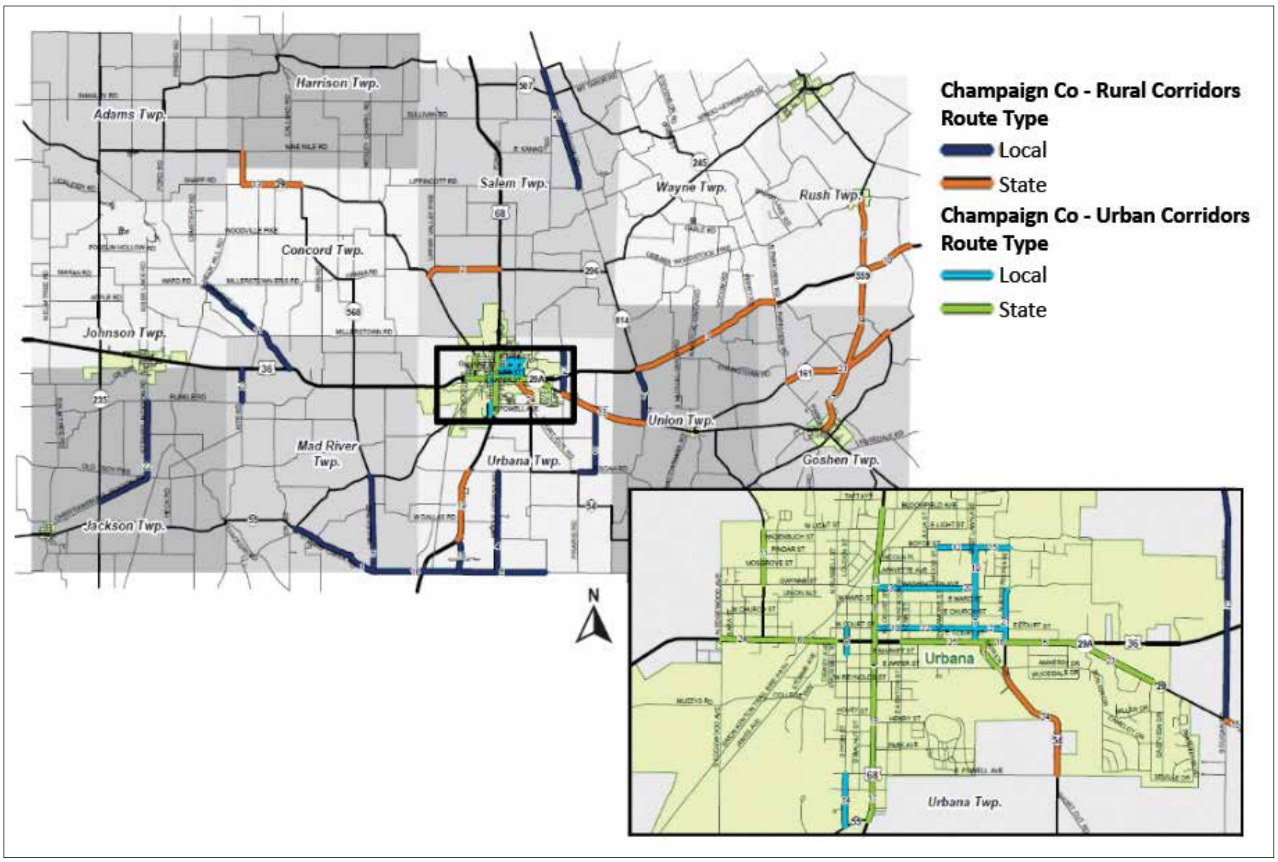

Figure 8. An Example of LRSP Priority Corridors (Courtesy of ODOT)

2. Roadway Departure

A Roadway departure crash is a result of a vehicle leaving its lane of travel and crashing. Roadway departure crashes continue to be one of the most over-represented crash types on all public roads. From 2015 to 2017 an average of 19,233 fatalities resulted from roadway departures, which is 52 percent of all the traffic fatalities in the U.S.[3] Three key principles are the basis behind efforts to reduce roadway departure crashes. First, keeping motorists in their lane of travel is the most effective method of reducing the frequency and severity of roadway departure crashes. This is done by providing guidance with pavement markings, delineation, and signing. Centerline and shoulder rumble strips alert drivers should their vehicle start to leave the travel lane due to driver distractions, drowsiness, or impairment. Second, if a vehicle leaves its lane of travel, providing for safe recovery is accomplished through the use of the safety edge, shoulders, flattened slopes and improved clear zones. Third, if a vehicle does leave the roadway, reduce the potential severity of a crash through the use of crashworthy roadside safety devices.

2.1 Strategic Approach to Addressing Roadway Departure Crashes—West Virginia

West Virginia is a very rural mountainous and heavily forested state with rivers and valleys. Sharp drop-offs, steep slopes and mountain faces adjacent to the roadway present conditions with a high potential for a fatality or serious injury if a driver leaves the roadway. Keeping drivers in their lane of travel is critical. For West Virginia, roadway departure crashes continue to represent the largest number of fatalities (65 percent) and serious injuries (56 percent), 12 percent above the next highest category of crashes.[4]

Through the implementation of West Virginia's SHSP, motor vehicle-related fatalities have been reduced by over 38 percent and serious injuries by 79 percent from 2007 to 2015. This was a result of a multi-discipline approach that also included West Virginia Department of Transportation (WVDOT) implementing a variety of infrastructure safety strategies such as High Friction Surface Treatment (HFST), shoulder and edge line rumble strips, guardrail in high risk locations, and enhanced traffic control devices. Furthermore, to improve lane delineation, WVDOT changed its policy to have all roads striped with 6-inch pavement markings.

With the update of the West Virginia SHSP, there was a renewed focus on Toward Zero Deaths. The goal set in the West Virginia SHSP projects is to reduce roadway departure fatalities by 50 percent in 2030. Strategies focused on keeping vehicles on the road and minimizing the consequences if the driver left the road. To accomplish the goal, an innovative approach was required.

WVDOT owns nearly 100 percent of its roads. In 2017, WVDOT decided to take a more strategic and focused approach to roadway departure crashes and to simultaneously address both higher classification roadways and rural routes. Roadway departure crashes were divided into two categories: 1) run-off-the-road right crashes on U.S. and WV two-lane routes, and 2) run-off-the-road left crashes on interstates and four-lane high speed corridors.

Working with FHWA, WVDOT developed an action plan that directed three years of HSIP funding to those roadways with fatalities and serious injuries above the state average. The agency also expanded use of HFST, rumple strips, curve delineation, enhanced pavement markings, and lighting and ITS.

Interstates: Interstates represent 1.4 percent of the roadway miles but 9 percent of the fatalities.[4] Crash data was analyzed to identify those corridors that had higher rates of roadway departure crashes, in particular those where the vehicle left the lane of travel towards the median. They directed $53 million to improve 128 miles of interstate medians (Figure 9).

- **High-Tension Cable Rail:** Older low-tension cable rail installations are being replaced with high tension cable rail systems and concrete mow strips are being added. The medians throughout this area are also being regraded to 6:1 side slopes to improve recoverability of the errant vehicle.
- **Guardrail End Treatments:** In addition, all guardrail end treatments are being upgraded.
- **Shielding of Bridge Piers and other fixed objects:** Modified thrie-beam bullnose median barriers (bullnose attenuators) are being added to shield bridge piers and other fixed objects in the median (Figure 10). This has required significant grading in the area.

Figure 9. Interstate Safety Improvements (Courtesy of WVDOT)

- **Intelligent Transportation System (ITS) and Traffic Management Center:** Inclement weather (snow, fog, rain) contributes to a portion of the roadway departure crashes. WVDOT has analyzed crash data in combination with the Road Weather Information System (RWIS) data to identify those corridors most likely to have roadway departure crashes during inclement weather. Based on this, criteria have been developed and an additional $4 million has been directed to install new Dynamic Message Signs (DMS) with cameras. WVDOT is evaluating the use of ITS enhanced signs for temporarily lowered speed limits during the inclement weather and is working to bring better information to commercial motor vehicle (CMV) traffic. CMVs account for 25 percent of crashes in West Virginia, particularly on those roadways across the state with steeper grades.

U.S. and WV State Routes: These two-lane facilities represent over half of the fatalities and serious injuries occurring on WV roadways. U.S. routes represent 25 percent of the fatalities but only 4.7 percent of the roadway miles and WV state routes represent 31 percent of the fatalities but only 9.5 percent of the roadway miles.[4] Crash data was analyzed, and categories of safety strategies were aligned with identified crash trends.

- **Roadside Updates:** WVDOT identified those corridors where enhanced barrier locations would be beneficial and directed $2 million to each of the 10 WVDOT districts to update existing roadsides and install new guardrail systems. Because fixed objects such as utility poles are often a factor in roadway departure crashes, guidance documents for delineation of utility poles within right-of-way have been developed and locations for utility pole delineation have been provided to utility companies. Recognizing that keeping vehicles on the roadway is critical, WVDOT developed criteria for using rumble strips in areas prone to inclement weather and is investigating the use of mumble strips.

- **Curves:** Improved delineation of curves is important, especially because of the terrain in West Virginia. WVDOT has identified those curves with higher rates of crashes and the associated geometric data. This information provides an indication of those features that are more likely to result in an increased number and severity of crashes and has allowed WVDOT to update existing guidelines. $12.5 million has been directed for delineation of curves. This would include added signing that would meet Manual on Uniform Traffic Control Devices (MUTCD) requirements (Figure 11).

- **Nighttime Crashes:** Traditional lighting warrants have been problematic in rural areas. WVDOT has attempted to address lighting for rural corridors with new criteria. Based on these guidelines, $3 million has been directed to either install new or upgrade to LED lighting at those locations with nighttime crashes.

- **HFST:** Systemic safety improvements of HFST have been implemented on curves and other locations such as bridge decks and vertical curves approaching intersections where friction demand is greater than available.

Contact Information:

Donna J. Hardy, P.E., Mobility and Safety Engineer, WVDOT, Donna.J.Hardy@wv.gov

Figure 10. Shielding Bridges with Bullnose median barriers (Courtesy of WVDOT)

Figure 11. Improved Curve Delineation (Courtesy of WVDOT)

2.2 Rural Safety Corridors—North Dakota

Addressing fatal and serious injury crashes on rural roadways can be more challenging due to the number of miles of roadway in relation to the number of fatal and serious injury crashes and the randomness of those crashes. Safety corridors can be another means by which to further address this challenge and provide for a more proactive approach to safety. A safety corridor is a designated section of highway in which a multi-discipline safety approach is implemented to leverage resources and the impact of potential crash reduction.

In 2009, North Dakota experienced unprecedented growth associated with the extraction of crude oil. This resulted in increased traffic volumes and motor vehicle crashes. Roadway departure crashes involving single vehicles on rural roadways represented the majority of the fatalities and serious injuries, with those related to overturning, rollovers, and hitting fixed objects such as trees, utility poles, and traffic signs being predominate. Alcohol and/or drugs, speeding, and lack of safety belt use were also contributing factors to these crashes. To address this growing trend, North Dakota Department of Transportation (NDDOT) directed safety resources to systemically implement a variety of low-cost safety strategies such as enhanced road edges (rumble strips and wider edge lines), horizontal curve delineation (warning signs), and intersection recognition (lighting, signing and pavement markings) on state and local roadways. This helped reduce traffic related fatalities by 22 percent.[5]

In 2018, when North Dakota developed its Vision Zero Plan, safety stakeholders recognized that they could build on these past successes and looked towards an additional approach that could be effective at reducing fatal and serious injury crashes. The concept of rural road safety corridors was identified as a Vision Zero priority strategy. NDDOT collaborated with state and local law enforcement to establish and implement the rural safety corridor initiative (https://youtu.be/11VOOrZrOh8) (Figure 12).

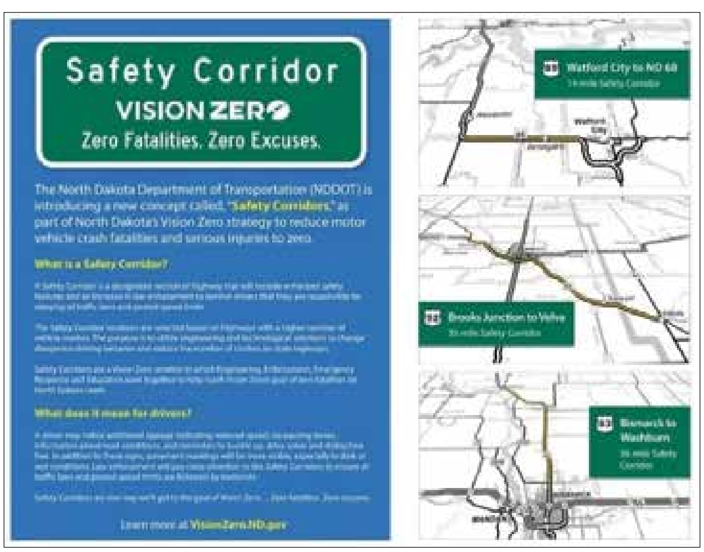

Figure 12. Safety Corridor Information Sheet (Courtesy of NDDOT)

From the beginning, this has been a collaborative partnership between NDDOT and law enforcement. Early input from law enforcement has been critical in identifying specific corridors and opportunities to maximize the effectiveness of this effort. The goal is to utilize engineering and technology solutions to change behavior and combine them with enforcement, education, and emergency response, to ultimately reduce motor vehicle fatalities and serious injuries.

NDDOT evaluated the state roadway system and selected three corridors based on those having a higher number of vehicle crashes and a higher crash density.

- Rte 85, Watford City to ND 68—14-mile Safety Corridor
- Rte 52, Brooks Junction to Velva—35-mile Safety Corridor
- Rte 83, Bismarck to Washburn—36-mile Safety Corridor

Large signs display the message "***Safety Corridor VISION ZERO, Zero Fatalities. Zero Excuses.***" They clearly identify the safety corridor upon entry. Changeable message signs (CMS) are used to convey safety messages, traffic laws, and road conditions to motorists. This is further supported with visible law enforcement to remind motorists about obeying the traffic laws. In the future, advanced technological solutions such as alerts provided through a vehicle's audio-visual systems may be added to the corridor.

These corridors already have shoulders and rumble strips in place. Wider pavement markings (6-inch wet reflective grooved in-place) and new delineators are being installed to provide increased visibility, especially in the dark or wet conditions. No passing zones are signed on both sides of the roadway and have pavement marking words "DO NOT PASS" at the beginning of these zones. Based on data analysis, some locations along Route 52 will have shoulders converted to turn lanes.

Sections of roadway with reduced speed limits will have "Reduced Speed Ahead" signs, pavement marking words "45 MPH" and transverse speed reduction zone pavement markings at the beginning of the zone. Digital speed indicator boards with the regulatory signs will also be installed.

Initial implementation is scheduled for Fall 2019 for Routes 85 and 52 with Route 83 to be completed in 2020. The average cost for this initiative is $65,000/mile.

Contact Information:

Jane Berger, P.E., NDDOT Programming Engineer,
jeberger@nd.gov
Karin Mongeon, P.E., NDDOT Safety Division Director,
kamongeon@nd.gov

2.3 Wider Pavement Markings

Increasing delineation of the travel lane is key to keeping motorists in their lane of travel and, ultimately, reducing roadway departure crashes This is done by providing guidance with pavement markings, delineators, and signing. Longitudinal pavement markings (centerlines, lane lines and edge lines) delineate travel lanes. The MUTCD specifies a minimum of 4 inches as the width for longitudinal pavement markings and historically that is what transportation agencies have used. A recent AASHTO survey shows that many states are transitioning to 6-inch wide markings as research demonstrates the safety benefits of wider pavement markings (Figure 13). Furthermore, 6-inch wide markings have also been shown to be beneficial for machine vision (MV) systems providing automated driving features. In 2018, ATSSA sponsored research to evaluate the effects of pavement marking widths, specifically 4-inch and 6-inch wide markings, and MV based advanced driver assistance systems (ADAS). Using preformed pavement marking tape, various lighting and environmental conditions were considered. The research results show that 6-inch wide markings provide improved and consistent MV detection performance, especially under the more challenging wet daytime conditions.[6]

In 2012, a FHWA research study "Safety Effects of Wider Edge Lines on Rural, Two- Lane Highways" was performed based on data from Michigan (6-inch edge lines), Kansas (6-inch edge lines) and Illinois (5-inch edge lines and centerlines). Winter crashes were excluded to ensure that the safety effectiveness of the pavement marking widths could be evaluated without any influence of snow or ice coverage. This study found the implementation of wider edge line markings on two-lane roadways resulted in significant reductions in crashes in all three states. Specifically, the estimated fatal and injury crash reduction for Kansas and Illinois was over 35 percent, and 15 percent for Michigan.[7]

Most recently, the Idaho Transportation Department (ITD) sponsored a study, "Safety Impacts of Using Wider Pavement Markings on Two-Lane Rural Highways in Idaho." This study is unique in that driver behavior simulation was performed to evaluate driver lane deviations related to varying edge line widths and pavement marking deterioration. The simulation results demonstrated that during nighttime driving conditions, drivers tend to position themselves closer to the edge line and as the line deteriorates, drivers will move closer still to the edge of pavement. Furthermore, the study indicates that 6-inch pavement markings deteriorate more slowly than 4-inch pavement markings, ultimately providing for longer term safety benefits. Based on the analyses, implementation of 6-inch edge line pavement markings results in an estimated 14 percent reduction in the number of fatal and serious injury crashes. The benefit-to-cost ratio for implementation of wider pavement markings on Idaho's rural two-lane roadways statewide is approximately 25:1.[8]

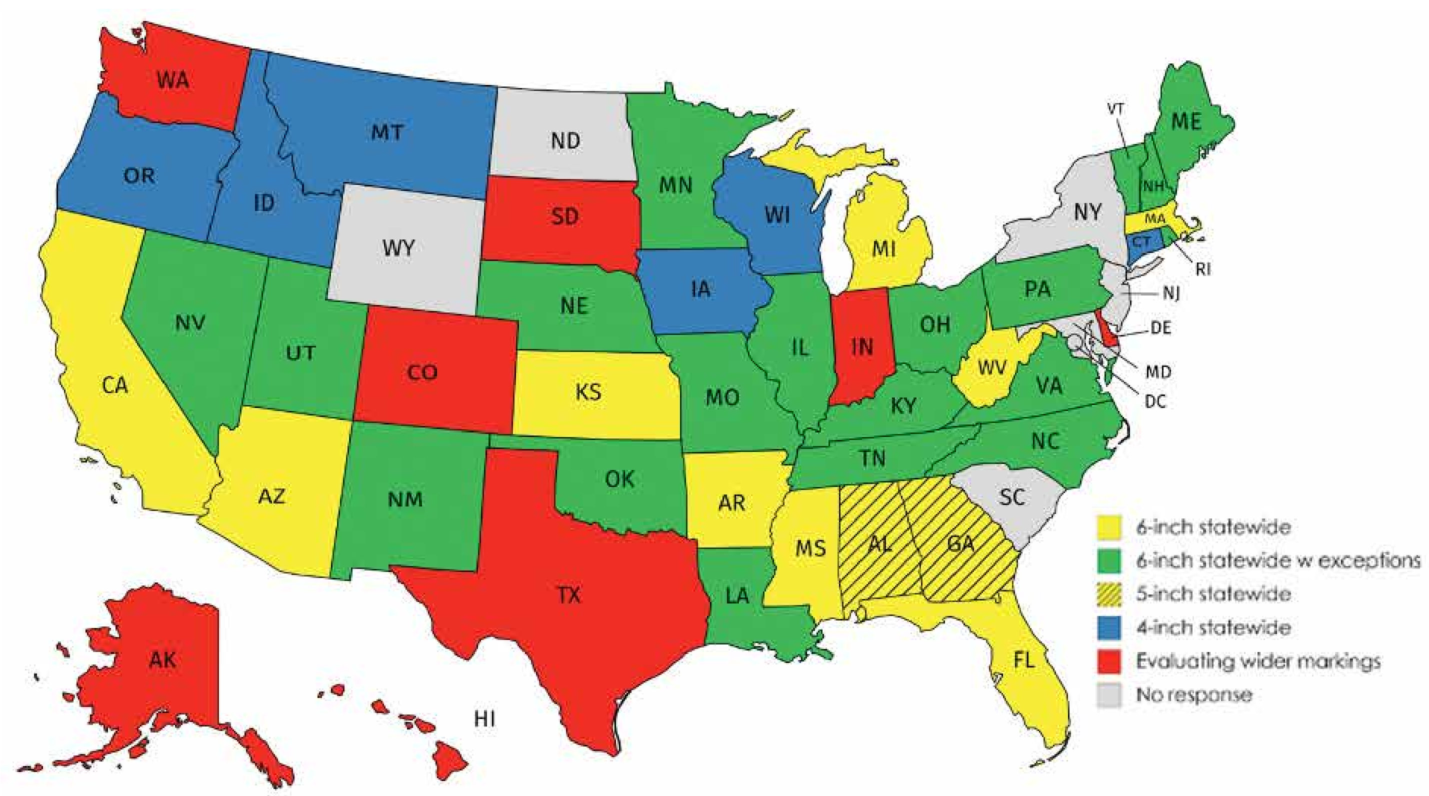

Figure 13. US Map of States and Longitudinal Pavement Marking Widths
(Courtesy of Paul J. Carlson, Ph.D., P.E, Chief Technology Officer Road Infrastructure Investment Holdings, Inc.)

2.3.1 Michigan

MDOT made a policy decision in 2004 to switch from 4-inch edge lines to 6-inch on all state trunkline roads. This was done to improve the visibility of the lane delineation on Michigan's roadways and thereby reducing roadway departure crashes. This changeover was implemented immediately with nearly all state roadways being re-striped with 6-inch longitudinal edge lines within the first year. The research study performed in 2012, which analyzed over 850 miles of Michigan rural two-lane roadways, supported this decision. Furthermore, the study indicated nighttime crashes in Michigan were estimated to be reduced by over 30 percent and wet weather crashes reduced by 67 percent.[7] Center line pavement markings have remained at 4-inches. MDOT is currently in the process of transitioning its freeway lane lines to 6 inches.

In 2007, more than 60 percent of Michigan's traffic fatalities were related to roadway departure. Implementation of the wider edge lines and other safety strategies directed at roadway departure crashes have helped Michigan reduce the associated fatalities to less than 50 percent of the total number of traffic fatalities.[9]

Well-maintained pavement markings are important in providing motorists with the necessary guidance to stay within their lane of travel, especially during inclement weather and nighttime conditions. Due to snow plowing activities throughout a significant portion of the year, MDOT restripes approximately 90 percent of the longitudinal pavement markings on an annual basis, totaling nearly 160 million feet of material. MDOT primarily uses both waterborne and spray thermoplastic pavement markings as that allows the agency to cover a significant number of miles of roadway at a relatively low cost and maintain the safety benefits of this treatment. MDOT recesses durable longitudinal markings to increase the longevity of the material and has also begun recessing all longitudinal marking materials placed on 3R/4R projects to retain increased presence after winter maintenance.

MDOT's pavement markings policy is very robust, detailing the purpose of the markings, requirements for installation, and the annual maintenance efforts. This includes a section where durable pavement marking material may be selected for use based on factors including AADT and a history of nighttime crashes.

Contact Information:

Mary K. Bramble, P.E., Pavement Marking and Delineation Engineer, Design Division, Traffic and Safety Section, MDOT, BrambleM1@michigan.gov

2.3.2 North Carolina

The 2012 research study results on the safety effectiveness of wider edge lines prompted the North Carolina Department of Transportation (NCDOT) to experiment with wider lines (centerlines and edge lines), longer life pavement marking materials, and highly reflective optics. Considerations for this were the improved durability of different types of pavement marking materials (long-term cost savings), improved safety performance, increased night-time visibility of the travel lanes, reduced exposure of workers applying pavement markings, and planning for use of autonomous vehicles. Between 2014 and 2017, NCDOT installed new pavement markings on 435 miles (99 sites) of rural two-lane roadways with an average AADT of 2,000. Thermoplastic was primarily used although polyurea was used in the mountainous area of North Carolina. Of the 99 sites, 41 locations had 4-inch centerline and edge lines (Figure 14) installed and 54 locations had 6-inch centerline and edge lines (Figures 15 and 16). Four locations had 5-inch markings applied. Standard beads were used in almost half of the total locations while highly reflective optics were used in the remainder of the applications.[10]

Before-and-after speed data was evaluated to determine if the newly striped roads and improved delineation would influence driver behavior. Results showed no significant increases in either the average speed or the 85th percentile speed.[11]

NCDOT has begun performing preliminary evaluation of the safety effectiveness of the wider lines as well as with the performance of the longer life pavement marking materials and higher reflective optics. While post-installation crash data is still being collected for the more recent installations, preliminary results for the older 6-inch pavement marking installation sites indicate an overall reduction in lane departure crashes of approximately 19 percent. The retroreflectivity numbers for the highly reflective optics were high for the first two years but were comparable to the standard reflective optics thereafter.[11]

NCDOT is now installing 6-inch, longer life pavement markings as a low-cost safety countermeasure on select secondary roads that have concentrations of roadway departure crashes and has directed $35 million of HSIP funding toward systemic longer life pavement markings on secondary roads.

Contact Information:

Matt Springer, P.E., Signing and Delineation Standards Engineer, Signing and Delineation Unit, NCDOT, mspringer@ncdot.gov

Carrie L. Simpson, P.E., Safety Evaluation Engineer, Traffic Safety Unit, Transportation Mobility & Safety Division, NCDOT, clsimpson@ncdot.gov

Figure 14. 4-inch Thermo Standard Media (Courtesy of NCDOT)

Figure 15. 6-inch Thermo Standard Media (Courtesy of NCDOT)

Figure 16. 6-inch Thermo Highly Reflective Media (Courtesy of NCDOT)

2.4 Rumble Strips

More than half of U.S. traffic fatalities occur after a driver crosses the edge or center line of a roadway. Almost two-thirds of these fatal crashes occur in rural areas.[12] Centerline rumble strips (CLRS) and shoulder rumble strips (SRS) have been implemented by states across the nation for several years and have proven to be an effective countermeasure to address these types of crashes. The grooved pattern causes the wheels of a vehicle to vibrate upon leaving the travel lane, creating a noise that alerts the driver and allows for self-correction. This helps address roadway departure crashes related to inattention, distraction, and drowsiness. Additionally, it can provide an indication of the lane limits to the driver during inclement weather.

FHWA lists CLRS and SRS as "Proven Safety Countermeasures." Studies have shown that for rural, two-lane roadways, CLRS provides a 44 percent reduction in head-on fatal and injury crashes and SRS provides a 29 percent reduction in single vehicle run-off-the road fatal and injury crashes.[13]

Transportation agencies have modified their CLRS and SRS design and installation practices to address issues such as pavement preservation, bicycle accommodation, and noise. Designs have included reducing the width, spacing and placement location of the rumble as well as even the type of rumble. The rumble stripe (Figure 17), where the pavement marking stripe is placed directly on the rumble, is an alternative to SRS. This also increases the visibility of the edge of pavement. In recent years, to address the noise issues, some states have experimented with alternative designs such as sinusoidal rumble strips, or "mumble strips." Mumble strips have a rolling sine wave pattern that is slightly recessed into the pavement surface. While research has been performed to evaluate the noise reduction, additional studies are underway to evaluate the safety effectiveness of this design. Furthermore, some southern states have also used alternative audible lane departure warning systems such as profiled pavement markings (pavement markings with audible bumps) or rumble bars (raised preformed thermoplastic strips adhered to the road surface).

Figure 17. Centerline and Shoulder Rumble Stripes (Courtesy of MoDOT)

2.4.1 Missouri

Missouri Department of Transportation (MoDOT) is a pioneer in systemically implementing CLRS and SRS to address roadway departure crashes and has had a policy in place for over a decade requiring the installation of CLRS and SRS on the state's major roads (principal arterials and higher) with some exceptions to the policy (e.g., city limits, noise concerns, etc.). Most major roads in Missouri have CLRS and SRS. MoDOT places the pavement markings in the rumble strip for both the CLRS and the SRS, creating a rumble stripe.

For installation of CLRS, MoDOT requires the pavement to either be concrete or to have at least 1-inch bituminous surface thickness. This is to ensure the integrity of the CLRS and the existing pavement. CLRS are 12 inches wide except when installed for median passing lanes. In those instances, two sets of 12-inch rumble strips are installed parallel to each other and separated by 24 inches, creating an overall centerline stripe/buffer of 48 inches (Figure 18). MoDOT policy does not recommend CLRS installation on roadways with pavement widths 20 feet or less.

SRS are required on all paved shoulders that are at least 2 feet wide and the road is posted at least 50 mph. To avoid shoulder deterioration, MoDOT requires surface material to be placed at least 18 inches beyond the edge of the travel way to accommodate milling in the SRS for the rumble stripe (Figure 19). The shoulder condition is required to be evaluated prior to installation of the SRS. A narrow 6-inch version of the standard SRS design can be used where the shoulder width or structure does not permit the typical installation.

While CLRS and SRS have not been required previously on its minor road system, they are now being installed during resurfacing projects as part of MoDOT's systemic approach to safety. New thresholds for systemic installation of paved shoulders and SRS have been established for these minor roads. For roads with an AADT of 4,500 or more, the expectation is to add 2-foot paved shoulders and SRS as part of resurfacing projects. Paved shoulders and SRS are to be considered for roads with an AADT of 2,500 to 4,500. Apart from the systemic approach, there are other lower volume roads that have received paved shoulders and SRS based on crash history.

Figure 18. Median Passing Lane CLRS (Courtesy of MoDOT)

Figure 19. Shoulder Rumble Stripes (Courtesy of MoDOT)

Contact Information:

Jonathan Nelson, P.E., Assistant to the State Highway Safety and Traffic Engineer, MoDOT, Jonathan.Nelson@modot.mo.gov

2.4.2 Michigan

In 2007, more than 60 percent of the total fatal crashes occurring in Michigan were due to roadway or lane departure. Strategies such as CLRS and SRS were identified to mitigate these types of crashes. In 2008, MDOT began a three-year initiative to install CLRS statewide on 5,400 miles of rural non-freeway roadways, while also adding SRS at sites that met the installation criteria but did not have SRS already installed. CLRS were installed on roadways that were greater than 20 feet in paved roadway width and were posted 55 mph. SRS were added to roadways with paved shoulders at least 6 feet in width and posted 55 mph. This was the largest installation of its kind in the United States at that time and provided MDOT an excellent opportunity to study the impact and effectiveness of these safety treatments. MDOT funded a two-phase project to do this.

Phase I studied the impacts of CLRS on driver behavior, bicycle safety, roadside noise, and short-term pavement performance. Results indicated that rumble strips cause drivers to better align their vehicle within the lane of travel and pay more attention to their driving, leading to improved driver performance and reductions in the frequency and severity of crashes. The shoulder width and the gap provided with SRS helped accommodate bicyclists' needs. Rumble depth affects noise and based on results, MDOT established a 0.5-inch standard depth for the rumbles.[14]

Phase II studied the impact of CLRS on crashes. Evaluating before-and-after data of the 5,400 miles of rural non-freeway roadways demonstrated the following reductions:

- Fatal crashes—51 percent reduction
- Serious (A-) injury—41 percent reduction
- Head-on crashes—50 percent reduction
- Opposite sideswipe crashes—55 percent reduction
- Run-of-the-road crashes—46 percent reduction

The benefit-to-cost ratio assuming a 2 percent discount rate was 58:1.[15] These results make CLRS a cost-effective countermeasure that has been instrumental in reducing roadway departure fatalities and serious injuries in Michigan. In an effort to expand CLRS installations across the state, MDOT developed an informational brochure (Figure 20) that documents the benefits, safety performance, and design considerations of CLRS.

MDOT uses a continuous CLRS with variations in the design dependent on the type of pavement. On HMA pavements, the CLRS is 16 inches wide. For concrete pavements, the CLRS is a 6-inch continuous rumble strip on each side of the centerline joint. The issue of long-term centerline joint deterioration associated with HMA pavements has been nearly eliminated by improving the agency's longitudinal joint density specification (12SP-501Y-04). Incentives are provided to the contractor for meeting or exceeding 90.50 percent density. Negative quality adjustments are used for densities below 90.50 percent and if any joint subsection density is less than 88.00 percent, the contractor is required to saw or route and seal the joint. If the density is below 86 percent, the contractor may be required to remove and replace the joint.[16]

SRSs are used on freeways and on non-freeway roadways in Michigan. MDOT uses a 7-inch rumble, 5-inch gap pattern. For freeways, the SRS is a 16-inch wide continuous rumble strip offset 4 to 6 inches from the pavement joint line, except in urban areas where the rumble may be offset up to 12 inches from the edge of the travel lane. For non-freeways with paved shoulders that are 6 feet or wider, MDOT uses a 12-inch wide rumble strip with a repeating cycle of 60 feet (48 feet of rumble strip,12 feet of gap).

Minnesota Department of Transportation (MnDOT) and a few other states have implemented mumble strips. MnDOT sponsored the "Sinusoidal Rumble Strip Design Optimization Study" to evaluate the sound level of four different types of CLRS mumble strip designs. The ultimate goal was to identify a design that would maximize safety performance while minimizing exterior noise associated with rumble strips. The study results provided a recommended design (14-inch sinusoidal wavelength, 14 inches wide, 1/16 – 1/2-inch depth) that performed better for pickup trucks and motorcycles.[17]

Figure 20. MDOT CLRS Informational Brochure (Courtesy of MDOT)

This research was the basis for the MDOT mumble strip design[18] (Figure 21). MDOT uses the same width as the MDOT CLRS and SRS design. A few pilot projects have been implemented in each MDOT region. Installations have included placement on the centerline, the shoulder, and the edge line. Project locations were selected considering those areas where the agency had received noise complaints and where narrower shoulders did not allow for the standard SRS installation. MDOT has begun to perform field evaluations for noise levels. Preliminary results for the shoulders installations indicate interior noise levels within the recommended range (NCHRP Report 641[13]) and exterior noise was 10 DB lower than the typical SRS design. MDOT will continue to evaluate the safety impacts and performance of the mumble strip installations to determine if and how to expand the use of this design.

Contact Information:

Mary K. Bramble, P.E., Pavement Marking and Delineation Engineer, Design Division, Traffic and Safety Section, MDOT, BrambleM1@michigan.gov

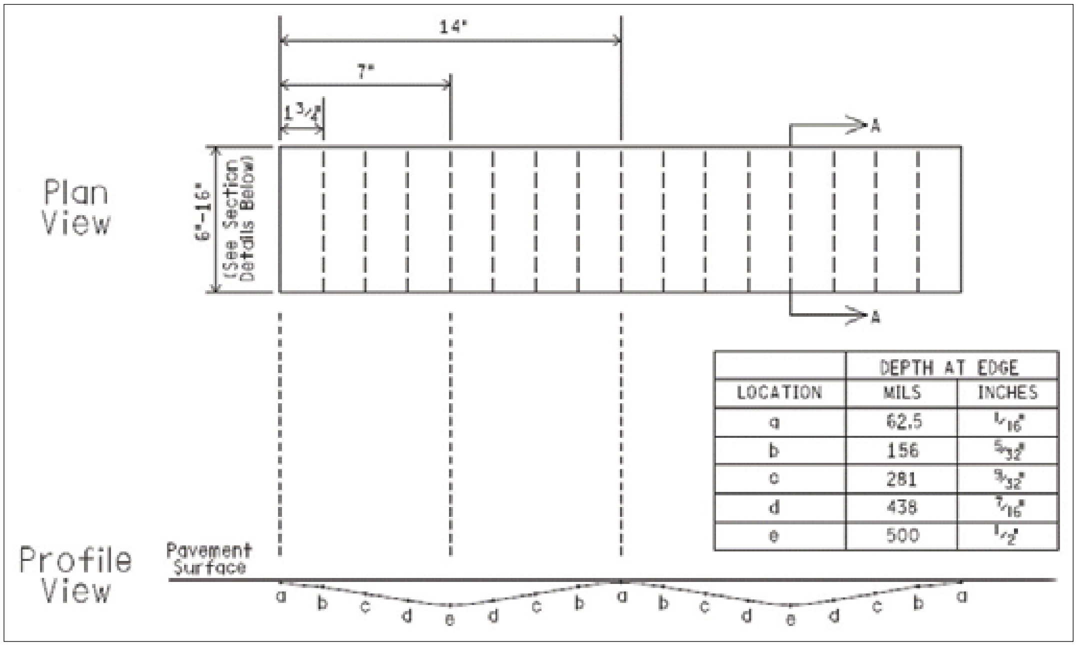

Figure 21. MDOT Mumble Strip Design Detail[18]

2.4.3 Nevada

Roadway departure crashes represent the highest number of fatalities for Nevada. In addition, because of the number of fatalities occurring on rural roads, Nevada meets the High Risk Rural Roads (HRRR) Special Rule requirements. Nevada Department of Transportation (NDOT) has looked to low cost safety improvements such as CLRS and SRS that can effectively reduce these types of crashes.

NDOT uses CLRS on its rural two-lane facilities. Many of these are very rural, low volume roadways with older pavement structures that were chip sealed every couple of years. NDOT installed several miles of CLRS on these roads as part of the HRRR program. The original design was a continuous 12-inch-wide rumble strip with a corrugation pattern consisting of a 12-inch gap, 7-inch rumble strip. While the safety benefits of the CLRS were positive, unfortunately, due to the age and condition of many of the pavements, the centerline joints deteriorated and created significant maintenance issues. NDOT needed to make modifications to its design in order to continue to implement this cost-effective safety countermeasure. NDOT changed its CLRS design from a continuous rumble to a repeating cycle 40 feet in length (20 feet of rumble strip, a gap of 20 feet) and narrowed the CLRS from 12 inches to 6 inches. In addition, NDOT changed the corrugation pattern to a 5-inch gap and 7-inch rumble strip. Two-way, left-turn lanes have the CLRS staggered as well. This new design addresses NDOT's pavement joint deterioration issues but also better accommodates motorcycles when passing other vehicles.

Many of the rural two-lane roadways in Nevada have narrow shoulders. Some of these same roads are also state-wide cross-country bicycle corridors. NDOT's design of SRS has been modified over time to address shoulder width and pavement preservation issues and to make the shoulders more bicycle friendly. The original SRS design was a 16- inch continuous rumble strip. It was used only on rural roadways with shoulders that were 4 feet and wider. This limited its application, but it also was not very bicycle friendly. In 2017, NDOT began implementing 6-inch edge line pavement markings on rural two-lane roads. This was done in combination with SRS. The new SRS design is a 6-inch wide rumble stripe that is placed on all rural roadways with shoulders that are 1-foot and wider (2 feet for inside shoulders of multi-lane rural divided highways). A repeating cycle of 60 feet (45 feet of rumble strip, 15 feet of gap) has replaced the continuous SRS. This new SRS design allows NDOT to expand its efforts to address roadway departure crashes and provides for improved and safer accommodations for bicycles (Figure 22).


Figure 22. Nevada Modified SRS Design (Courtesy of NDOT)

Contact Information:

Lori Campbell, Traffic Engineering, NDOT, LCampbell@dot.nv.gov

Figure 23. Profiled Pavement Markings[19]

Figure 24. Typical Rumble Bar Installation (Courtesy of Paul J. Carlson, Ph.D., P.E., Chief Technology Officer, Road Infrastructure Investment Holdings, Inc.)

2.4.4 Texas

Texas Department of Transportation (TxDOT), like many states has installed CLRS and SRS on roadways across the state to address roadway departure crashes. However, because of narrow shoulder widths or thin pavement surfaces such as seal coats, installing the traditional milled CLRS or SRS is not desirable. TxDOT has implemented other alternatives. These include various audible lane departure warning systems such as profiled pavement markings (Figure 23) and more recently, rumble bars (raised preformed thermoplastic strips adhered to the road surface) (Figure 24) which provide auditory and tactile warnings.[19] TxDOT sponsored research to evaluate the safety effectiveness of 189 miles of rural two-lane roadways. Research results estimated fatal and injury single vehicle run-off-the-road and opposite direction crashes were reduced by 32.5 to 39.9 percent.[19]

Further research was performed to evaluate the noise levels and determine if the various alternative designs provided sufficient auditory levels to alert the driver. Research results indicated that while the noise levels were dependent on the vehicle type and speed, the levels were typical of the standard milled rumble strips.[20]

Overall, based on the two research reports, these alternatives are viable options to milled rumble strips, particularly for roadways that have seal coat treatments or narrow shoulders.[20]

Contact Information:

Douglas Skowronek, P.E., PTOE, Policy & Standards Branch Manager, Traffic Safety Division, TxDOT, Doug.Skowronek@txdot.gov

2.5 Assessing Roadside Barriers—Washington State

Roadside barriers are designed to shield obstacles or features along the roadway and reduce the severity of a crash should a vehicle leave the lane of travel. These devices are developed by manufacturers and tested under standardized conditions set forth in National Cooperative Highway Research Program (NCHRP) Reports 350 or AASHTO's Manual on Assessing Safety Hardware (MASH). Transportation agencies approve the use, establish policies and guidelines for the design and installation, and maintain these devices on their highways. Contractors are trained by manufacturers to properly install the approved devices. Each of these stakeholders plays an important role in the practical application and in-service performance of roadside barriers.

The WSDOT initiative was prompted by its interest in confirming proper initial guardrail installation and maintenance. The agency’s solution is a collaborative approach that engages not only representatives from WSDOT but also FHWA and the various guardrail manufacturers. WSDOT included representatives within the agency responsible for the administration and implementation of policy, design, construction and maintenance. By including FHWA and the guardrail manufacturers, it provides unique opportunities for open communication between everyone involved with roadside hardware to work collectively to identify systemic issues and a variety of solutions (Figure 25).

Washington is a very diverse state with differing topographic and environmental conditions to consider when designing, constructing, and maintaining roadside safety hardware. This is important when assessing locations to determine if they meet WSDOT and manufacturers’ requirements, and if the designs and installations meet expectations and address safety issues. The team visited three of the six WSDOT regions over a four-day period and looked at over 30

Figure 25. Guardrail Assessment Team (Courtesy of WSDOT)

Figure 26. Guardrail Assessment Team and Design Considerations (Courtesy of WSDOT)

Figure 27. Grading and Guardrail Assessment Team (Courtesy of WSDOT)

recent installations of NCHRP 350 and MASH guardrail end terminals on rural two-lane roadways, freeways, and interchange ramps, along with a number of associated barrier installations. Issues and recommendations were categorized as design, pavement preservation projects, construction, and terminal specific.

Specifically for design, the results of the field reviews demonstrated the value of continuing to look for design guidance improvements (Figure 26). It was noted during the field reviews that WSDOT is very thorough in its design policies. The importance of the basics such as length of need, especially at curves, and gaps between sections of guardrail was emphasized. The field reviews also provided an opportunity to capture unwritten best practices and consider highlighting in design guidance documents.

WSDOT utilizes buried-in backslopes terminals, the preferred end treatment by FHWA, as it eliminates any possibility of a direct terminal hit. The field reviews reaffirmed the design details, specifications, and the installation procedures are appropriate and recognized that there could be an increased opportunity to expand the use of this type of terminal. The team determined improved design guidance and web-based training could be used to promote the use of buried-in backslope designs and to work to eliminate gaps less than 300 feet between runs of guardrail to reduce the number of terminals.

Grading in advance and around the terminals as well as along the runs of guardrail is important to ensure the guardrail system functions properly if impacted by a vehicle. AASHTO provides two recommended options for grading around the terminal, a preferred option and an alternate design. A state may choose to have its own layout. Manufacturer specifications reference using a state standard or AASHTO preferred designs. The team noted that adopting the AASHTO preferred design as the state standard would be one option for providing more consistent and predictable installations.

Grading was more of an issue on preservation projects where guardrail systems were being upgraded without any additional other work beyond the edge of pavement (Figure 27). For these types of projects, a more thorough evaluation of existing site conditions during the design phase could have better addressed issues of existing grades of shoulders and earth slopes. While the WSDOT design standards for terminals specify the required grades, existing conditions may require additional earthwork, yet the appropriate earthwork pay items and quantities often have not been accounted for in the plans. This is common among states. The collaborative review process provided a platform for these types of issues to be discussed and resolved collectively. In this case, the team recommended modifying design policies to address this systemic issue, but also educating the WSDOT staff on the importance of grading with guardrail systems.

Several issues related to the actual installation of the various devices were identified during the field reviews. They included incorrect transition connection selection, challenges associated with installing tangent terminals on tight curves, missing post leave-outs, an unawareness of installation options for differing conditions (e.g., posts in rock), and challenges meeting certain manufacturer's tolerances. This is where the open communication and collaboration provided the most significant benefit and where having the construction staff and the manufacturers as part of this team was critical. The discussions focused on understanding the issues and potential solutions. These discussions resulted in a number of suggestions to modify WSDOT design standards, specifications and guidance to highlight manufacturers' instructions or provisions. Requiring the use of manufacturer checklists was thought to be a good way to address some of these common issues. One challenge is to what degree these devices need to meet the manufacturer specifications. This brings up discussions as to what level of tolerance is acceptable, how critical it is if a device is built outside the stated level of tolerance and whether there are best practices in achieving certain tolerances.

Figure 28. Collaborative Guardrail Assessment Team (Courtesy of WSDOT)

During the field reviews, one of the findings was an inconsistent application of the terminal manufacturer installation checklist. In order to help make sure the checklist was getting used during construction, one idea raised was to make the checklist an official part of the documentation process. Another benefit of this approach was to document the proper installation of the device for future verification in the event of a crash. Because the field reviews included region maintenance staff, they shared that their field activity tracking tool might be a good alternative for this purpose. The tool (called HATS for Highway Activity Tracking System) is deployed in the field using tablet computers, includes a section for end terminals, and allows for the attachment of photographs. The suggestion was made that either maintenance or inspectors with tablets could create a HATS record for the terminal, provide basic information, and attach photos to the record. They could also take a photo of the checklist and attach that as well. This collaborative approach ensures that the checklist would be immediately accessible by location and would become part of the history of the device as it is maintained over time. This was seen as a significant advantage for design and construction staff. For maintenance staff, making the record using HATS provides a way to explore how inventory of a range of constructed items (not just terminals) taken immediately following construction could be used to make sure that HATS is as current as possible with the constantly changing highway environment. A pilot location for the initiative has been identified on a recent project, in this case one managed by a co-located construction/maintenance office, to see how the idea can be brought into mainstream practice.

Overall, one of the key findings as a result of the reviews was that routine communication between each of the stakeholders and reviews such as the one performed can be very useful in identifying issues early, and moving findings into meaningful processes, updating guidance, and implementing training improvements. All team members recognized that special attention is needed by all for new devices to ensure proper installation, and the use of such reviews can identify where additional training is needed (Figure 28). To a large extent, existing guidance, specifications, and standards appeared to properly address many of the issues identified; however, the team determined that more explicit information and direction would be beneficial, especially when supported by increased training. This is especially true where an increasing number of new devices are being deployed, and staff turnover has impacted availability of field experience. It is important to note that following each review, a detailed communication with the contractor or appropriate maintenance staff was made to bring the issues found during the review up to standard; this needs to be a standard practice in all reviews of this kind. Ultimately, the findings with recommendations will be documented in a final report and WSDOT is exploring how they use this collaborative process review on a regular basis.

Contact Information:

John P. Donahue, PE, AICP, Design Analysis and Policy Manager, WSDOT Development Division, DonahJo@wsdot.wa.gov

2.6 In-Service Evaluation of Roadside Safety Devices—Maine

Roadside safety devices are installed in conditions that vary widely from the sterile conditions of crash testing. Because of this, transportation agencies are encouraged to perform in-service evaluations of these devices. This provides for a better understanding of the devices' performance, helps to identify potential issues that may exist, and allows for improvement by all stakeholders.

Maine Department of Transportation (Maine DOT) has established an in-service performance program for roadside safety devices. This includes a robust inventory of over 23,000 end terminals and over 14,000 other guardrail assets, a field review of existing and new installations, risk assessment, and training.

As part of its asset management program, Maine DOT has a database with GIS mapping for all roadside hardware. This inventory is developed by maintenance staff within Maine DOT and includes the type of device, location, and pictures of the device when inspected and whether it is on the “State Property Damage” list. Each district within Maine DOT has a Guardrail Transportation Operations Manager (TOM) who is knowledgeable on roadside hardware devices and regularly drives the district to assess the condition and follows established protocols on repairing or replacing damaged roadside devices. The GIS layer in the inventory has a “State Property Damage” layer so that the Guardrail TOM can track repairs and update the inventory once a device has been replaced. Repairs are performed through an on-call contract.

In 2015, Maine DOT performed a detailed inspection of a random sample of end terminals. A checklist was developed using the manufacturers' installation guide. This assessment included evaluating the installation of the device itself and the grading of shoulders and earth slopes adjacent to the terminal. If an issue was identified, a determination was made as to whether it was critical to the operation of the system if hit. Based on this checklist, each device was rated as fully functional, some deficiency, or non-functioning. From this detailed inspection, Maine DOT determined that more was needed to ensure:

- Proper site conditions for the product application
- Proper installations
- Proper maintenance and repairs

Maine DOT began an aggressive training program. Inspectors are now trained on an annual basis. YouTube videos have been developed by Maine DOT for each end-terminal device using the manufacturers' check sheets and are on Maine DOT's qualified products list by device. These videos point out things to look for and are readily available to inspectors and contractors during installation.

Trinity SoftStop
(https://youtu.be/OISlz5UY05A)

Road Systems Inc. MSKT-SP-MGS
(https://youtu.be/7W9KvWHA6Gc)

Lindsey Transportation Solutions MAX-Tension TL3
(https://youtu.be/AgfXg-b5-bM)

The "Guardrail Garden" (Figure 29) was established in partnership with Maine DOT and manufacturers and contractors. Each of the terminals on Maine DOT's qualified product list is installed along with a run of guardrail. During the installation of these devices, the manufacturer representative was on site to ensure proper installation. The industry partners installed this "Guardrail Garden" in a Maine DOT maintenance yard to provide a visual training ground for inspectors and contractors. Maine DOT has held training events at the Guardrail Garden. There are plans to add MASH end treatments and cablerail to the "Guardrail Garden."

Figure 29. "Guardrail Garden" (Courtesy of Maine DOT)

Detailed inspections continue annually to assess most recent installations. Maine DOT has also performed a risk assessment of all barrier systems (rail, terminals, etc.). Crash records were reviewed, and states were surveyed to gain knowledge of their experiences with roadside barrier performance. This risk assessment determined that the roadside barriers are doing what they are intended to do. To enhance in-service performance evaluation efforts, Maine DOT will be piloting an In-Service Evaluation Tool.

Contact Information:

Dale Peabody, P.E., Director, Transportation Research, MaineDOT, Dale.Peabody@maine.gov

3. Wrong Way Driving (WWD)

Wrong way driving (WWD) (Figure 30) crashes on freeways continue to be a challenge for transportation agencies as these types of crashes occur infrequently but typically result in fatalities. While WWD crashes represent approximately three (3) percent of total crashes occurring on high-speed divided highways, these crashes have a higher fatality rate.[21] Past research has helped transportation agencies better understand the issue of WWD and the factors leading to these types of crashes. Virginia found the fatality rate for WWD crashes on controlled access highways to be 27 times that of any other type of crash.[22] WWD crashes are distinctly different from head-on median crossover crashes. Most wrong way driving incidents begin with the driver entering a controlled-access exit ramp the wrong way although there are instances where the adverse driver has accessed the opposing lanes of travel through median crossover points. Studies continue to confirm alcohol-impaired driving to be the most significant contributing factor. With respect to their age group, older drivers are also more likely to be involved in wrong way driving crashes. In analyzing FARS data from 2004 to 2009, NTSB determined that drivers aged 70 to 79 years old and 80 years and older represented 2.5 times and 30 times, respectively, the number of wrong way drivers compared to right-way drivers involved in fatal WWD crashes. These factors provide unique challenges when selecting and implementing safety countermeasures. Resources developed through past research have helped states across the nation implement traditional and advanced technological safety countermeasures.

Figure 30. Wrong Way Driving (Courtesy of Jeff Frost, FDOT)

3.1 WWD Advanced Countermeasure Implementation—Florida

Florida Department of Transportation (FDOT) has taken a proactive and process-centric approach to systemically address WWD. This approach has included leadership involvement, strategic implementation of countermeasures, and extensive research. Since 2014, FDOT has performed a series of research, development, and implementation studies focused on analyzing trends and contributing factors, identifying needs for enhanced design standards, understanding human cognitive processes and limitations, and implementing a variety of safety countermeasures. The frequency and severity of WWD incidents are being monitored to evaluate the impacts of these data-driven and multi-discipline efforts.

Between 2011 and 2015, there were 435 fatalities and 1,486 serious injures due to WWD crashes in Florida. Contributing factors in Florida are similar to the national trend. A greater number of WWD crashes occurred in urban areas, on weekends and during late night hours, in particular, for the impaired driver. Diamond, partial diamond, partial cloverleaf, and trumpet interchange types have experienced a high number of WWD crashes.

Daytime and nighttime field reviews were performed to evaluate locations and determine the predominant factors. Based on recommendations from the 2012 NTSB Special Investigation Report[21] and recognizing the driving characteristics and limitations of both impaired and older drivers, FDOT developed and implemented new signing and pavement marking standards (Figure 31) for interchange exit ramp terminals. These standards include:

- MUTCD “optional” signs
    - Second DO NOT ENTER sign
    - Second WRONG WAY sign
    - ONE WAY signs
- NO RIGHT TURN and NO LEFT TURN signs
- 3.5 feet by 2.5 feet WRONG WAY signs mounted at a 4-foot height with retroreflective strip on sign supports
- 2-4 dotted guideline striping for left turns between ramps entrances/exits and cross-streets
- Retroreflective yellow paint on ramp median nose where applicable
- Straight arrow and route interstate shield pavement markings in left-turn lanes extending from the far-side ramp intersection through the near-side ramp intersection to prevent premature left turns
- Straight arrow and ONLY pavement message in outside lane approaching the ramp exit

Human factors research focused on several aspects including nighttime crashes with impaired drivers and daytime crashes with older drivers. The researchers determined a combination of visual cues that assist drivers in making better decisions, and that an optimum combination of countermeasures should be considered by transportation agencies.[23]

FDOT began its systemic process-centric approach to WWD mitigation by performing systemic and hot spot analysis of WWD crashes (2011-2015) on freeways with a specific focus on all FDOT maintained off-ramp locations. Heat maps were developed to evaluate the correlation between demographics and land use (Figure 32) and WWD incidents (Figure 33). These heat maps reflected density of alcohol sales establishments, locations that attract older drivers such as senior communities and healthcare facilities, and additionally, tourist attractions. The correlation between the location of alcohol establishments and WWD crashes was high. This analysis provided an opportunity to develop a WWD Countermeasures Implementation Plan to mitigate WWD incidents.

The evaluation of all off-ramps on the Florida state highway system allowed FDOT to identify the primary factors that could be contributing to a potential WWD incident. From this, FDOT was able to prioritize each off-ramp location for implementing the WWD safety countermeasures. As a first step, FDOT identified and prioritized 520 ramps by each FDOT District and is providing funding to implement advanced WWD safety countermeasures statewide. FDOT has implemented the following advanced WWD safety countermeasures and seen significant success in detecting and mitigating WWD incidents.

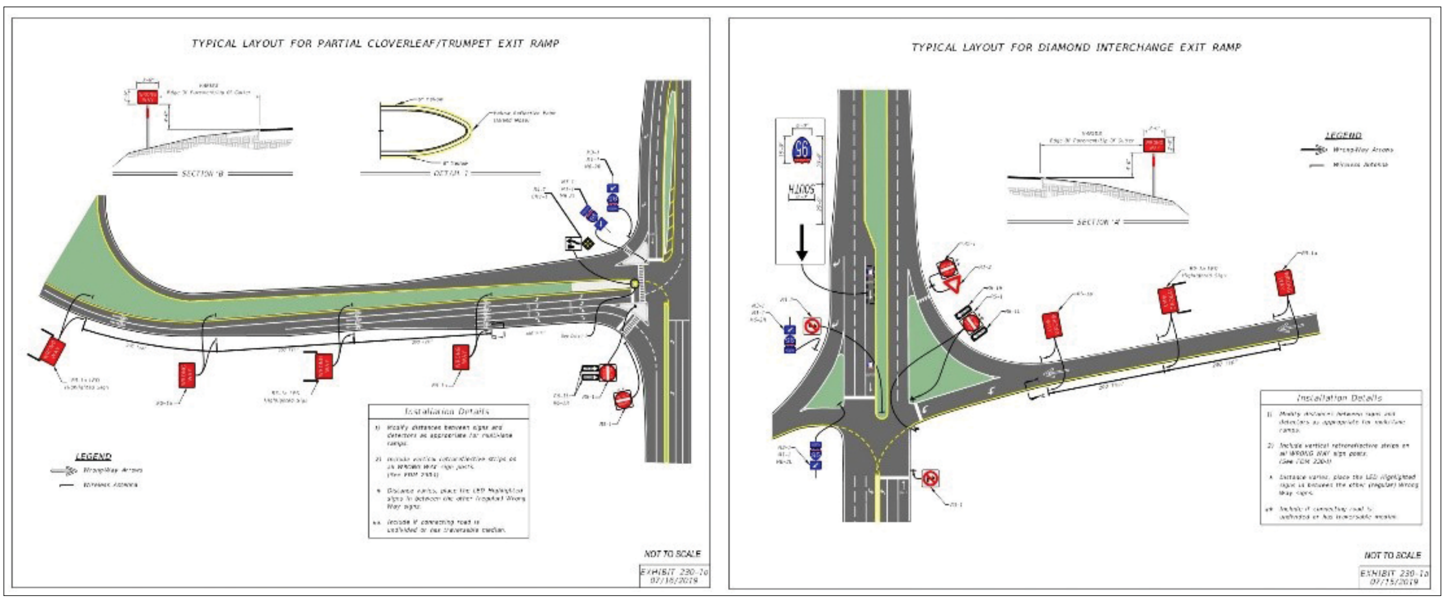

Figure 31. Standards for Interchange Exit Ramp Terminals (Courtesy of FDOT)

Figure 32. Density of Alcohol Sales Establishments in Florida (Courtesy of FDOT)

Figure 33. Density of Alcohol-related WWD Crashes in Florida (2011-2015) (Courtesy of FDOT)

1. **Red Rapid Rectangular Flashing Beacon (RRFB):** FDOT has found these devices to be an effective WWD safety countermeasure. A set of two Red RRFB per ramp were installed.
2. **Light-emitting Diode (LED) Highlighted WWD Signs:** FDOT has found these signs to be effective as well. The LED highlighted sign system (Figure 34) detects and deters WWD incidents. The devices are either solar powered or line powered and are integrated by fiber optic or wireless communications into the FDOT District's Traffic Management Center (TMC). For long ramps or ramps with limited sight distance, two sets of the pairs of highlighted signs may be used.
3. **Red Flush-Mounted Internally Illuminated Raised Pavement Marker (IIRPM)**
4. **Detection-Triggered Blank-out Signs that flash "WRONG WAY**
5. **Wigwag Flashing Beacons**

The Red RRFB and LED-Highlighted WWD signs were the most frequently deployed WWD countermeasures. While all FDOT District offices are now implementing the countermeasures, FDOT Districts 3 and 7 and the Florida Turnpike Enterprise (FTE) have implemented the initial pilot projects. Research results have shown the following effectiveness:

FTE system:

- **LED Warning Signs** were installed at 17 ramps in South Florida in late October 2014 and monitored through February 2019. There were 68 confirmed WWD events and over 95 percent turnaround rate.
- **Red RRFB** were installed at 18 ramps in Central Florida in June 2017 and monitored through February 2019. There were 34 confirmed WWD events at these locations with over 95 percent turnaround rate.

FDOT District 7 installed Red RRFB in June 2016 and has monitored the location for a 2-year period. Prior to installation there had been seven WWD crashes. After installation, no WWD crashes have occurred.

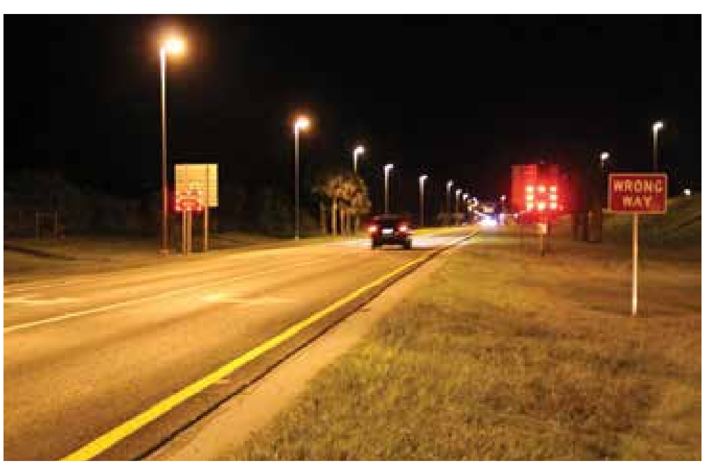

Figure 34. LED Highlighted WWD Signs (Courtesy of FDOT)

These countermeasures have demonstrated success but if a driver misses all of these alerts then there needs to be a means to warn other drivers on the roadway as well as transportation and law enforcement agencies of a WWD driver. FDOT is currently testing and evaluating various WWD detection systems. These systems detect the vehicle traveling in the wrong direction, and record and send video to the TMC for incident verification. Once confirmed as a WWD incident, the public is alerted through a message on the DMS. The Florida Highway Patrol is notified as part of a standard operating procedure in place for immediate response.

FDOT leadership has placed WWD as a high priority crash type and made the commitment to prevent all WWD incidents in the state. To aggressively tackle the WWD issue, the Department's leadership has directed resources to strategically implement advanced WWD safety countermeasures and has created education campaigns through collaboration with the Florida Highway Patrol and other safety partners.

Contact Information:

Raj Ponnaluri, PhD, P.E, PTOE, PMP, Connected Vehicles and Arterial Management Engineer, FDOT, raj.ponnaluri@dot.state.fl.us

3.2 WWD Vehicle Detection—Wisconsin

The Wisconsin Department of Transportation (WisDOT) has had success using technology and working with core stakeholders in the Milwaukee area to identify and alert wrong way drivers and reduce the potential for crashes that are often deadly. The challenge with WWD incidents and crashes is understanding the issue, identifying locations with higher risk for these occurrences, and determining the contributing factors. For WisDOT, solving this problem started as a collaboration between local law enforcement and a DOT champion.

Milwaukee County Sheriff's Office (MCSO) approached WisDOT to initiate discussions on how best to address the issue of WWD. A WisDOT safety engineer in the Milwaukee area worked with law enforcement to analyze crash and citation data. Crash analysis results (2012-2016) indicated that approximately 8.2 percent of fatal crashes occurring on freeways were a result of WWD and over 40 percent of the WWD crashes occurred in the southeast region of Wisconsin (Milwaukee County). More than 47 ramps in the Milwaukee County area had been entered the wrong way.[24] WisDOT noted that it was difficult to determine where drivers would enter the freeway and that not all wrong way driving incidents resulted in crashes. Impaired driving combined with unique interchange designs due to the dense urbanized area and high traffic volumes contribute to the frequency of WWD incidents in this region.

Figure 35. WWD Countermeasure Implementation (Courtesy of WisDOT)

Figure 36. WWD Video Verification (Courtesy of WisDOT)

Figure 37. DMS Messaging for WWD Alert (Courtesy of WisDOT)

Improved signing and pavement markings were installed at interchanges with side-by-side entrances and exit ramps to enhance visibility and deter wrong-way entry. In addition, WisDOT installed flashing signs that were set to activate based on time of day (Figure 35).

WisDOT Southeast Region partnered with the MCSO to fully implement WWD detection systems at 20 locations in the county. The systems provide 24-hour radar detection, have photo verification capability, and are linked to the overhead DMS on the freeway system. Once a wrong way driver is detected, the system software sends a "High Priority Alert Detected!" notification with an audio pop-up to WisDOT's TMC. Email and text alerts are also received. A series of photos is provided through the software for verification (Figure 36).

The WisDOT TMC operator activates the DMS with a "WRONG WAY DRIVER REPORTED" message (Figure 37) and, if possible, identifies or locates the vehicle traveling the wrong way. The notification is also linked to the MCSO. A photo confirmation is provided to MCSO ensuring the agency is not chasing false calls, and an officer is immediately dispatched. If the wrong way driver cannot be confirmed by the video camera or law enforcement within 10 minutes, the message is removed from the DMS.

WisDOT and MCSO have developed standard communication protocols on required information if a law enforcement officer becomes aware of a WWD incident. This allows for immediate response and incident tracking. It has helped engage law enforcement statewide in this effort. A new crash report form with additional fields of data that could be useful in filtering for WWD crashes was implemented January 1, 2017.

Since implementation of this collaborative initiative, WWD crashes have decreased in this area. Video has captured incidents where vehicles have turned around due to the alert system. This new technology is used at higher risk locations to monitor the site and better focus mitigation strategies. WisDOT and MCSO continue to be active partners in this initiative.

Contact Information:

Brian Porter, P.E., PTOE, State Traffic Safety Engineer, Bureau of Traffic Operations WisDOT, brian.porter@dot.wi.gov

4. Pedestrian Safety

Walking is one of the simplest ways to be active and to get from one place to another, making it an attractive mode of transportation. Unfortunately, each year pedestrian fatalities comprise about 16 percent of all traffic fatalities with approximately 5,000 pedestrian deaths. Another 65,000 pedestrians are injured in roadway crashes annually.[25] Even more alarming is that while all other traffic fatalities decreased 6 percent between 2008 and 2017, pedestrian fatalities increased by 35 percent.[26] While many state SHSPs include pedestrians as an emphasis area, transportation agencies are approaching this issue with an entirely new focus and communities are using Vision Zero as a platform to increase emphasis on identifying and expanding successful safety solutions. FHWA has identified several Proven Safety Countermeasures such as the pedestrian hybrid beacon (PHB) (Figure 38) and the leading pedestrian interval (LPI) directed at pedestrian safety. Pedestrian safety action plans are providing a framework to apply innovative approaches to data analysis, identification of crash trends and contributing factors, and systemic implementation of a variety of safety strategies.

Figure 38. Pedestrian Hybrid Beacon (Courtesy of VDOT)

4.1 Pedestrian Action Plans and Systemic Safety

The increasing trend in pedestrian fatalities and serious injuries has transportation agencies looking to move beyond the typical “hot spot” improvement. Agencies are performing systemic safety analysis, using other non-traditional data sources to better understand factors contributing to these types of crashes, and developing pedestrian safety action plans to implement a variety of safety countermeasures systemically.

4.1.1 Virginia

From an all-time low number of traffic related fatalities and serious injuries in 2014, Virginia experienced an increase for three years. A large part of the increase was an approximate 50 percent rise in pedestrian-related traffic fatalities. As a result, in 2017 Virginia DOT (VDOT) conducted a detailed review of all pedestrian fatalities and a sample of serious injuries to identify the causal factors, built environment and land uses. The assessment revealed that a significant number of these pedestrian crashes occurred at unsignalized intersections and mid-block crossings where land-use creates pedestrian demand.

Following the crash assessment, VDOT worked with a coalition of interdisciplinary and intergovernmental stakeholders and initiated the development of a statewide Pedestrian Safety Action Plan (PSAP). The Virginia PSAP establishes a national model for rapid plan development and delivery of safety projects. It includes five elements:

1. geospatial crash analysis to identify priority clusters;
2. geospatial analysis of pedestrian crash risk and propensity for travel to identify priority corridors;
3. creation of example ‘cut sheets’ of systemic countermeasures for the top clusters and corridors;
4. sharing the results with safety partners and programming quickly deployed systemic projects; and
5. evaluating VDOT policies and procedures to improve pedestrian accommodations and countermeasures.

The PSAP priority clusters focused on dense pedestrian crash locations, which allowed VDOT to focus on specific crash types. The associated Priority corridors were identified using a systemic methodology that seeks to identify locations based on risk factors and not necessarily a recorded crash history. The 12 criteria used in this methodology included factors such as volumes, crashes, speeds, land use, census population and employment data, and proximity to parks and schools. Categories of the criteria were weighted based on input from stakeholders to score each corridor segment. To enhance the methodology, additional criteria were identified for future PSAP updates when statewide, regional or jurisdictional data is available. The individual roadway segments that scored high in the systemic corridor analysis were pieced together to create cohesive sections of roads that represent a similar context. These became priority corridors for further consideration (Figure 39). For this first PSAP, only the top 1 percent or 181 corridors were prioritized for projects.

The PSAP included a description of countermeasures that are proven with expected crash reductions. The four types of countermeasures that VDOT commonly cited in the PSAP for priority locations included high visibility crosswalks (Figure 40), curb extensions, PHB, and RRFB. Criteria for selecting countermeasures included number of lanes, speed limit, volumes, presence of medians, crosswalks, signalized crossings, pedestrian activity, and driver compliance.

VDOT used the data from the spatial analysis to create an online mapping tool (https://bit.ly/VDOTPSAP) for local agencies to see all the priority sites. "Cut sheets" identifying the crash cluster or priority corridor sites were developed as part of the PSAP and are accessed through hyperlinks on the mapping tool. Crash history, crash severity, crashes by year, descriptions of the crash cluster locations, and countermeasure recommendations are provided for each location. This allows the local agency to consider both candidate systemic and higher cost spot improvements.

Since completion of the PSAP, VDOT has shared the plan and the associated resources with local agencies and has hosted several educational workshops to provide them assistance. To demonstrate commitment to this initiative, VDOT directed its 23 U.S.C. Section 154 "Open Container" transfer funds to HSIP to support implementation of the PSAP. During VDOT's call for 2018 HSIP Bicycle and Pedestrian Safety projects, applicants were to identify if the project was at a PSAP identified location and a systemic treatment. Over $17 million in needs were submitted with the top scoring receiving $8 million in available funding. Projects were low cost safety improvements with high benefit and quickly implementable, with most expected to be completed in 2019. VDOT is working closely with MPOs to expand the PSAP implementation.

Contact Information:

Stephen Read, P.E., Highway Safety Planning Manager, VDOT, Stephen.Read@vdot.virginia.gov

Figure 39. Pedestrian Safety Corridors (Courtesy of VDOT)

Figure 40. High-Visibility Crosswalks (Courtesy of VDOT)

4.1.2 Ohio

As many other states, Ohio has seen an increasing trend in pedestrian fatalities and serious injuries. ODOT has created a Pedestrian Safety Improvement Program (PSIP) to address the pedestrian safety issue strategically. This program will provide eligible high-risk jurisdictions the funding and assistance to implement proven low-to-medium cost pedestrian safety countermeasures along high-risk facilities.

Ten counties that include major population centers across the state represent 65 percent of Ohio's pedestrian fatalities. A significant number of pedestrian-related fatal and serious injury crashes occur on arterial roadways and when compared to the number of miles of roadway, are over-represented. Crashes occurring at mid-block crossings are the most predominant fatal crash type on these high-risk pedestrian facilities. The other two top crash types are related to through-vehicle movements at intersections and walking along the roadway.

Eight cities with the highest number of fatal and serious injury numbers on arterials are considered "high-risk jurisdictions" for purposes of the PSIP. ODOT has directed $10 million to the PSIP with each of the eight cities receiving $500,000 base funding and an additional allocation based on the percent of pedestrian fatalities. ODOT has established a process to fully implement this action plan. Each jurisdiction identifies, prioritizes and submits project locations and safety countermeasure bundles to ODOT for review and approval. Once locations and strategies are finalized, ODOT designs and advertises the project for construction.

Eligible Countermeasures (Figure 41) include:

Roadway Geometry:

- Curb Ramps with Detectable Warnings
- Raised Crosswalks
- Curb Extensions
- Pedestrian Refuge Islands
- Reduced Curb Radii

Signalization:

- Pedestrian Hybrid Beacons
- Accessible Pedestrian Signals
- Pedestrian Countdown Signals

Other Elements:

- Street Lighting

Pavement Markings:

- High-Visibility Crosswalk Markings
- Advanced Yield Markings

Signage:

- Standard Crosswalk Signage
- Overhead Signage
- Rectangular Rapid Flashing Beacons

Contact Information:

Jordan Whisler, AICP, Local Safety & Active Transportation Manager, Office of Program Management, ODOT

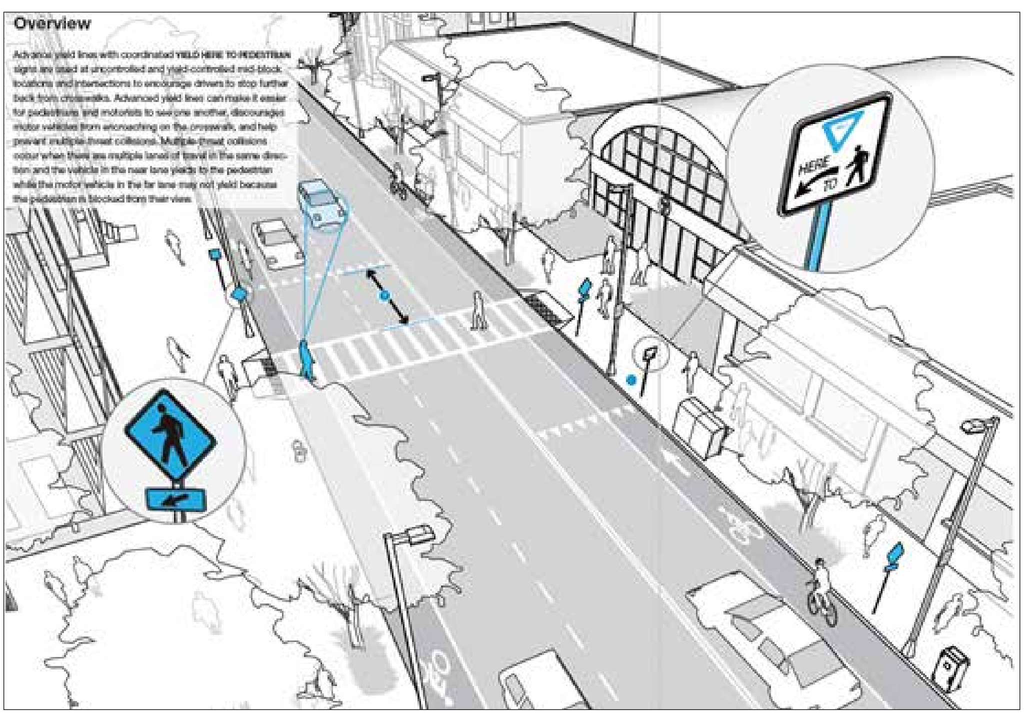

Figure 41. Pedestrian Safety Countermeasures (Courtesy of ODOT)

4.2 Strategic Approach to Pedestrian Safety—Delaware

Delaware is a very small but densely populated state with distinct highly urbanized areas and substantial transit use. This translates to challenges addressing pedestrian related traffic crashes and a pedestrian fatality rate that has continued to climb. In 2017, Delaware's pedestrian fatality rate per 100,000 population was the second highest in the nation[26], making pedestrian safety a significant issue. While pedestrian safety is evaluated and engineered as part of most transportation projects, Delaware felt like a more strategic approach would change this alarming trend.

Pedestrian safety is an emphasis area in the "Delaware Strategic Highway Safety Plan: Toward Zero Deaths" which identifies crash trends, corridors, and several "best practice" safety countermeasures focused on reducing pedestrian fatalities and serious injuries. A large number of pedestrian crashes are occurring in urban areas on high-speed, multi-lane arterials and divided highways, in dark conditions, and involving no contributing factors by the driver of the vehicle. While a portion of these crashes are occurring at intersections, mid-block crossings are an issue.

A Pedestrian and Bicycle Safety Working Group that includes representatives from state and local transportation and law enforcement agencies was established to develop ideas and methods for improving pedestrian and bicycle safety through multi-discipline strategies. This collaborative approach works because it is not just one agency's problem to solve. The Delaware Department of Transportation (DelDOT) identifies principal arterial corridors with high concentrations of pedestrian crashes. These corridors are typically considered for pedestrian safety audits by a multi-discipline team.

The pedestrian safety audit process involves performing a detailed pedestrian safety study. Pedestrian and bicycle crash history is analyzed, existing data is compiled, and pedestrian counts and observations are performed. Data elements include pedestrian facilities, bus stop locations and ridership, roadway facilities such as channelization and lighting, and vehicular and pedestrian volumes. Mapping of the corridor is provided to the audit team (Figure 42), and the team conducts a walking tour of the corridor. Additional analysis is performed to evaluate potential improvements, both short- and long-term, as needed.

Figure 42. Pedestrian Corridor Mapping (Courtesy of DelDOT)

The three components of DelDOT's efforts are:

1. Increase the visibility of the pedestrians,
2. Direct pedestrians to safer crossing locations, and
3. Gain motorist and pedestrian compliance for safer pedestrian crossings.

This is accomplished through a "toolbox" of pedestrian safety countermeasures (Figure 43).

DelDOT Toolbox of Pedestrian Safety Countermeasures

- Sidewalks, Shared-Use Paths, Trails
- Adding or relocating Crosswalks
- Pedestrian Signals
- New Traffic Signals
- Pedestrian Hybrid Beacons
- ADA Upgrades
- Roadway Lighting
- Bus Stop Relocations
- RRFB
- Barriers
- Road Diets
- Refuge Islands

Increase Visibility of Pedestrians:

DelDOT has made roadway lighting a common safety countermeasure to ensure consistent and uniform lighting along corridors and at intersections, specifically those with crosswalks.

Direct Pedestrians to Safer Crossing Locations:

Existing transit stop locations are being evaluated. The evaluation results are being used as a basis for consideration of future transit locations and safety evaluations. Furthermore, DelDOT began to systemically implement directional "Use Crosswalk" signs at bus stop locations that provide connectivity to nearby crosswalks on multi-lane divided highways.

DelDOT is actively researching natural and manmade barriers (Figure 44) in order to redirect pedestrians to a location that is safer for them to cross. The challenges are making sure that such a location exists and finding the type of barrier that is appropriate for the roadway facility and the surrounding land use. Landscaping or other beautification approaches may be options. DelDOT is considering changes to the agency's mowing practices as a potential option. A physical barrier must meet crash test criteria based on

Figure 43. DelDOT Pedestrian Safety Toolbox Implementation (Courtesy of DelDOT)

Figure 44. Consideration of Barriers to Redirect Pedestrians (Courtesy of DelDOT)

proximity to the road and vehicle speeds, but at the same time meet aesthetic needs of the location. This is an opportunity for industry partners to collaborate with transportation agencies and other vested parties to meet this need.

Gain Motorist and Pedestrian Compliance for Safer Pedestrian Crossings:

DelDOT has installed the RRFB (Figure 45) at multiple locations around the state and has seen significant increases, at some locations as much as 80 percent, in compliance in vehicles yielding to pedestrians.

DelDOT's partnering agencies, the Delaware Office of Highway Safety and the Delaware State Police, have organized and conducted pedestrian safety enforcement and outreach campaigns. During these efforts, portable message boards are used along high pedestrian crash corridors to increase awareness to motorists and pedestrians and encourage pedestrians to use marked crossings. Enforcement campaigns are directed both at pedestrians and motorists. Most notably, from December 2014 to January 2015, message boards were placed on U.S. 13 in a historically high pedestrian crash area and pedestrian crashes were reduced by 50 percent when compared to 2013-2014 data.[27]

The Pedestrian and Bicycle Safety Working Group tracks the implementation status of the recommendations. But it does not stop there. Safety countermeasures are implemented systematically on an ongoing basis beyond the pedestrian safety audits. They are also evaluated after the fact to determine effectiveness in order to expand implementation.

Contact Information:

Scott Neidert, P.E., PTOE, RSP, HSIP Manager/Design Resource Engineer, DelDOT, Scott.Neidert@delaware.gov

Peter Haag, P.E., PTOE, Traffic Studies Manager, DelDOT, Peter.Haag@delaware.gov

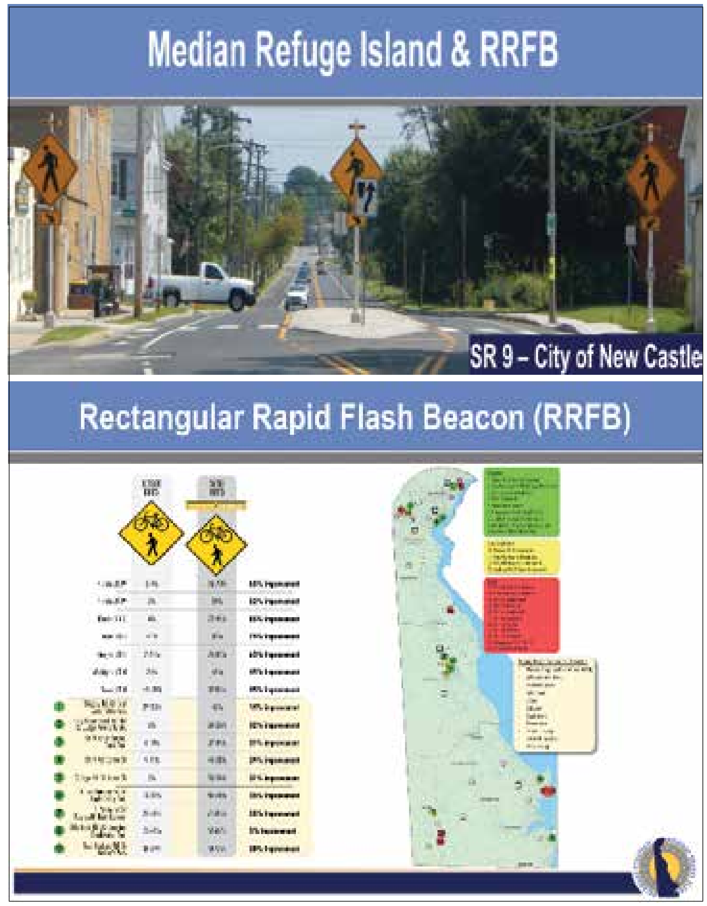

Figure 45. DelDOT RRFB Use and Compliance (Courtesy of DelDOT)

4.3 Leading Pedestrian Interval (LPI) Systemic Safety Application—City of San Diego

Pedestrian-vehicle conflicts are more prominent in highly urbanized areas. One means of reducing those conflicts at signalized intersections is to eliminate the simultaneous release of pedestrian versus vehicle conflicting movements by staggering the onset of the Pedestrian Walk versus the Vehicular Green indication, typically by three to seven seconds, for the pedestrian to begin crossing prior to vehicles being allowed to proceed through the intersection. LPI is one of FHWA's new "Proven Safety Countermeasures," is a low-cost technique, and has been shown to reduce intersection-related pedestrian-vehicle crashes by 60 percent.[28] The City of San Diego has implemented LPI systemically at over 30 intersections, with hundreds of additional locations planned.

The City of San Diego has adopted a Vision Zero focused approach to reducing traffic fatalities and serious injuries on its facilities. In San Diego, pedestrian fatalities and serious injuries represent 39 percent of the total number with 75 percent of these crashes located at or near intersections.[29] With over 1,500 signalized intersections, San Diego has expanded its Vision Zero approach to incorporate systemic safety into its analysis and implementation of safety countermeasures. San Diego received a $250,000 HSIP grant from Caltrans to develop a Systemic Safety Analysis Report Program (SSARP).

The first step was to perform a safety analysis to better understand the magnitude, and where and what the pedestrian safety issues were. San Diego used University of California at Berkeley SafeTREC to analyze three years of injury data for the entire network of intersections, which represented approximately 12,000 injury crashes. Crashes were categorized and mapped (Figure 46) using GIS according to three primary location categories:

1. Intersection footprint
2. Intersection influence area
3. Mid-block

The mode of travel was separated into three categories: bicycles, pedestrians, and vehicles (Figure 47).

Figure 46. Pedestrian Crash Location Analysis Mapping[29]

MODE	LOCATION	CRASH FACTORS (ROWS)	ROADWAY FACTORS (COLUMNS)
VEHICLE COLLISIONS	Intersection Footprint	1. Collision type 2. Violation type	1. Traffic control type 2. Number of lanes of the primary and secondary roads 3. Traffic volume of the primary road 4. Traffic volume of the secondary road
	Intersection Influence Area	1. Collision type 2. Violation type	1. Traffic control type 2. Speed limit 3. Median presence and type
	Mid-block	1. Collision type 2. Violation type	1. Median presence and type 2. Speed limit 3. Traffic volume of the primary road
PEDESTRIAN COLLISIONS	Intersection Footprint (Shown Above)	1. Violation type 2. Pedestrian action 3. Movement of party 1	1. Traffic control type 2. Number of lanes of the primary and secondary roads 3. Traffic volume of the primary road
	Intersection Influence Area	1. Violation type	1. Traffic control type 2. Number of through lanes of primary road in both directions 3. Traffic volume of the primary road
	Mid-block	1. Violation type 2. Pedestrian action	1. Speed limit 2. Number of through lanes of primary road in both directions 3. Traffic volume of the primary road
BICYCLE COLLISIONS	Intersection Footprint	1. Party at fault 2. Violation type	1. Traffic control type 2. Number of lanes of the primary and secondary roads
	Mid-block (Combined intersection Influence Area & Midblock)	1. Party at fault 2. Violation type	1. Bike lane presence 2. Speed limit 3. Parking presence

Figure 47. Data Correlated with Crashes[29]

They created a methodology that looked at locations and linked them to types of violations that contributed to the crash and the road environment items such as traffic control type, number of lanes, and volumes. This would lead to identification of hot spots.

A matrix (Figure 48) was developed based on FHWA's Systemic Safety Selection Tool and Caltrans' Systemic Pedestrian Safety Analysis. Each row represents a unique crash type or violation code and each column represents a unique roadway environment. The number in each cell represents the number of crashes of that type in that roadway environment. Green cells represent the lowest number of crashes and red cells represent the highest number of crashes. The red cells with the highest numbers represent hotspots. The intent is to identify trends and locations with the highest risk of pedestrian, bicycle, and vehicular crashes. Traditionally, they would have looked at individual locations and tried to find crash patterns. Now, crash types are analyzed across the city network, seeking shared physical features connected with them.

Failure to yield to the pedestrian during a turning maneuver (both left and right turns) was the most predominant scenario of pedestrian injury crashes. Typically, the pedestrian was already in the crosswalk legally when these crashes occurred, and the vehicle was in the wrong. Signalized four-lane major roads with volumes of 7,000 to 25,000 ADT intersecting with two-lane minor roads were over-represented. For left turn crashes, a permissive left turn was the common denominator. The study showed that these crashes occurred even with low pedestrian volumes as well as low turning volumes. San Diego has approximately 300 intersections like this.

Once locations were identified, implementation became critical. The implementation efforts are two-fold. First, the key is to proactively address multiple locations across the city's network where these crashes are occurring or have the potential to occur. Low-cost countermeasures would be implemented at multiple locations. The second aspect of implementation is to review and make changes to policies to ensure that these safety treatments are integrated into new intersection designs.

A countermeasure table (Figure 49) was developed that identified a series of both low cost and higher cost countermeasures associated with the hot spots and identified safety issues. Several countermeasures could be applied but as an example, a protected left turn would be difficult to warrant and expensive to retrofit after the fact.

	Signalized																			
	Thru Lanes 2+2				4(	4+2					4+4					6+2				
	<7,000 - local	<7,000 - non-local	7,001-15,000	15,001-25,000	7,001-15,000	<7,000 - local	<7,000 - non-local	7,001-15,000	15,001-25,000	>25,000	<7,000 - local	<7,000 - non-local	7,001-15,000	15,001-25,000	>25,000	<7,000 - local	<7,000 - non-local	7,001-15,000	15,001-25,000	>25,000
Control Violation other movements		2	1	1			2	1	4	4	1		9	10	3			1	1	
Control Violation through movement		1	3			1	2	8	11	4		1	7	3	2		2	1	1	4
Control Violation turning movement			1					3	3	1			1	2						
Entering from minor facility							1	1	1				3						1	
Failure to Yield																				
Crossing In Crosswalk At Intersection																				
Making Left Turn	1	5	12	5		6	8	14	29	14	7	3	33	14	1	1	1	1	6	4
Proceeding Straight				1			2	3	3	3	1	1	4	1	2			1	3	
Making Right Turn			2			7	2	7	17	4	1	2	8	6	5	1		1	1	2
Other		1	1				3	4	6	4			4	1	2			1		1
Crossing In Crosswalk Not At Intersection	1								2					1						
Crossing Not In Crosswalk	2		2	1		1		3	4	2		1		2	1					
In Road			2			2			1				1							
Not In Road			1				1			2		1	2	1		1	1			1
Not Stated	1		1	3			1		2	1			1							
Others	4	3	3	8		6	5	12	21	7	6		22	15	3		1		5	3
Pedestrian not in dedicated areas	1	2	4	3	1	2	2	6	11	6			7	4	7					2
Unsafe Speed				2		1	1	2	4	2			2	1			1		1	
Unsafe Turning Left		1	5			4	2	5	10	1			5	1	3	1		1		
Unsafe Turning other			1					1	2	1		1		2	3			1		1
Unsafe Turning Right							1	2	1	2				1	1					
Grand Total	10	18	39	24	1	30	35	75	133	59	16	10	110	66	33	4	7	8	19	18

Figure 48. Crash Matrix[29]

EXAMPLES	HOTSPOTS	COUNTERMEASURES
	• Turning vehicle fails to yield to **pedestrian** crossing in the crosswalk at a traffic signal • Signalized (permitted left turn) • 3x3 (both 1-way), (1-way) 3x4, 4x2 • Primary Roadway ADT: 7,001 – 25,000 (varies by lane configuration)	**Low-cost Recommendations** • Leading Pedestrian Interval (LPI) with blank-out turn restriction signs (expect 60% drop in crashes)* • High Visibility Pedestrian Crosswalks (expect 40% drop in crashes)* • Pedestrian Countdown Signal Heads (expect 25% drop in crashes)* • Left Turn Lane • Other improvements as appropriate **Higher-cost Recommendations** • Left Turn Lane and Protected Left Turn Phase (expect 55% drop in crashes)* • Flashing Yellow Arrows (expect 36.5% drop in crashes)* • Roundabout (expect 35-67% drop in crashes)*
	• **Bicyclist** proceeding straight and not stopping at a red light or stop sign • Signalized 4x4, 4x2 • Stop-controlled 2x2	**Low-cost Recommendation** • Robust detection and robust detector maintenance • Other bicycle infrastructure as appropriate **Higher-cost Recommendation** • Roundabout (expect 35-67% drop in crashes)* or other bicycle infrastructure as appropriate
	• **Vehicle** proceeding straight and not stopping at a red light. • Signalized 4x2, 4x4, 6x4, 3x3 (both 1-way) • Primary and Secondary Roadway ADT varies by lane configuration	**Low-cost Recommendation** • Reflective border around traffic signal heads (expect 15% drop in crashes)* • Other improvements as appropriate **Higher-cost Recommendation** • Roundabout (expect 35-67% drop in crashes)* • Other improvements as appropriate

**Expected drop in crashes are taken from the California Local Roadway Safety Manual. http://www.dot.ca.gov/hq/LocalPrograms/HSIP/2016/CA-LRSM.pdf*

Figure 49. Systemic Hotspots and Safety Countermeasures[29]

LPI is an ideal countermeasure in that it establishes pedestrians as the priority at the intersection, and it can be implemented relatively quickly and inexpensively. San Diego will systemically install the combination LPI with an electronic blank-out turn restriction sign at all LPI intersections (Figure 50). The blank-out sign has been key to the success of this treatment as it raises awareness of pedestrians at the intersection and only restricts vehicles during the brief time the restriction is needed, just a few seconds out of the entire cycle. This will allow San Diego to install LPIs at any traffic signal where it is deemed appropriate, not just the ones with light right-turning traffic. In the past if an LPI was used, a "NO RIGHT TURN ON RED" sign would have been installed, creating a negative impact on traffic flow.

Figure 50. LPI and Electronic Blank-out Turn Restriction Signs (Courtesy of City of San Diego)

San Diego's systemic approach at these intersections includes a comprehensive approach of safety countermeasures.

Continental Crosswalks: These are now a standard, helping to alert turning vehicles to the presence of a dedicated pedestrian crossing area that conflicts with their intended movement.

Pedestrian Countdown Signal Heads: They have been successful in encouraging more pedestrians to use the pushbutton rather than not using the crosswalk to cross or crossing against a red light.

Public Safety Campaigns: This includes developing and distributing information related to crash statistics and safe behaviors for drivers of vehicles, pedestrians, and bicyclists at signalized intersections.

Pedestrian Safety Zones: This targeted enforcement is focused on turning vehicles at signalized intersections. Enforcement would be most effective immediately following the installation of the initial phase of LPIs and blank out signs.

One of the most valuable aspects with this initiative is that this methodology, the findings, and implementation approach can be applied beyond the City of San Diego and in other states and cities.

Contact Information:

Julio Fuentes, P.E., Senior Traffic Engineer, City of San Diego, JFuentes@sandiego.gov

Philip Rust, P.E., Traffic Engineer, City of San Diego, PRust@sandiego.gov

Offer Grembek, Co-Director, SafeTREC, University of California, Berkeley, grembek@berkeley.edu

5. Work Zone Safety

As transportation agencies across the nation maintain, reconstruct and expand the roadways, work zone activities are in place and may occur at all times of the day. Work zones introduce unique traffic conditions, can be complex with changing conditions and speeds, and require more cognitive awareness by the driver (Figure 51). Changing conditions require motorists to react quickly. Unfortunately, high risk behaviors such as distracted driving and speeding continue to be the leading causes of crashes in work zones. While enforcement and education and outreach programs have been put in place to combat these issues, between 2016 and 2017, fatal crashes in work zones increased by 3 percent while fatal crashes outside of work zones decreased by 1.5 percent.[30] Transportation agencies are assessing their work zones to identify trends and are implementing unique safety countermeasures to influence driver behavior and improve work zone safety. Queue detection and temporary rumble strips alert drivers as they approach the work zone, allowing them to slow down. Presence lighting highlights an active work zone area and alerts motorists to the presence of workers during nighttime operations. Driveway assistance devices (DAD) can better direct traffic entering a one-lane work zone from a driveway or sideroad.

Figure 51. Active Work Zone with Lane Closures (Courtesy of IDOT)

Figure 52. Smart Work Zone Technology and Queue Detection (Courtesy of IDOT)

5.1 Queue Detection—Illinois

Depending on the facility type and other factors such as traffic volumes, number of lane closures, length of work zone, time of day and vehicle speeds, queues can occur in advance of a work zone and potentially extend several miles beyond the work zone taper. Across the nation, a significant number of work zone traffic related fatalities and serious injuries are due to queuing in advance of interstate work zones and the resulting rear-end crashes. A number of factors such as changes in traffic patterns and available capacity due to the presence of work zones, traffic volumes and the mix of CMVs as well as higher speeds and the motorists' expectations of free-flow speeds influence the number and severity of these crashes, in particular on interstates. Speeding and distracted driving further contribute to this trend.

Illinois ranks third in the nation for the number of interstate miles[31] and maintaining that system results in many work zones each year. Although work zone traffic fatalities and serious injuries account for only 2 to 4 percent of Illinois' total fatalities and serious injuries, work zone safety is an emphasis area in the Illinois SHSP. Each year a significant number of those fatalities and serious injuries have been due to rear-end crashes that have occurred, typically at the end of a queue that has extended well past the entry point of the taper. Certain interstate corridors have heavier traffic volumes (upwards of 35,000 ADT) and higher truck volumes (upwards of 30 percent), where any lane closures can result in significant queuing, especially during peak hours. Other areas may have periodic queuing occur, depending on the location of the project, during weekend travel or special events. Because of this, the Illinois Department of Transportation (IDOT) has expanded its use of Smart Work Zone Technologies (Figure 52) from its original experimental application to a multi-prong approach that better addresses the agency's needs.

IDOT's first use of Smart Work Zone Technology began after a multi-vehicle fatal crash in southern Illinois. After that incident, IDOT began utilizing work zone ITS on large construction projects where recurring queueing was expected. One of the first installations was utilized on three concurrent multi-million-dollar projects that covered a 30-mile corridor on I-55 including six miles in advance of the work zone. The ITS system included 73 portable CMSs spaced at one-mile intervals in each direction throughout the length of the corridor and 56 doppler sensors. These automated systems were complex and tailored to meet the needs of the project. The cost for these systems ranged from $350,000 to $800,000 depending on the level of complexity and area covered. The installation of these systems has continued to be implemented on a project-by-project basis, typically on very large projects, and have appeared to be effective at reducing rear-end crashes.

IDOT identified that typical interstate projects involving patching, resurfacing, bridge repairs or replacements can still have significant impacts to traffic. Therefore, IDOT has implemented different levels of Smart Work Zone systems and contracts to fit large scale, moderate level, and short-term operations. The moderate level systems are a scaled down version of the complex installations, like the one on I-55, and include sensors to detect queues and multiple portable CMSs or static boards with flashing lights (Figure 53) to communicate the presence of queues to motorists.

Figure 53. Static Signs with Flashing Lights and Sensors (Courtesy of IDOT)

Figure 54. Smart Work Zone Technology and Queue Detection (Courtesy of IDOT)

IDOT identified activities that may be very short-term in nature but, depending on the location, could potentially result in queues. To address these instances, IDOT established an On-Call Smart Work Zone System program that allows the deployment of small-scale Smart Work Zone technology through a work order contract managed by each IDOT district. Each contract is approximately $500,000 in value, covers a period of three years, and provides flexibility to the district to use as needed. These smaller scale installations can be used at a single location for a short period of time, typically anywhere from one day to four weeks. Many of the districts use these on maintenance projects such as recurring bridge inspections or bridge paintings to warn motorists of the presence of slowed or stopped traffic in unexpected locations.

In the Chicago area, the on-call Smart Work Zone contract supplements the District's on-call traffic control contracts and is used for recurring annual bridge inspections. The contract includes three pay items: Call Out, Smart Traffic Monitoring System, and Changeable Message Signs. When the district contacts the contractor to mobilize the system, the contractor is required to begin work within a week. Dependent on the work, a maximum of two systems may be deployed at one time. The District provides an approved list of systems and requires the contractors to furnish, install, maintain, program and remove various components. The typical deployment consists of four Smart traffic monitoring devices and must be capable of collecting real-time vehicle data, calculating the actual traffic backup delay time and distance within a half-mile to stopped or slowed traffic, and calculating travel times to major destinations. The District successfully used this system at two locations that have extremely high traffic volumes and that have experienced multiple queue-related crashes in the past.

- I-80 over the Des Plaines River in Joliet
    - 2 separate cantilever truss bridges
    - 3 lanes in each direction
    - Yearly Inspection, 1 week per direction
- I-55 over the Des Plaines River in Channahon
    - 2 separate cantilever truss bridges
    - 2 lanes in each direction
    - Every other year inspection, 1 week per direction

IDOT has collaborated with manufacturers and vendors to improve specifications and implementation of Smart Work Zone Technology. Most recently, IDOT implemented a hybrid system on an I-55 project. The original contract did not include any Smart Work Zone systems. Traffic impact analyses and previous experiences in this general location did not warrant the use of them. After a few months in construction, the resident engineer identified recurring queues during Friday afternoons and Sunday. IDOT added Real Time Traffic Control Systems (RTTCS) to address these queues and the potential safety concerns associated with them. RTTCS includes additional sensors and static boards with flashing beacons to inform drivers if slow or stopped traffic is ahead. Even with the system in place, queues continued to develop. To help address the queuing, IDOT included portable CMSs and additional sensors to be able to provide dynamic merging and travel times in addition to queue warning. This new approach provides multiple benefits.

With the addition of the new technology, the system can provide queue detection, travel time, and dynamic merge technology all at once, allowing IDOT to better manage the traffic in advance of and into the work zone (Figure 54). The dynamic merge system tells the motorists when and where to merge based on current traffic conditions, improving communications to the motorists. IDOT is able to fully utilize the available capacity of both lanes of travel; thus, substantially reducing the occurrence and length of queues. This eliminates unnecessarily long queues and avoids issues related to impatient drivers and speed differentials. Motorists are notified if a queue occurs; however, now, any resulting queues occur near the taper where motorists would more expect it to be. The additional signing near the taper better directs motorists into the taper. This hybrid system has been so successful that IDOT is planning to add it to other projects that have had recurring queue issues.

Contact Information:

Juan David Pava, P.E., Safety Programs Unit Chief,
Bureau of Safety Programs and Engineering, IDOT,
Juan.Pava@illinois.gov

5.2 Temporary Rumble Strips—Texas

Rumble strips provide audible warnings and physical vibration to alert motorists as their vehicle traverses the rumble strip. Transverse or “in-lane” rumble strips are a series of strips placed across the lane of travel where all vehicles will cross them. Permanent applications typically are grooved into the existing pavement at rural intersection approaches with stop signs. Work zone operations and the associated traffic control as well as traffic conditions are temporary by nature and are subject to change. Temporary rumble strips are an array of strips used in advance of a work zone to alert motorists, especially those that may be distracted or drowsy, of changing conditions such as reduced speeds, lane closures or shifts, worker presence, and traffic backups. The ability to easily install, relocate and remove the temporary rumble strips is advantageous, and because of this, temporary rumble strips are typically comprised of multiple layered applications of preformed pavement marking tape or portable reusable rumble strips. The publication, “Guidance for the Use of Temporary Rumble Strips in Work Zones”[32] (Figure 55) describes the different types of temporary rumble strips and when and how to implement them based on the duration of the work zone, the configuration, e.g., pattern, spacing, location, and height.

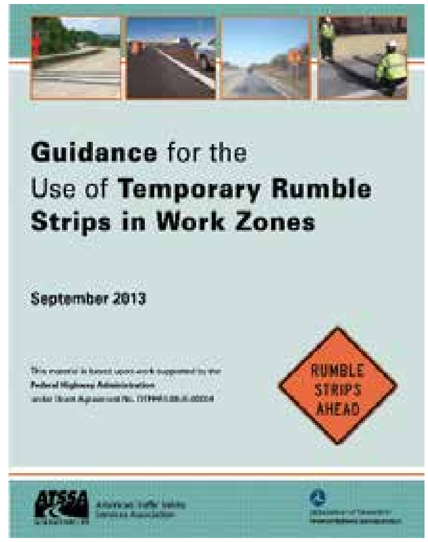

Figure 55. ATSSA Publication[32]

TxDOT began requiring the use of portable temporary rumble strips in 2012 for non-freeway or expressway maintenance work activities that required a daytime lane closure. Each TxDOT maintenance section has its own set of portable temporary rumble strips and continues to use these devices to enhance safety for the maintenance workers. TxDOT’s use of portable temporary rumble strips expanded to include construction work zones shortly thereafter in the spring of 2013 when the agency issued a standard. Since then, the standard has been modified to address lessons learned.

Figure 56. Temporary Rumble Strip Arrays (Source: TxDOT WZ (RS)-16)

The use of portable temporary rumble strips (Figure 56) is primarily for daytime short-term operations or short duration activities on conventional highways with a posted speed limit of 75 mph or less with lane closures or during one-lane, two-way flagging operations. Flagging operations include the use of flaggers, automated flagger assistance devices (AFADs) and portable traffic signals while the portable temporary rumble strips can be used on freeways and expressways based on engineering judgement.

Table 2.
Required Number of Temporary Rumble Strip Arrays[33]

Flagger to Flagger/ Length of Work Area	ADT	# of Rumble Strip Arrays
1/8 mile	< 4500	1
	≥ 4500	2
1/4 mile	< 3500	1
	≥ 3500	2
1/2 mile	< 2600	1
	≥ 2600	2
1 mile	< 1600	1
	≥ 1600	2
> 1 mile	N/A	2

The current TxDOT standard and associated memo establishes criteria for the number and placement of the arrays per lane based on the length of the work area and the ADT[33] (see Table 2). Each array is comprised of a series of three hinged portable rumble strips with the required spacing of

Table 3.
Rumble Strip Spacing[33]

Posted Speed Limit	Distance Between Strips on Arrays
≤ 40 mph	10’
> 40 mph	15’
≤ 55 mph	15’
> 55 mph	20’

the strips varying from 10 feet to 20 feet based on the posted speed limit (see Table 3). Spacing is important for proper performance of these devices. Advance signing “RUMBLE STRIPS AHEAD” is required. In addition, if queueing is expected or occurring, the signing and the first temporary rumble strip array may be moved in advance of the “ROAD WORK AHEAD” sign.

TxDOT has found the portable temporary rumble strips to be effective and has continued to require their use in both maintenance and construction zones. The devices are removed at the end of the work activity each day.

The temporary rumble strips need to be installed and maintained properly to perform correctly and be effective. Because of the potential for possible shifting on pavements, the use of the temporary rumble strips is prohibited under specific conditions such as horizontal or vertical curves, loose gravel or recent seal coat applications, bleeding asphalt, and soft or heavily rutted pavements. Prior to any installation of temporary rumble strips, TxDOT meets with the contractor to confirm the pavement condition is acceptable and, once installed, monitors the temporary rumble strips to ensure there is not any shifting. In addition, consideration of potential noise issues and complaints is necessary.

Contact Information:

Douglas Skowronek, P.E., PTOE, Policy & Standards Branch Manager, Traffic Safety Division, TxDOT, Doug.Skowronek@txdot.gov

5.3 Work Zone Presence Lighting—North Carolina

As transportation agencies perform more work maintaining their roadway systems, to meet the needs of their users, they are performing more construction and maintenance work during nighttime hours. While this helps with mobility, workers are more at risk. As noted, distracted driving and speed are major contributing factors in work zone crashes. As the number of active work zones increases, so does the number of crashes in work zones, in particular, those on interstates. Nighttime hours bring additional factors that can contribute to potential for increased frequency and severity of work zone crashes such as reduced visibility, impairment, and drowsy driving.

Looking to improve the safety for motorists and workers during nighttime work zones, North Carolina Department of Transportation (NCDOT) has implemented Work Zone Presence Lighting (WZPL). They are using balloon lighting, an illuminated traffic control device, in advance and sometimes inside the lane closure. This is in addition to the typical application of task lighting (Figure 57). WZPL increases the visual footprint of the work zone and improves worker visibility. The intent is to make drivers more aware of the work zone and have them reduce speeds in advance and through the work zone.

Figure 57. Task Lighting and Presence Lighting (Courtesy of NCDOT)

Table 4.
Presence Lighting Demonstration Project Results (Data Source: NCDOT[34])

State	Route	WZ Speed Limit	Speeds Without PL	Speeds With PL	Avg. Speed Reduction
North Carolina	US 17	55	57.7	51.94	5.76
Michigan	US 23	55	56.92	51.27	5.65
Michigan	I-94	60	65.19	57.94	7.25
Michigan	I-94	60	67.78	62.82	4.96
Michigan	I-94	60	68.48	62.82	6.95
Tennessee	I-40	65	68.76	63.82	4.94
Tennessee	I-40	70	74.76	68.89	5.87
Virginia	I-64	65	67.47	60.62	6.85
Georgia	I-85	60	64.76	60.05	4.71

Rural interstates can benefit greatly from WZPL. These locations do not have ambient lighting that is typically found in urban settings and therefore have very low visibility at night. NCDOT used WZPL on a U.S. Route 17 resurfacing project. The posted work zone speed limit was 55 mph. NCDOT measured speeds with and without the WZPL. When WZPL was not in place, speeds were slightly higher than the posted work zone speed limit. When the WZPL was in place, the average speed reduction was almost 6 mph.[34]

Figure 58. Presence Lighting (Courtesy of NCDOT)

Other states such as Michigan, Tennessee, Virginia, and Georgia have implemented Work Zone Presence Lighting through demonstration projects to evaluate the impact on motorists' speeds. These states have seen similar results as North Carolina, higher speeds without WZPL and decreases speeds when WZPL is used (Table 4). The average speed reduction is 5.88 mph with the highest speed reduction just over 7 mph. NCDOT conducted additional speed studies in 2019 on eight interstate resurfacing projects.

NCDOT believes the most appropriate location to place these devices to change high risk driver behavior and improve overall work zone safety is in advance of the work zone (Figure 58). Devices installed in advance of a work zone will alert motorists so that they will slow as they approach the work zone. However, additional installations inside the lane closure can highlight a specific active work area(s).

NCDOT also believes the WZPL, when used in conjunction with Digital Speed Limit Signs, Sequential Flashing Lights and law enforcement can significantly impact drowsy/hypnotic, distracted driving as well as work zone speeds.

Contact Information:

Steve Kite, P.E., CPM State Work Zone Engineer, NCDOT, skite@ncdot.gov

5.4 Drive-Way Assistance Device (DAD)—Michigan

Work zones introduce different traffic conditions that can be confusing to motorists and potentially lead to crashes. The presence of entrances and side roads can present unique challenges when trying to safely maintain traffic movement. This is especially true when travel lanes are reduced to a single bi-directional lane.

A Drive-Way Assistance Device (DAD) was created as a combined effort between industry and the Texas Transportation Institute (TTI) to provide better guidance to motorists. It is a temporary traffic control device used in conjunction with temporary traffic signals to direct traffic entering a one-lane work zone from a driveway or side road. The temporary traffic signal and the DAD are linked together and communicate wirelessly. DADs should conform to the same conflict monitoring requirements as signals.

The DAD provides a flashing yellow or red arrow in the direction of the intended work zone traffic flow (Figure 59), allowing the motorist to proceed into the work zone with the flow of traffic based on the gap in traffic. The DAD turns solid red (Figure 60) before the mainline traffic fully passes the driveway. When the red ball is displayed, the motorist should not proceed into the work zone.

MDOT implemented the DAD on five projects with low volume driveways under the FHWA Experimental Feature process. For each project, turning movement data was collected and classified as proper, improper, safe, and unsafe to determine level of compliance while using the DAD. For evaluation purposes, a car that turns onto the roadway when the arrow is flashing red, and in the correct direction, is classified as making a correct (and safe) movement. A car that turns out from a solid red but joining the end of the mainline traffic is classified as making an improper but safe movement. A car that turns unsafely would be a car that turns in the opposite direction of traffic.

Based on MDOT's observations, the DADs meet their intended objective of maintaining driveway traffic in a work zone operated by temporary signals, especially with bridge projects; however, there are important factors that could impact the effectiveness of the DADs.[34]

These include the visibility, mainline traffic and driveway volumes, the geometrics of the driveway, how the signal timing is set up, and the location of the DAD in relation to the mainline temporary signals.

Visibility at the DAD had a role in the compliance level and needs to be considered. If the DAD is located too close to the mainline signal, this will promote vehicles turning on the red light. For example, if a driver is able to see traffic stopped at the mainline signal there is a greater chance of the driver proceeding on a solid red, presuming it is safe. Based on MDOT's experience, if there is a clear line of sight from the DAD to the mainline temporary signal, the optimal spacing distance is 500 feet.[34]

Figure 59. DAD (Courtesy of MDOT)

Figure 60. DAD and Temporary Traffic Signal (Courtesy of Horizon Signal[35])

Traffic volumes on both the mainline and driveways need to factor into the signal timing and location selection. Mainline traffic needs to allow gaps for traffic merging at the DADs in order to have time to enter mainline. Adding additional lead time or extension to the DAD signal timing can help. Location and volumes should be reviewed for peak hour factors to determine if DADs are appropriate. If traffic volumes increase over 400 vehicles per day, an additional temporary signal phase should be considered.[34] On one project that had high traffic volumes, excessive queues were created at the DADs because there was only one collector lane at the locations. This problem would be solved by having a separate turning lane for traffic turning left and right.

Driveway geometrics should allow for two to three vehicles to queue in the right and left lane.

Signal timing should allow for increased all red times to allow the improper safe movements (vehicle joining the end of the queue) to take place. Programing the signal timing for a lower speed than the posted work zone speed will build in the additional all red time to account for traffic joining the queue. Allowing the additional all red clearance time allows for the additional traffic to clear the mainline signal. Traffic pulling out at the DADs and joining the end of the queue (improper but safe) occurred with approximately 15 percent of the traffic.[34] The highest rate occurred at higher volume driveways. DADs should have the capability to be sequenced to accommodate driveways that are in close proximity to one another and long work zones.

With respect to overall compliance, 82.8 percent of the traffic at the DADs proceeded correctly and 15.7 percent proceeded incorrectly but in a safe manner by joining the end of the queue, for a combined total of 98.5 percent of safe movements.[34] MDOT was extremely satisfied with the performance of the DAD. One significant advantage of using the DAD is that it can eliminate lengthy detours due to directional closures and project staging by allowing controlled through-access that is not feasible using flaggers 24 hours a day. When applied appropriately, the DAD can be successful for much more than just residential driveways.

MDOT has been supportive of pursuing additional experimental features to evaluate the use of the DAD at higher volume locations such as commercial driveways and residential side streets. Several states have used the DAD (Figure 61), including as part of traffic management during disaster recovery situations. The DAD has been presented at the National Committee on Uniform Traffic Control Devices (NCUTCD) for consideration in the next version of the MUTCD.

Contact Information:

Chris Brookes, Work Zone Delivery Engineer, MDOT,
brookesc@michigan.gov

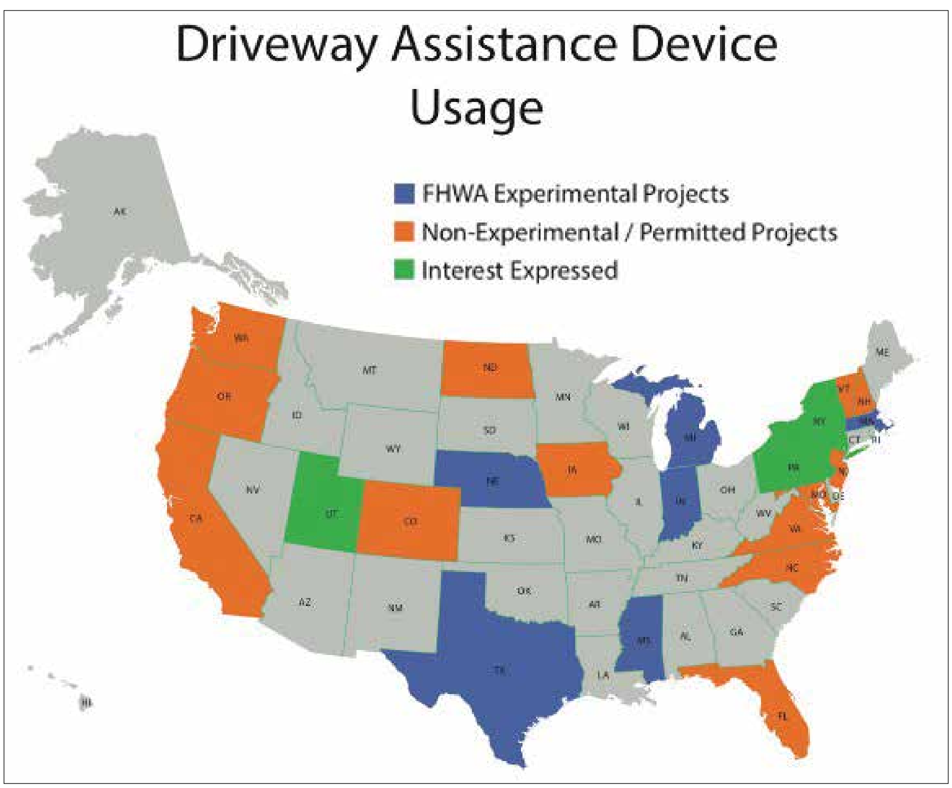

Figure 61. Driveway Assistance Device Usage in U.S. (Courtesy of Horizon Signal[35])

References

1. Michigan Department of Transportation. “Local Safety Initiative (LSI).” Available at: https://www.michigan.gov/mdot/0,4616,7-151-9615_11261_45212-161513--,00.html
2. California Department of Transportation. “Safety Analysis Report Program (SSARP).” Available at: "https://dot.ca.gov/programs/local-assistance/fed-and-state-programs/highway-safety-improvement-program/local-roadway-safety-plans
3. Federal Highway Administration. “Roadway Departure Safety.” U.S. Department of Transportation, Washington, D.C., 2019. Available at: https://safety.fhwa.dot.gov/roadway_dept/
4. West Virginia Department of Transportation. “2017-2021 West Virginia Strategic Highway Safety Plan.”
5. North Dakota Department of Transportation, “2018: North Dakota Vision Zero Plan Strategic Highway Safety Plan Update 2018-2023,” pp. iv.
6. Pike, Adam M., Timothy P. Barrette, and Paul J. Carlson. “Evaluation of The Effects of Pavement Marking Width on Detectability by Machine Vision: 4-Inch vs. 6-Inch Markings” Prepared for the American Traffic Safety Services Association, 2018.
7. Park, Eun Sug, Paul J. Carlson, Richard J. Porter, and Carl K. Anderson. “Safety Effects of Wider Edge Lines on Rural, Two Lane Highways,” Accident Analysis & Prevention, Federal Highways Administration, 2012.
8. Abdel-Rahim, Ahmed, Kevin Chang, Maged Mohmed, Andrew Skinner, and Emad Kassem. “Safety Impacts of Using Wider Pavement Markings on Two-Lane Rural Highways in Idaho.” Idaho Transportation Department Research Report RP 244, 2018.
9. Michigan Department of Transportation. “2013-2016 State of Michigan Strategic Highway Safety Plan,” 2012.
10. North Carolina Department of Transportation and Carrie L. Simpson, “Wider Edge Lines & Highly Reflective Elements on 2-Lane Rural Roads –Prelim Safety Evaluation, Presentation, 2019.
11. North Carolina Department of Transportation and Carrie L. Simpson, “Wider Edge Lines & Highly Reflective Elements on 2-Lane Rural Roads – Prelim Evaluation,” Presentation, September 2018.
12. Federal Highways Administration. “Roadway Departure, Safety, Rumble Strips and Rumble Stripes.” Available at https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/safety.cfm
13. Torbic, Darren J., Jessica M. Hutton, Courtney D. Bokenkroger, Karin M. Bauer, Douglas W. Harwood, David K. Gilmore, Joanna M. Dunn, John J. Ronchetto, Eric T. Donnell, Henry J. Sommer III, Philip Garvey, Dr. Bhagwant Persaud, and Craig Lyon. National Cooperative Highway Research Program (NCHRP) Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips, 2009.
14. Datta, Tapan K., Timothy J. Gates, and Peter T. Savolainen. “Impact of Non-Freeway Rumble Strips Phase 1.” Michigan Department of Transportation Office of Research and Best Practices, 2012. ORBP Reference Number: OR09084A
15. Datta, Tapan K., Peter T. Savolainen, Timothy J. Gates, Jonathan J. Kay, Nicholas B. Nicita, Sahadev Parajuli, and Jacob Finkelman. “Evaluation of Non-Freeway Rumble Strips - Phase II,” Michigan Department of Transportation Office of Research and Best Practices, 2015.
16. Michigan Department of Transportation. “Special Provision for Acceptance of Longitudinal Joint Density in Hot Mix Asphalt Pavements.” 2013.
17. Terhaar, Edward, David Braslau, and Katie Fleming. “Sinusoidal Rumble Strip Design Optimization Study,” Minnesota Department of Transportation, 2016.
18. Michigan Department of Transportation. “Special Provision for Sinusoidal Corrugations.” 2017.
19. Wu, Lingtao, Srinivas R. Geedipall, and Adam M. Pike. “Safety Evaluation of Alternative Audible Lane Departure Warning Treatments in Reducing Traffic Crashes: An Empirical Bayes Observational Before-After Study,” TRB Paper No.: 18-01098, 2017.
20. Pike, Adam M., Bryan T. Wilson. “Evaluation of Audible Lane Departure Warning Treatments on Seal Coats,” TRB Paper, 2019.
21. National Transportation Safety Board. “Wrong-Way Driving. Highway Special Investigation Report NTSB/SIR-12/01.” NTSB/SIR-12/01 PB2012-917003, 2012.
22. N. K. Vaswani. “Measures for Preventing Wrong-Way Entries on Highways,” Report Number VHRC 72-R41, Charlottesville, VA: Virginia Highway Research Council, 1973.
23. Alluri, Priyanka, and Raj Ponnaluri. “Drafting, Designing, and Deploying Wrong-Way Driving Countermeasures - A Florida DOT Initiative,” 2018.

24. Pierce, Stacey. “Wrong Way Driving (WWD) in Wisconsin,” Presentation, 2017.
25. Federal Highways Administration. Pedestrian & Bicycle Safety. U.S. Department of Transportation, 2018. Available at: https://safety.fhwa.dot.gov/ped_bike/
26. Retting, Richard. “Pedestrian Fatalities by State, 2018 Preliminary Data.” Spotlight on Highway Safety, Governors Highway Safety Association, 2019.
27. Delaware Department of Transportation. Delaware Pedestrian/Bicycle Safety Working Group April 15, 2015 Meeting Minutes.
28. Federal Highways Administration. “Proven Safety Countermeasures-Leading Pedestrian Intervals.” 2017. Available at: https://safety.fhwa.dot.gov/provencountermeasures/pdfs/fhwasa17063.pdf
29. The City of San Diego. “Systemic Safety: The Data Driven Path to Vision Zero.” 2019. Available at: https://www.sandiego.gov/sites/default/files/systemic-safety-the-data-driven-path-to-vision-zero.pdf
30. Fatality Analysis Reporting System (FARS) 2016 Final and 2017 Annual Report File, National Highway Traffic Safety Administration (NHTSA). FARS data shown here are from the 50 States and the District of Columbia. Accessible at: https://www.workzonesafety.org/crash-information/work-zone-fatal-crashes-fatalities/#national
31. Illinois Department of Transportation. http://www.idot.illinois.gov/transportation-system/Network-Overview/highway-system/index
32. Federal Highway Administration and American Traffic Safety Services Association. “Guidance for the Use of Temporary Rumble Strips in Work Zones.” FHWA and ATSSA Grant Agreement No. DTFH61-06-G-00004, 2013.
33. Texas Department of Transportation. Standard WZ(RS-16) Temporary Rumble Strips and memo. 2017.
34. North Carolina Department of Transportation and Steve Kite. “Work Zone Presence Lighting,” Presentation, ATSSA 2019.
35. Michigan Department of Transportation. “MDOT’s Final Report, Permission to Experiment – 6(09)-35 (E) - Driveway Assistance Device- MDOT.” 2018.
36. Horizon Signal Technologies and David Krahulec. “Driveway Assistance Device”, Presentation, ATSSA 2019.

Page intentionally left blank

SAFER ROADS SAVE LIVES

American Traffic Safety Services Association
15 Riverside Parkway
Fredericksburg, VA 22406
800-272-8772 • ATSSA.com