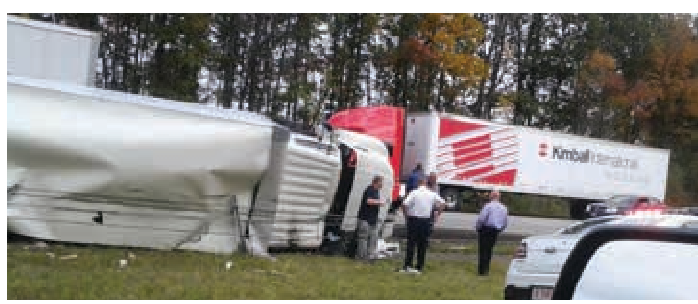
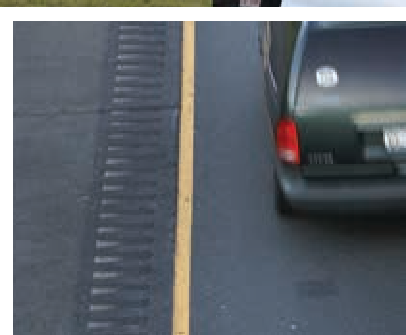
# PREVENTING VEHICLE DEPARTURES FROM ROADWAYS







ATSSA
SAFER ROADS SAVE LIVES

**American Traffic Safety Services Association**
15 Riverside Parkway, Suite 100
Fredericksburg, VA 22406-1022
540-368-1701 ▮ www.atssa.com ▮

# Table of Contents

# List of Figures

# List of Tables



# List of Acronyms

| | |
|---|---|
| AADT | Annual Average Daily Traffic |
| AASHTO | American Association of State Highway and Transportation Officials |
| ADT | Average Daily Traffic |
| ALDOT | Alabama Department of Transportation |
| ATSSA | American Traffic Safety Services Association |
| AU | Auburn University |
| B/C | Benefit-Cost |
| CLRS | Centerline Rumble Strips |
| CMF | Crash Modification Factor |
| DCWS | Dynamic Curve Warning System |
| DOT | Department of Transportation |
| EA | Emphasis Area |
| EB | Empirical Bayes |
| FARS | Fatality Analysis Reporting System |
| FASTER | Funding Advancements for Surface Transportation and Economic Recovery |
| FHWA | Federal Highway Administration |
| HFST | High-Friction Surface Treatments |
| HMA | Hot-Mix Asphalt |
| HRRR | High Risk Rural Roads |
| HSIP | Highway Safety Improvement Program |
| Iowa DOT | Iowa Department of Transportation |
| KYTC | Kentucky Transportation Cabinet |
| LED | Light-Emitting Diode |
| MAP-21 | Moving Ahead for Progress in the 21st Century Act |
| MDOT | Michigan Department of Transportation |
| MnDOT | Minnesota Department of Transportation |
| MoDOT | Missouri Department of Transportation |
| MRI | Midwest Research Institute |
| MUTCD | Manual on Uniform Traffic Control Devices |
| NACE | National Association of County Engineers |
| NCDOT | North Carolina Department of Transportation |
| NCHRP | National Cooperative Highway Research Program |
| NHPP | National Highway Performance Program |
| NHS | National Highway System |
| NHTSA | National Highway Traffic Safety Administration |
| ODOT | Oregon Department of Transportation |
| PDO | Property Damage Only |
| PennDOT | Pennsylvania Department of Transportation |
| ROR | Run-off-Road |
| ROTRR | Run-off-the-Road to the Right Side |
| RPM | Raised Pavement Markers |
| RwD | Roadway Departure |
| SHSP | Strategic Highway Safety Plan |
| SPF | Safety Performance Function |
| SP&R | State Planning and Research |
| SRS | Shoulder Rumble Strips |
| SSD | Stopping Sight Distance |
| STP | Surface Transportation Program |
| TZD | Toward Zero Deaths |
| VMT | Vehicle-Miles Traveled |
| WSDOT | Washington State Department of Transportation |

# Overview and Acknowlegements

A Roadway Departure (RwD) crash is defined by the Federal Highway Administration (FHWA) as *"A crash in which a vehicle crosses an edge line, a centerline, or otherwise leaves the traveled way."* These crashes, comprising run-off-road (ROR) and head-on collisions, tend to be more severe than any other crash type. In 2012, RwD crashes accounted for 56 percent of all motor vehicle traffic fatalities.

There are a number of reasons a driver may leave the travel lane (e.g., an avoidance maneuver, inattention or fatigue, or traveling too fast for weather or geometric conditions). Roadway geometric design features, such as lane and shoulder width or horizontal curvature, play a role in whether the human error results in a crash.

Over the past few decades, different engineering countermeasures have been proposed, implemented, and tested by various state and local agencies to mitigate RwD crashes. These countermeasures include, but are not limited to:

- Installing centerline and shoulder rumble strips
- Adding pavement edge line
- Eliminating shoulder drop-offs
- Enhancing pavement markings
- Improving barrier design
- Providing skid-resistant high-friction surfaces
- Designing safer slopes
- Removing and relocating objects within roadside clear zones
- Delineating objects with retroreflective material

However, there has been a lack of comprehensive documentation that brings various safety countermeasures related to RwD together in one place to serve as an enriched reference for transportation agencies to help them select suitable solutions to achieve targeted outcomes for their existing problems.

This publication is developed in the framework of an executive summary of various case study examples that provide transportation practitioners with a good understanding of RwD safety countermeasure effectiveness. In addition to bringing available information together in one document, a contact person(s) is suggested for each case study example.

This report was developed by the Auburn University (AU) under contract with the American Traffic Safety Services Association (ATSSA). The AU undertook a synthesis of existing technical literature and research for the development of the case study examples. ATSSA would like to recognize the principal researchers: Dr. Huaguo Zhou (Associate Professor, Department of Civil Engineering, AU), Mohammad Jalayer (Ph.D. Graduate Student, AU), Fatemeh Baratian-Ghorghi (Ph.D. Graduate Student, AU), Jin Wang (Ph.D. Graduate Student, AU), Lingling Yang (M.S. Graduate Student, AU), Mahdi Pour-Rouholamin (Ph.D. Graduate Student, AU), and Isaac Wasilefsky (Undergraduate Student, AU).

In addition, we acknowledge the participation, the support, and the contributions of the U.S. Department of Transportation (DOT) and FHWA. Finally, we express our gratitude to the following individuals who served on the Blue-Ribbon Panel to identify case studies and provide technical reviews of the document:

James S. Baron
Project Manager
American Traffic Safety Services Association

Cathy Satterfield, P.E.
Office of Safety
U.S. DOT FHWA

Priscilla Tobias, P.E.
State Safety Engineer, Bureau of Safety Engineering
Illinois Department of Transportation (IDOT) Division of Highways

Melisa Finley, P.E.
Research Engineer
Texas A&M Transportation Institute

Neal Hawkins, P.E.
Director, Center for Transportation Research and Education
Iowa State University

Joe Jeffrey
President
Road-Tech Safety Services Inc.

Louis Fuselier
Business Development Manager
Advanced Mobile Asset Collection

Joanne Conrad
Digital Division Manager
Traffic & Parking Control Co., Inc. (TAPCO)

Richard Fulmer
Chief Executive Officer
AKCA Inc.

Peter Johnston
Marketing Manager
3M-Traffic Safety and Security Division (TSSD)

Pete Speer
Vice President of Sales
Pexco/Davidson Traffic Control Products

Jim Kalchbrenner
Northeastern Region Sales Manager
Pexco/Davidson Traffic Control Products

Dan Waddle, P.E.
Traffic Engineer/Division Manager
Traffic Engineering Division
Nebraska Department of Roads

Jeff Tidaback
Regional Sales Manager
Plastic Safety Systems Inc. (PSS)

David Brand
Chair
NACE Roadway Safety Working Group

Ken Smith
President
Ken Smith & Associates

Richard Baker
Market Development Manager
DBI Services

Eric Healey
Pavement Marking Supervisor
New Hampshire Department of Transportation

Tom McSwain
Director of Sales-U.S. Eastern
Ennis-Flint

Mark Bloschock
Consultant
Austin, Texas

John Durkos
Vice President Technical Support & Marketing
Road Systems Inc.

Mark Council
Safety Sales and Sign Manufacturing
Spivey Rentals Inc.

Gary Lallo
General Manager
Hill & Smith Inc.

David Rush
Work-Zone Safety Programs Manager
Virginia Department of Transportation

Kathi Holst
President
RCMS

Paul Billups
Manager
RoadSafe Traffic Systems Inc.

Laren Billingslea
Pavement Technician
Alaska Department of Transportation

Raymond C. Somich II
Vice President
Poly-Carb Inc.

David Minor
Business Development Manager
Unitex - A Division of Dayton Superior

Andrew C. McNair
Transportation Engineer
Mississippi Department of Transportation

Brian Roberts, P.E.
Executive Director
National Association of County Engineers (NACE)

# Introduction

A Roadway Departure (RwD) happens when a vehicle departs from the traveled way by either crossing an edge line or a centerline (FHWA 2014a). RwD events comprise both run-off-road (ROR) and head-on collisions. The reasons for ROR events are varied and include the driver attempting to avoid a vehicle, an object, or an animal in the travel lane; inattentive driving due to distraction, fatigue, sleep, or drugs; the effect of weather on pavement conditions; and traveling too fast through a curve or down a grade.

There also a number of roadway design factors that can increase the probability that a driver error will become an ROR crash (e.g., travel lanes that are too narrow, substandard curves and unforgiving roadsides) (Neuman et al. 2003a). Most head-on crashes are similar to ROR crashes—in both cases, the vehicle strays from its travel lane (Neuman et al. 2003b).

RwD is one of the more severe types of crashes compared with all other crash types. According to the Federal Highway Administration (FHWA), in 2012, 56 percent of fatal motor vehicle traffic crashes involved a RwD. Figure 1 depicts the percentage of total RwD fatal crashes across the United States, categorized by the first event in the crash. According to a query of six years of crash data (2007-2012) from the Fatality Analysis Reporting System (FARS) database, an average of 57 percent of motor vehicle traffic fatalities occurred each year due to roadway departure in the United States. The distribution of this number differs from one state to another (see Figure 2).

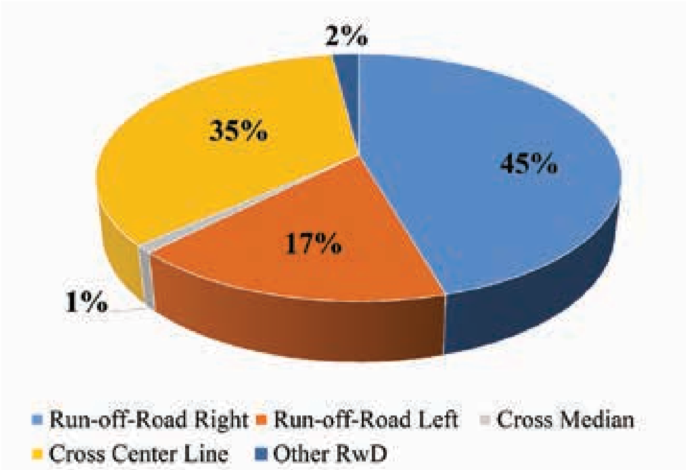
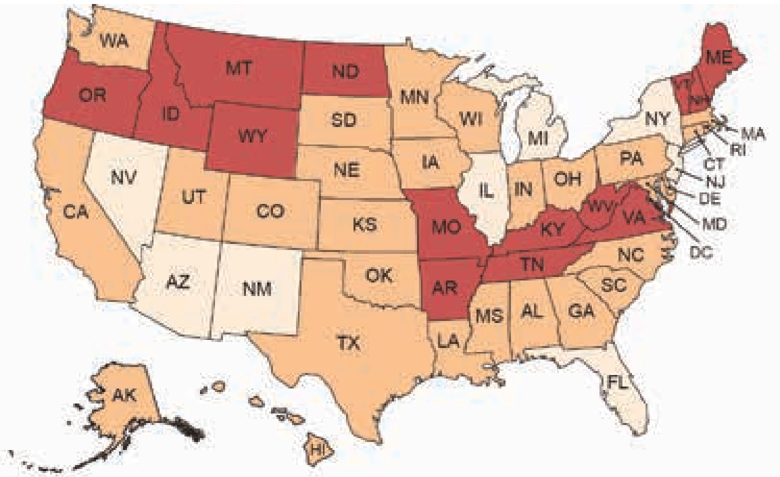



Figure 1. Percentage of Fatal Crashes in the United States in 2012 (FHWA 2014a)




| Average Annual Roadway Departure Fatalities (2007-2012) | | | | | |
| --- | --- | --- | --- | --- | --- |
| Group 1 (65% and Higher) | | Group 2 (Between 50-65%) | | Group 3 (Below 50%) | |
| State | % RwD | State | % RwD | State | % RwD |
| Wyoming | 78.0% | Oklahoma | 64.0% | Michigan | 49.0% |
| Vermont | 77.0% | Alabama | 63.0% | Nevada | 49.0% |
| West Virgina | 76.0% | Kansas | 63.0% | Illinois | 49.0% |
| Montana | 73.0% | Rhode Island | 63.0% | New York | 48.0% |
| Arkansas | 72.0% | Washington | 63.0% | Arizona | 46.0% |
| Maine | 71.0% | Wisconsin | 63.0% | New Jersey | 46.0% |
| Kentucky | 70.0% | Alaska | 63.0% | New Mexico | 44.0% |
| Tennessee | 70.0% | Pennsylvania | 62.0% | Florida | 43.0% |
| Idaho | 69.0% | Nebraska | 62.0% | Dist. of Columbia | 29.0% |
| Virginia | 68.0% | South Dakota | 62.0% | | |
| New Hampshire | 66.0% | North Carolina | 62.0% | | |
| Oregon | 66.0% | South Carolina | 61.0% | | |
| Missouri | 65.0% | Ohio | 61.0% | | |
| North Dakota | 65.0% | Iowa | 61.0% | | |
| | | Louisiana | 61.0% | | |
| | | Colorado | 60.0% | | |
| | | Connecticut | 58.0% | | |
| | | Indiana | 57.0% | | |
| | | Georgia | 57.0% | | |
| | | Massachusetts | 56.0% | | |
| | | Hawaii | 55.0% | | |
| | | Texas | 54.0% | | |
| | | Minnesota | 53.0% | | |
| | | Mississippi | 52.0% | | |
| | | Utah | 52.0% | | |
| | | Maryland | 51.0% | | |
| | | Delaware | 50.0% | | |
| | | California | 50.0% | | |

Figure 2. Average Percentage of RwD Fatalities in Each State (2007-2012)

The probability of severity of RwD crashes depends on the roadside features, including side slopes, fixed-object density, offset to fixed objects, shoulder width, etc. (Jalayer et al. 2015). Collision with a fixed object is identified as the first harmful event in ROR crashes (Noyce et al. 2008). A recently conducted inquiry of the FARS database revealed that 7,416 people perished in crashes involving fixed roadside objects in 2012, accounting for 22 percent of the total fatalities for that year (IIHS 2014).

Many techniques (e.g., roadway cross-section improvements, hazard removal or modification, and delineation) have been utilized in urban, suburban, and rural areas to keep the vehicles in travel lanes and to reduce potential collisions with roadside objects, such as trees, signs, and utility poles (Neuman et al. 2003a).

The American Association of State Highway and Transportation Officials (AASHTO) defined several strategies to mitigate the ROR crashes, including (AASHTO 2008):

- Centerline and shoulder rumble strip installation
- Pavement edge-line installation
- Pavement marking enhancement
- Horizontal curves geometric improvement
- Skid-resistant roadway surface provision
- Shoulder drop-offs elimination
- Safer slopes design
- Objects removing/relocation within the clear zone
- Objects delineation using retroreflective tape
- Barrier design improvement

Most of these strategies are low-cost countermeasures and can be implemented systemically. The purpose of this publication is to provide several concise case study examples that will serve as easy-to-read resources and references for local public officials who hold the responsibility of making their roadways safer. The case study examples consist of a series of cost-effective improvements for preventing vehicle departure from roadways.

This publication includes four parts: (1) Introduction; (2) Fourteen Case Study Examples; (3) Examples of Funding for Local Safety Projects; and (4) A List of References. Fourteen implementation examples were developed based upon a comprehensive literature review, phone interviews, and inputs from the panel members. Implementation case study examples in this booklet include:

1. Chevrons (Washington State)
2. Dynamic Curve Warning Systems (Douglas County, Ore.)
3. Advanced Curve Warning and Advisory Speed Sign (Estill County, Ky.)
4. High-Friction Surface Treatments (Kentucky)
5. Raised Pavement Markers (Mobile County, Ala.)
6. Edge-Line Pavement Markings (Missouri)
7. Safety Edge$_{SM}$ (Georgia and Indiana)
8. Centerline Rumble Strips (Michigan)
9. Shoulder Rumble Strips (Washington State)
10. Cable Barrier (Minnesota)
11. Guardrail (North Carolina)
12. Breakaway Supports for Signs and Lighting (Nationwide)
13. Clear-Zone Improvements (Dallas County, Iowa)
14. Shoulder Widening (North Carolina)

### *Special Notes*

At the time of publication, some of the RwD countermeasures presented in this report, while anticipated to be effective in addressing RwD crashes, have not been formally evaluated using statistically valid methods. Readers are encouraged to obtain more up-to-date information by contacting their corresponding agency directly.

# CASE 1: Chevrons Washington State

Statistics from the FARS database indicate that more than 83 percent of the fatal crashes at horizontal curves involve RwD (Satterfield et al. 2009). Enhancing curve delineation with chevrons (see Figure 3) is a low-cost safety improvement, providing positive guidance in horizontal curves. It also may encourage drivers to decrease their speeds and, as a result, would reduce the frequency of RwD and head-on crashes (Srinivasan et al. 2009).

Figure 3. Sample of Installed Chevron (Image: Neal Hawkins)

According to the Manual on Uniform Traffic Control Devices (MUTCD), chevrons and/or one-direction large arrows shall be used where the difference between speed limit and the advisory speed is more than 15 mph (FHWA 2009a). In order to delineate the curve and provide additional guidance for drivers, chevrons must be spaced properly. The 2009 MUTCD provides guidance on the spacing of chevrons as shown in Table 1 (FHWA 2009a). See section 2C.09 in the 2009 MUTCD for more detailed information.

Table 1. Typical Spacing of Chevron Alignment Signs on Horizontal Curves (FHWA 2009a)

| Advisory Speed (mph) | Curve Radius (ft) | Sign Spacing (ft) |
|---|---|---|
| 15 or less | Less than 200 | 40 |
| 20 to 30 | 200 to 400 | 80 |
| 35 to 45 | 401 to 700 | 120 |
| 50 to 60 | 701 to 1,250 | 160 |
| More than 60 | More than 1,250 | 200 |

Moreover, the retroreflective sign sheeting material used makes the curve more visible to drivers during nighttime conditions. A series of these signs may be placed in one or both directions of travel, on the outside of a curve, and positioned in line with approaching traffic at a right angle to the driver's sightline (FHWA 2011a).

In an attempt to evaluate the safety effectiveness of chevron signs (W1-8 signs), the Washington State Department of Transportation (WSDOT) gathered data for 139 treated curves on rural two-lane roads. The data includes a total of 71.5 mile-years in the before period and a total of 95.0 mile-years in the after period (Srinivasan et al. 2009). In order to incorporate Empirical Bayes (EB) methods in a before-after analysis, data were also collected at reference sites without chevron signs.

Safety performance functions (SPFs) were estimated for five crash classifications as follows:

1. Total nonintersection crashes (all severities and all crash types)
2. Nonintersection lane-departure crashes (all severities)
3. Nonintersection fatal and injury crashes (all crash types)
4. Nonintersection crashes during dark (all severities and all crash types)
5. Nonintersection lane-departure crashes during dark (all severities)

The study found that chevrons along the horizontal curves on two-lane rural roads decreased the total number of lane-departure and all crashes during dark conditions by up to 22.1 and 24.5 percent, respectively (Srinivasan et al. 2009). In addition, results from a disaggregate analysis indicated that the chevrons are more effective for the sites with higher annual average daily traffic (AADT) than the sites with lower AADT. Table 2 lists the before-after analysis results based on the aggregate analysis.

In order to estimate the benefit-cost (B/C) ratio, an economic analysis was also conducted. Costs were estimated based on actual installation costs of the chevron signs. Benefits were estimated based on the RwD crash reductions using unit crash cost data from the Federal Highway Administration (FHWA). Table 3 illustrates the range of estimated B/C ratios. It should be noted that the lowest installation cost per sign was assumed to be $30, and the upper limit was considered to be $160. This case study demonstrated that installing chevron signs can be a very cost-effective treatment with the B/C ratio exceeding 8:1 (Srinivasan et al. 2009).

**Table 2. Before-After Analysis Results of Treatment Curves (Srinivasan et al. 2009)**

| Crash Types | EB Estimate of Crashes | Observed Crashes in "After" Period | Percent Reduction |
|---|---|---|---|
| 1 | 374.8 | 361 | 4.3 |
| 2 | 308.6 | 292 | 5.9 |
| 3 | 211.8 | 179 | 16.4 |
| 4 | 169.5 | 129 | 24.5* |
| 5 | 147.7 | 116 | 22.1* |

* Significant at the 95 Percent Confidence Level

**Table 3. Summary of Economic Analysis Results (Srinivasan et al. 2009)**

| Sites | Years | Total Crash Reduction Per year | Total Crash Reduction | Crash Savings Per Site-Year | B/C Ratio |
|---|---|---|---|---|---|
| 139 | 6.76 | 4.69 | 0.03 | 2938 | 8.6-45.9 |

**Agency Contact:**

**Rick Mowlds**
State Sign Engineer
Washington State Department of Transportation
360-705-6826
mowldsr@wsdot.wa.gov

# CASE 2: Dynamic Curve Warning Systems Douglas County, Oregon

Dynamic curve warning systems (DCWSs), as traffic control devices, are programmed to provide drivers exceeding a certain speed threshold with a message, flashing light-emitting diodes (LEDs), or their speed display. Otherwise these signs are blank or blacked-out. The system can interact with drivers individually by a relatively personalized message and may lead to better compliance with speed limits (FHWA 2013a). DCWSs typically consist of a speed measuring device (e.g., loop detector and radar) and a message sign displaying feedback to drivers.

Figure 4 shows two different types of signs: speed feedback sign and curve warning sign. A national demonstration project (Hallmark et al. 2012) evaluated these two types of signs at 22 sites in seven states on rural two-lane curves. The study found that there was a 1.8-mph reduction in mean speed at one month after installation, a 2.6-mph reduction in mean speed at one year after installation, and a 2.0-mph reduction in mean speed at two years after installation (all of these speed reductions occurred at the point of curvature or beginning of the curve).

Taking advantage of a full Bayes analysis, the study developed crash modification factors (CMFs) for DCWSs. Results indicated that crashes were 5-7 percent lower after installation of the sign, depending on type and direction of crash. More specifically, RwD crashes in the direction of the new sign reduced by 5 percent regardless of the severity (Hallmark et al. 2014).


Figure 4. Two Examples of Installed DCWS (MTC 2009)

However, it should be noted that most curves do not require this level of signage, and proliferation of any device is likely to cause drivers to lose respect for signs. In addition, the high initial installation costs ($2,000 to $11,000 per display) and the maintenance costs limit their use to selective high-crash curve locations. Before installation, the DCWS should be checked for MUTCD compliance (Hallmark et al. 2013a, Hallmark et al. 2013b).

In 2002, the Oregon Department of Transportation (ODOT) installed a DCWS system in advance of a curve on Interstate 5 between mileposts 107 and 109, near Myrtle Creek in Douglas County. This curve carried about 16,750 vehicles per day with the advisory speed of 45 mph. Figure 5 depicts a comparison between the conditions before and after installation of the DCWS system.

This system consisted of a dynamic message sign, an advisory speed sign, a controller unit, a radar unit, and computer software. With a 95 percent level of confidence, the evaluation results demonstrated that installation of the DCWS was followed by a reduction of 2.6 mph in passenger-car mean speeds and 1.9 mph in commercial-vehicle mean speeds (Bertini et al. 2006). In addition, the results showed that 76 percent of drivers slowed down due to the system's installation.


Figure 5. Before (top) and after (bottom) Pictures of DCWS at Interstate 5 (Bertini et al. 2006)

**Agency Contact:**


**Shyam Sharma**
Region 3 Traffic Manager
Oregon Department of Transportation
541-774-6335
shyam.sharma@odot.state.or.us

# CASE 3: Advance Curve Warning and Advisory Speed Sign Estill County, Kentucky

Advance curve warning signs are placed in advance of curves to alert drivers of what lies ahead on their route (see Figure 6). Curve warning signs are required or recommended to be supplemented with advisory speed signs based on the difference between the speed limit and advisory speed per Table 2C-5 of the MUTCD. Where emphasis of a specific sign is needed, techniques to increase the likelihood of drivers perceiving and reacting to the sign, such as flags, warning beacons, and retroreflective sign supports, can be added. See section 2A.15 in the 2009 MUTCD for more detailed information (FHWA 2009a).

Properly installed curve warning signs are proven to improve safety for horizontal curves. According to the Crash Modification Factor Clearinghouse, the curve warning signs with advisory speed plaque can reduce 13 percent of all serious- and minor-injury crashes and 29 percent of all property-damage only (PDO) crashes (Hallmark et al. 2013).

One challenge for this countermeasure is setting proper advisory speeds. Studies have found that drivers do adjust their speed even though compliance with lower advisory speed is low (Milstead et al. 2011). The cost for most commonly used curve warning signs with advisory speed plates ranges from $500 to $700 per sign, considering a wooden post (ODOT 2014). Updating existing signs with higher types of prismatic sheeting can improve nighttime visibility. Fluorescent sheeting will increase sign visibility during low-light conditions like dawn, dusk, or cloudy weather. The fluorescent products currently available have good daytime visibility and nighttime visibility, as well, due to the overall quality of the available materials. ODOT switched to fluorescent curve signs, resulting in up to 25 percent reduction in nonintersection fatal and injury crashes (ODOT 2014).


Figure 6. Example of Advisory Ramp Speed Sign and Chevrons (FHWA 2009b)

In response to a number of fatal crashes, the Kentucky Transportation Cabinet (KYTC) installed an LED-enhanced curve warning sign[1] in advance of a curve on KY 82 in Estill County. This roadway segment carries more than 3,500 vehicles per day. In addition to the LED sign, a proper advisory speed limit was determined to be 25 mph at this location (Elkins 2007). Figure 7 illustrates the LED-enhanced curve warning sign installed.


Figure 7. LED-Enhanced Curve Warning Sign, KY 82 (Image: KYTC)

The installed sign is solar-powered and has an auto dimming feature for nighttime visibility. Similar signs, installed at other locations across the state, have shown to be effective in lowering RwD crashes. Since the installation at one specific location, on KY 82 near Salem Baptist Church in Estill County in 2006, no fatalities have been recorded, even though the crash history indicated one fatality per year for three consecutive years prior to the installation of the advance curve warning sign.

1-Since some LED sign designs have been known to obscure the sign message, special attention should be paid to purchase

**Agency Contact:**

**H. B. Elkins**
Public Information Officer
Kentucky Transportation Cabinet, District 10
606-666-8841
hb.elkins@ky.gov
www.transportation.ky.gov/district-10

# CASE 4: High-Friction Surface Treatments Kentucky

RwD crashes may occur when there is insufficient friction between the tire and pavement surface, which is one contributor to a vehicle leaving the pavement, especially at horizontal curves or intersections. One strategy that has been used to address problem locations is applying high-friction surface treatments (HFSTs), a thin layer of durable aggregates (typically calcined bauxite) that are highly resistant to polishing (ATSSA 2013, ATSSA 2014). The aggregate is bonded to the asphalt, concrete, or other pavement surfaces using polymer binders.

This treatment should only be applied to structurally sound pavement, as it only changes the surface friction not the pavement's structural performance. HFSTs can be installed by either machine or hand tools with a minimal impact on traffic during construction. A sample of the finished product can be seen in Figure 8. The HFST provides greater friction, allowing motorists to maintain better control in dry and wet road conditions, resulting in reduced RwD crashes.

Figure 8. Sample of High-Friction Surfacing Treatment on a Roadway, Madison County, Ky. (Image: Kentucky Transportation Cabinet)

HFSTs are considered a cost-effective safety countermeasure, since the friction has a long life. Despite the fact that its initial costs are higher than other traditional thin overlay treatments, the outstanding crash reductions experienced by the many installations and the longevity of the friction makes it a cost-effective solution. A similar product using the same method of installation can also be colored to identify special areas (e.g., bus or bike lanes and sidewalks). If the area does not have a high friction demand, lower-cost aggregates can be used.

According to the FHWA, *Every Day Counts (EDC) 2012 Initiatives*, a B/C ratio of about 24:1 can be achieved by implementing pavement friction treatments (FHWA 2012a).

Due to the high rates of RwD crashes on rural roads in Kentucky, the KYTC launched a three-year HFST program to enhance friction for horizontal curves at 75 locations statewide in 2010. A photo taken during application of the pavement surface treatment is shown in Figure 9.

Figure 9. High-Friction Surfacing Treatment, Kentucky (Image: Kentucky Transportation Cabinet)

The KYTC reported that the total number of RwD crashes at the installation sites dropped by 91 percent (from 357 to 33) and 78 percent (from 126 to 28) in wet and dry weather conditions, respectively (RST 2013).

**Agency Contact:**

**Tracy Allen Lovell, P.E.**
Division of Traffic Operations
Kentucky Transportation Cabinet
502-782-5534
tracy.lovell@ky.gov

# CASE 5: Raised Pavement Markers Mobile County, Alabama

Raised pavement markers (RPMs) are often used by transportation agencies as delineation treatments to improve nighttime visibility, particularly in wet conditions. According to AASHTO's Strategic Highway Safety Plan (SHSP), RPMs are considered as one of the effective, low-cost strategies to mitigate RwD crashes (ATSSA 2011).

These devices are widely used to supplement centerlines and edge lines to provide critical guidance and sight distance recognition for road users (FHWA 2009a). Inclement weather and low-light conditions, especially on rural roads, are such circumstances that justify the application of RPMs due to the need for more visual clues to identify and maintain travel lanes. RPMs can provide increased visibility and tactile feedback by reflecting vehicle headlights to show road alignment to reduce RwD crashes and fatalities.

The 2009 MUTCD offers guidance in using RPMs: *"raised pavement markers should not substitute for right-hand edge line markings unless an engineering study or engineering judgment indicates the benefits of enhanced delineation of a curve or other location would outweigh possible impacts on bicycles using the shoulder, and the spacing of raised pavement markers on the right-hand edge line is close enough to avoid misinterpretation as a broken line during wet night conditions"* (FHWA 2009a). See section 3B.11-14 in the 2009 MUTCD for more detailed information.

According to the Crash Modification Factor Clearinghouse website, the CMFs associated with installing raised pavement markers are 0.81-0.87, which means a reduction of 13-19 percent in the total crashes regardless of severity (FHWA 2013b).

With the increasing number of RwD crashes on local rural roadways, Mobile County, Ala., assisted by the FHWA and the Alabama Department of Transportation (ALDOT), implemented a systematic application of RPMs along 10 rural roadways. These roadways, measuring more than 65 miles, experienced the highest number of RwD crashes within the county. One-directional white RPMs were easily placed just outside the existing edge line using traffic maintenance department equipment and manpower (FHWA 2013c).

In this project, the RPMs were installed with 80-foot spacing in tangent sections of roadways, 40-foot spacing between the advance warning curve sign and the beginning of the curve, and 20-foot spacing through the curve (see Figure 10).


Figure 10. Example of 20-foot RPM Spacing for a Curve During Daytime/Nighttime (FHWA 2013b)

The crash evaluation results revealed a significant decrease in injuries and fatalities occurring on treated roadways. Compared with 2004-2008 crash data, which included 287 RwD crashes that resulted in eight fatalities and 177 injuries, RwD crashes during 2009-2012 on the same roadways dropped to 33, resulting in an average annual decrease of 85.6 percent in RwD crashes. More specifically, this change eliminated the fatalities and reduced injuries from 177 to 10. Now, RPM installation is a part of most roadway projects in Mobile County, Ala. (FHWA 2013).

**Agency Contact:**


**James Foster**
Traffic Manager
Mobile County Engineer Office
251-574-8595
jfoster@mobilecounty.net

# CASE 6: Edge-Line Pavement Markings Missouri

Edge-line pavement markings separate travel lanes from the adjacent shoulders, and they delineate the travel path and roadway alignment. By facilitating quick recognition of travel lanes, they help prevent vehicles from running off roads (see Figure 11).

Figure 11. Sample of Installed Edge-Line Pavement Markings (Carlson et al. 2010)

Based on the MUTCD, edge-line markings shall be white when they are on the right edge of the roadway. In addition, the normal width of edge-line markings is 4-6 inches, and wider edge-line markings can range from 8 to 12 inches, with a larger width measurement (FHWA 2009a).

The MUTCD 2009 edition details the standard for installing edge-line markings: *"Edge line markings shall be placed on paved streets or highways with the following characteristics: Freeways, Expressways, and Rural arterials with a traveled way of 20 feet or more in width and an average annual daily traffic (AADT) of 6,000 vehicles per day or greater"* (FHWA 2009a). See section 3B.07 in the 2009 MUTCD for more detailed information. However, many state departments of transportation (DOTs) and local agencies use these markings on low-volume rural roads where the RwD crash is a notable concern.

The Missouri Department of Transportation (MoDOT) initiated a program to install edge-line markings, from 2009 to 2012, on eligible high-risk rural roads (HRRRs).

Since more than 219 fatalities and 1,500 incapacitating crashes occurred over a three-year time frame on high-risk roadway segments in rural areas with the ADT between 400 and 1,000 vehicles per day, the program focused on installing the edge lines on all eligible HRRRs that carry an ADT greater than 400 vehicles per day.

Considering five years of crash data, MoDOT performed a safety evaluation of implemented countermeasures on 73 high-risk roadway segments. Since the completion of this project, the number of RwD crashes at those locations has declined from 113 (27 severe crashes) per year during the three-year before period (2006-2008) to 87 (16 severe crashes) per year during the two-year after period (2010-2011). The total of RwD crashes and the total of severe RwD crashes decreased by 23 and 38 percent with the installation of the edge-line markings. Final evaluation results, using the EB method, concluded that the edge-line markings contributed to a 15.2 percent decrease in all crashes and a 19.3 percent decrease in severe crashes. The results support that adding edge-line markings at these lower volumes can offer benefits at an acceptable cost by reducing both total and RwD crashes.

According to the FHWA "Manual for Selecting Safety Improvements on High Risk Rural Roads," the B/C ratios of implementing edge-line markings varies between 27.9 and 336.1 (see Table 4). It should be noted that a volume of 1,000 vehicles per day is defined as the threshold between lower and higher volumes. Additionally, optimal conditions consist of 12-foot travel lanes with 6-foot paved shoulders, while narrower conditions may be as little as 10-foot travel lanes without any shoulders (FHWA 2014b).

The CMFs associated with edge-line markings vary between 0.56 and 0.62, which demonstrates a reduction of 38- 44 percent in the total crashes regardless of severity (see Table 4). More specifically, the number of RwD crashes has dropped by 30 percent for all crash severities combined (FHWA 2014).

Table 4. Results of B/C and CMFs Analysis for Edge-Line Markings (FHWA 2014b)

| | B/C Ratio | CMF |
|---|---|---|
| Lower Volume Optimal Conditions | 27.9 | 0.56-0.62 |
| Higher Volume Optimal Conditions | 222.8 | 0.56-0.62 |
| Lower Volume Narrower Conditions | 34.1 | 0.56-0.62 |
| Higher Volume Narrower Conditions | 336.1 | 0.56-0.62 |

**Agency Contact:**

**John P. Miller, P.E.**
Traffic Safety Engineer
Missouri Department of Transportation
573-526-1759
john.p.miller@modot.mo.gov

# CASE 7: Safety Edge$_{SM}$ Georgia and Indiana

Safety Edge$_{SM}$ is a simple but effective countermeasure to prevent roadway drop-off crashes, particularly on rural roads with unpaved shoulders. It can save lives by allowing drivers who drift off highways to return to the pavement safely. The Safety Edge$_{SM}$ is one of the nine proven safety countermeasures by the FHWA in 2012. It mitigates the vertical elevation difference by sloping the edge of the pavement to 30 degrees during paving or resurfacing projects, using a commercially available device that can be attached to the hot-mix asphalt (HMA) paver (FHWA 2012b).

The Safety Edge$_{SM}$ is also highly cost-effective. The added cost of resurfacing with this treatment was found to be very small, because the asphalt just needs to be reformed to create the Safety Edge$_{SM}$. It can extend pavement life by providing an additional level of consolidation so that edge raveling is decreased (FHWA 2012b).

The FHWA developed a guide for the Safety Edge$_{SM}$ design and construction, sharing the findings from 10 demonstration projects in multiple states (FHWA 2012d). It also provides information on the various elements to consider when designing and constructing pavement projects with the Safety Edge$_{SM}$ (FHWA 2012c).

In Figure 12, the main photo shows pavement construction with a Safety Edge$_{SM}$. Upon project completion, the adjacent unpaved material should be graded flush with the top of the pavement (inset photo) (FHWA 2012b).

Figure 12. The Safety Edge$_{SM}$ (Image: FHWA)

A safety evaluation of the Safety Edge$_{SM}$ was conducted by the Midwest Research Institute (MRI) with 261 treated sites (685 miles) in Georgia and 148 sites (514 miles) in Indiana. Figures 13 and 14 show examples of typical treated sites in Georgia and Indiana that were resurfaced with Safety Edge$_{SM}$ (FHWA 2011b).

Figure 13. Example of Georgia Treatment Site (FHWA 2011b)

Figure 14. Example of Indiana Treatment Site (FHWA 2011b)

The evaluation results indicated that there was a 5.7 percent reduction in total crashes by the Safety Edge$_{SM}$, based on crash data of six years before (1999 to 2004) and three years after (2006 to 2008) resurfacing the study sites in Georgia, and those of two years before (2003 to 2004) and three years after (2006 to 2008) in Indiana. Additionally, the B/C ratio for two-lane highways with paved shoulders ranged from 3.8 to 43.6 for Georgia and from 3.9 to 30.6 for Indiana. For two-lane highways with unpaved shoulders, the B/C ratio ranged from 3.7 to 62.8 for Georgia and from 2.8 to 12.8 for Indiana (FHWA 2011b). Efforts have been initiated to develop CMFs for the Safety Edge$_{SM}$ based on a large sample size (FHWA 2012c).

**Agency Contact:**

**Michael Turpeau**
State Safety Program Supervisor
Georgia Department of Transportation
404-635-2831
mturpeau@dot.ga.gov

# CASE 8: Centerline Rumble Strips Michigan

Centerline rumble strips (CLRS), as a longitudinal safety feature, can be installed at or near the centerline of undivided roadways. The CLRS include a series of milled or raised elements on the pavement (FHWA 2011c). Figure 15 shows a sample of milled CLRS. It should be noted that the centerline pavement markings are typically installed on the rumble strips, which are also sometimes known as centerline rumble stripes.

Figure 15. Sample of Installed Milled CLRS (Image: Neal Hawkins)

The CLRS are typically employed as a treatment to mitigate the multivehicle cross-centerline and single-vehicle RwD crashes, which are some of the most severe crash types (Iowa DOT 2013). Tires rolling over rumble strips generate noise and vibration, which alert a distracted or drowsy driver to make a safe steering correction. Additionally, the CLRS help to keep drivers in their travel lanes in poor-visibility conditions like fog, rain, snow, and darkness.

In 2012, longitudinal rumble strips and stripes on two-lane roads became one of the FHWA's nine proven safety countermeasures. It is necessary to consider the safe accommodation of all road users throughout the design and application of CLRS. The FHWA provides some recommendations on CLRS installation, accommodation, and mitigation (FHWA 2011c).

Based on the National Cooperative Highway Research Program (NCHRP) report results, the number of injury crashes for these crash types dropped from 38 to 50 percent and 37 to 91 percent for rural two-lane and urban two-lane roads, respectively (Torbic et al. 2009).

The Michigan Department of Transportation (MDOT) initiated a CLRS installation program during the period of 2008 to 2010. Approximately 5,400 miles of nonfreeway roadways were included in this program. At that time, the program was the largest of its kind across the nation. The MDOT guideline recommends the installation of CLRS on all rural, nonfreeway highways with a speed limit of 55 mph or higher and a width of lane plus paved shoulder beyond the centerline corrugation greater than 13 feet. Table 5 lists standard installation details. Figure 16 compares before and after the CLRS installation in Michigan.

**Table 5. MDOT CLRS Standard Installation Details (Datta et al. 2012)**

| Standards |
|---|
| Transverse dimension of corrugation: 16 inch (±1/2 inch)* |
| Longitudinal dimension of corrugation: 7 inch (±1/2 inch) * |
| Spacing between corrugations: 5 inch (-1/2 inch, +1 inch) * |
| Longitudinal length center-to-center between corrugation pairs: 17 inch |
| Depth of corrugation: 3/8 inch (+1/8 inch) * |

*Acceptable tolerance according to MDOT's standards


Figure 16. Before (left) and after (right) Pictures of the CLRS Installation (Datta et al. 2012)

Following this program, MDOT conducted a two-phase safety evaluation study of effectiveness of the CLRS. Phase I study results demonstrated that the implementation of rumble strips resulted in a significant reduction in both centerline and edge-line encroachments in tangent sections and through the curves (Datta et al. 2012). More specifically, after CLRS installation, the centerline encroachments within the curves to the left side dropped by 87 percent (from 11.9 to 1.5 percent) (see Figure 17).


Figure 17. Sample of Captured Centerline Encroachment (Datta et al. 2012)

Phase II study contains a comprehensive safety analysis using three-year period before-after dataset. Based on the preliminary results, the total number of crashes at the treated sites has declined from 4,137 during the three-year before period to 2,775 during the three-year after period. There was a 33 percent reduction in all types of crashes.

Table 6 lists percentage of crash reduction for three related crash types. The opposite-direction sideswipe collisions, multivehicle head-on crashes, and single-vehicle RwD crashes decreased by 46, 35, and 31 percent, respectively.

Table 6. Preliminary Before-After Safety Performance by Crash Types (MDOT 2014)

| Crash Types | Reduction (%) |
|---|---|
| Opposite-direction Sideswipe | 46 |
| Head-on | 35 |
| Single-vehicle RwD | 31 |

With a 95 percent level of confidence, the percent reductions for fatal and severe injury crashes (A or B) were more pronounced than for possible injury crashes (C) and PDO crashes. Table 7 illustrates the before-after safety evaluation results by severity levels. While a benefit-cost (B/C) analysis for CLRS is currently underway as part of the Phase II study, it is noted that the typical cost per foot during the initiative installations was only $0.13 (MDOT 2014).

Table 7. Preliminary Before-After Safety Performance by Severity Levels (MDOT 2014)

| Crash Severity | Reduction (%) |
|---|---|
| Fatal | 47 |
| A | 35 |
| B | 37 |
| C | 31 |
| PDO | 32 |
| Total | 33 |

**Agency Contact:**

**Mary K. Bramble**
Pavement Marking and Delineation Engineer
Michigan Department of Transportation
517-335-2837
bramblem1@michigan.gov

# CASE 9: Shoulder Rumble Strips Washington State

Shoulder rumble strips (SRS) are commonly installed in paved shoulders that are adjacent to the travel lane. SRS provide acoustical and vibrational warnings to drivers who are leaving travel lanes due to inattention, fatigue, drowsiness, or poor visibility due to adverse weather conditions. In order to increase the visibility or accommodate narrow shoulder conditions, SRS can be painted with edge line markings, usually known as edge line rumble stripes.

Shoulder or edge line rumble strips on two-lane roads is on FHWA's most recent proven safety countermeasures list (FHWA 2012e). Past studies have shown a high B/C ratio when considering the amount of RwD crashes reduced. The B/C ratio for SRS was estimated to be approximately 50:1 based on a survey of 50 State DOTs (OKLADOT 2014).

Following significant reductions in RwD crashes in rural interstate system after SRS installation in 1998, the WSDOT investigated the possibility of applying SRS on undivided highways. To date, WSDOT has installed over 260 miles of SRS, a mix of milled and raised, on its rural two-lane undivided highways. Table 8 lists the WSDOT's design policy guiding the installation of SRS. Figure 18 depicts examples of SRS installed in Washington State.

Figure 18. Sample of Installed SRS in Washington State (FLG 2014)

In early 2013, the WSDOT undertook a review of historical crash data for nine years (2002-2010). The study examined a total of 190.53 miles of roadways with SRS in 45 segments, covering all geographic areas of the state (Olson et al. 2013). The study focused on the combined performance of shoulder and CLRS, where the SRS is specifically designed to address the run-off-the-road to the right side (ROTRR) crashes.

In cases where SRS were added during or after CLRS installation, the results showed that ROTRR crash rates were reduced by between 47.0 percent and 61.6 percent in all-severity crashes, and by between 15.3 percent and 66.6 percent in fatal and serious injury crashes. Table 9 illustrates the before-after safety evaluation study results by severities for these two conditions. Note that a rate approach, using per 100 million vehicle miles traveled (VMT), was used in the analysis.

**Table 8. WSDOT SRS Standard Installation Details (Olson et al. 2013)**

| Standards |
|---|
| Use on rural roads where posted speed is 45 mph or higher |
| Provide for at least 4 feet of usable shoulder between the rumble strip and the outside edge of shoulder. If guardrail or barrier is present, increase the dimension to 5 feet of usable shoulder |
| Ensure shoulder pavement is structurally adequate to support milled rumble strips |
| Do not place SRSs on downhill grades exceeding 4 percent for more than 500 feet in length along routes where bicyclists are frequently present |
| Consult the region and Headquarters Bicycle and Pedestrian Coordinators to determine bicycle usage along a route, and involve them in the decision-making process when considering rumble strips along bike touring routes or other routes where bicycle events are regularly held |

**Table 9. Before-After Safety Performance by Crash Types and Severity Levels (Olson et al. 2013)**

| Condition | Crash Type Related to SRS | All-severity Crash Rates | | | Fatal and Injury Crash Rates | | |
|---|---|---|---|---|---|---|---|
| | | Before | After | % dropped | Before | After | % dropped |
| SRS and CLRS simultaneously | ROTRR | 0.145 | 0.056 | 61.6 | 1.155 | 0.386 | 66.6 |
| SRS installed after CLRS | ROTRR | 0.163 | 0.086 | 47.0 | 2.035 | 1.724 | 15.3 |

**Agency Contact:**

**John P. Donahue**
Design Policy and Analysis Manager
Washington State Department of Transportation
360-705-7952
DonahJo@wsdot.wa.gov

# CASE 10: Cable Barrier Minnesota

A Barrier is a device designed to stop or redirect errant vehicles to prevent a more serious crash. Although barriers cannot reduce the total number of crashes, the benefits of cable barriers are that they tend to minimize the severity of injuries by absorbing the impact of the crash and have a safer consequence compared with striking the shielded obstacles. However, installing a safety barrier should be taken into consideration only after other treatment options (e.g., removing/relocating hazard, making the hazard traversable, etc.) have been investigated.

Three main types of safety barriers are used by transportation agencies, including flexible barriers, semi rigid barriers, and rigid barriers. Flexible barriers, made from wire rope strung between posts, are the most forgiving type of barriers and the best option for minimizing injuries to vehicle occupants (iRAP 2011).

Semi rigid barriers, also known as guardrails or guiderails, are the most common type being widely used and can be effective at preventing:

- RwD crashes
- Vehicles from hitting fixed objects
- Vehicles from going over steep embankments.

Guardrails have a low life-cycle cost since they often remain functional without immediate repair needs (ATSSA 2011). Rigid barriers, such as concrete barriers, are very effective in keeping vehicles within the roadway and often used as a median barrier when providing a wide median is not feasible (MnDOT 2014a).

According to the Crash Modification Factor Clearinghouse website, the CMF for fatal cross-median crashes associated with median cable barriers is 0.34, which means a reduction of 66 percent in fatal crashes regardless of the type of crash (FHWA 2013d).

In an effort to reduce fatal and severe crashes, the Minnesota Department of Transportation (MnDOT) initiated a Toward Zero Deaths (TZD) program in 2003. In 2004-2008, cable barriers were implemented at 31 segments along approximately 150 miles of a freeway to reduce the number of fatalities and severe injuries caused by cross-median crashes in Minnesota (MnDOT 2008). Figure 19 depicts a cable barrier system being installed and tensioned.

**Figure 19. Sample of Cable Barrier System, Minnesota (Image: Mark J. Bloschock)**

Table 10 illustrates the results of before-after crash-data evaluations in all treated sites for a three-year time period (DeVoe and Monroe 2012). It should be noted that the cost of material and installation per mile for concrete and cable median barriers includes $400,000 to $500,000 and $140,000 to $150,000, respectively (MnDOT 2014a).

**Table 10. Before-After Crash Data Analysis Results**

| Crash Severity | Before Cable Barrier Installation | After Cable Barrier Installation |
|---|---|---|
| Fatal Cross-Median Crashes | 19 | 0 |
| Serious Injury Cross-Median Crashes | 8 | 6 |
| Possible Injury Cross-Median Crashes | 99 | 114 |
| PDO Cross-Median Crashes | 281 | 1,022 |

*Continued on next page*

Figure 20 depicts a significant cross-median crash reduction (from eight fatal and three serious injuries to zero fatal and two serious injury crashes) on a sample segment of I-35 (MnDOT 2014a).

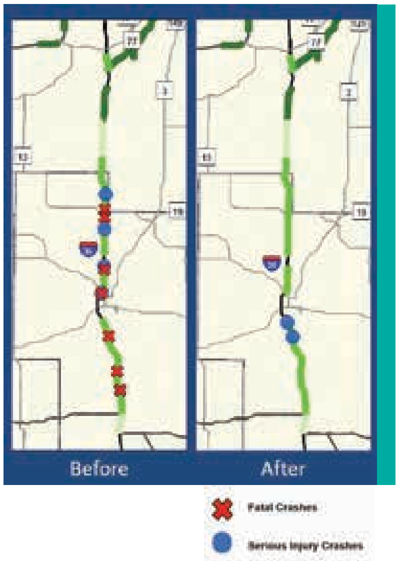



Figure 20. Before-After Crash Reduction on I-35
(Image: MnDOT Office of Traffic, Safety and Technology)

It is important to note that installation of any type of barrier may result in a significant increase in lower severity (e.g., PDO or possible injury) crashes as shown in Table 10. However, since fatal and serious injury crashes average significantly higher costs, the total crash cost at these locations had a 38 percent reduction due to the cable barrier installation, comparing the crash cost in the three-year before period with the three-year after period.

**Agency Contact:**


**Kevin Gutknecht**
Director of Communication
Minnesota Department of Transportation
651-366-4266
kevin.gutknecht@state.mn.us

# CASE 11: Guardrail North Carolina

Properly designed and installed guardrail can reduce the severity of RwD crashes by containing and/or redirecting errant vehicles. Guardrail will not necessarily reduce the number of RwD crashes, because it is longer than and closer to the traveled way than the object it shields. Therefore, guardrail should only be installed where it is judged that striking the guardrail is less severe than consequences of striking fixed objects or slopes behind the guardrail (Caltrans 2012).

There are a number of barrier systems (including various types of guardrail) that will perform the function described above. The most common guardrail system used in the United States is the metal beam guardrail, which is made up of W-shaped metal beam rail elements fastened to wood or galvanized steel posts (Ray and McGinnis 1997). W-beam guardrail is in the semi rigid barrier category, with deflections ranging from 2.6 to 7 feet (AASHTO 2011a).

It is worth mentioning that an untreated end of a roadside barrier can result in more severe crashes. Therefore, crash-worthy end treatments should be employed to safely decelerate the vehicle to a stop or redirect it from an object of concern (AASHTO 2011a).

Approximately, 70 percent of W-beam guardrail collisions were reported to be PDO crashes (Ray et al. 2003). Overall, evidence suggests that the installation of W-beam guardrail is a low-cost safety improvement that reduces the severity of RwD crashes (ATSSA 2008). Among the post-and-beam barrier systems, the strong-post W-beam guardrails yield lower deflections (Ray and McGinnis 1997). It is relatively low maintenance because in a minor crash it may require no repairs.

According to the Crash Modification Factor Clearinghouse website, installing guardrail in rural roadways can reduce up to 33 percent of RwD fatal and injury crashes (FHWA 2014c).

In an attempt to reduce the RwD crash severity, the North Carolina Department of Transportation (NCDOT) completed the evaluation of spot-safety and hazard-elimination projects for 14 divisions in the state. Since the most prevalent crash type at the subject locations was RwD crash, the guardrail was installed with the aim of reducing their severity (NCDOT 2014). Figures 21 through 23 depict the three of many treatment sites.

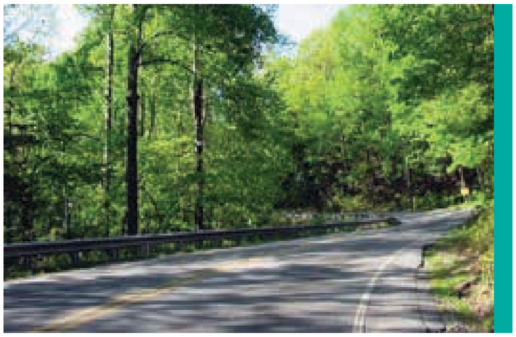


**Figure 21. Site 1: Driving West on U.S. 64 (NCDOT 2014)**

**Figure 22. Site 2: Driving West on U.S. 74/19 (NCDOT 2014)**

**Figure 23. Site 3: Driving Toward Nutley Drive (NCDOT 2014)**

*Continued on next page*

In order to measure the effectiveness of the implemented guardrail, a before-after analysis of the three treatment sites was conducted by NCDOT.

The crash analysis results and background information of the three sites are summarized in Table 11. The crash severity index is defined to be equal to the total equivalent PDO crashes (76.8 for "K=Fatal" and "A= Incapacitating injury" crashes, and 8.4 for "B=Non-Incapacitating injury" and "C=Possible injury" crashes) divided by the total number of crashes. The analysis results suggest that the percent reduction in the total severity index and RwD severity index range from 16.6 percent to 36.7 percent at the three sites (NCDOT 2014). The number of total and RwD crashes increased at Site 1 and Site 3 but were reduced at Site 2.

**Table 11. Before-After Analysis Results of Three Treatment Sites (NCDOT 2014)**

| Site | Crash Type/ Severity | Before Period | After Period | Percent Reduction/Increase (-/+) |
|---|---|---|---|---|
| Site 1:<br>Location: US 64<br>Length: 7.6 mi<br>Shoulder Width: 3 ft.<br>Speed Limit: 55 mph | | (1990-1996) | (1997-2004) | |
| | Total Crashes | 177 | 258 | 45.8 |
| | Total Severity Index | 13.7 | 8.81 | -35.7 |
| | Total RwD Crashes | 115 | 143 | 24.3 |
| | RwD Severity Index | 14.71 | 9.31 | -36.7 |
| Site 2:<br>Location: US 74/19<br>Length: 8.6 mi<br>Shoulder Width: 2-10 ft.<br>Speed Limit: 35-50 mph | | (1996-2001) | (2002-2007) | |
| | Total Crashes | 191 | 139 | -27.2 |
| | Total Severity Index | 14.07 | 11.7 | -16.6 |
| | Total RwD Crashes | 115 | 102 | -11.3 |
| | RwD Severity Index | 17.61 | 13.9 | -20.8 |
| Site 3:<br>Location: US 401<br>Length: Spot Location<br>Speed Limit: 50 mph | | (1995-2000) | (2001-2004) | |
| | Total Crashes | 19 | 28 | 47.4 |
| | Total Severity Index | 8.5 | 6.9 | -19 |
| | Total RwD Crashes | 12 | 17 | 41.7 |
| | RwD Severity Index | 11 | 8.1 | -26.6 |

**Agency Contact:**

**Shawn A. Troy**
Safety Evaluation Engineer
North Carolina Department of Transportation
919-773-2897
stroy@ncdot.gov

# CASE 12: Breakaway Supports for Signs and Lighting Nationwide

Breakaway supports are various devices designed and constructed to break or yield when they are hit by a vehicle (FHWA 2012f). Rigid objects (e.g., traffic signs, utility poles, lighting structures, traffic signals, railroad warning devices, motorist-aid call boxes, and mailboxes) can become deadly roadside hazards when struck by vehicles in RwD crashes. Based on the National Highway Traffic Safety Administration's (NHTSA) traffic safety facts in 2012, collisions with fixed objects accounted for 36 percent of all fatal crashes across the United States (NHTSA 2012).

It is not always feasible to maintain object-free roadside clear zones (the total roadside border area starting at the edge of the traveled way); however, crash severity can be diminished by using breakaway supports for those objects. Figure 24 depicts an example of an information sign with breakaway supports within the clear zone (FHWA 2012f).


Figure 24. An Information Sign with Breakaway Supports (FHWA 2012f)

Many breakaway designs for traffic signs, luminaires, and mailboxes have been crash tested and meet current standards. The 2009 MUTCD states that post-mounted roadside sign supports in the clear zone shall be breakaway, yielding, or shielded (FHWA 2009a). This requirement applies to all roads open to public travel, whether publicly or privately owned.

Although state highway agencies are generally in compliance already, many local agencies may not be aware of this requirement (FHWA 2014d). Additionally, the AASHTO *Roadside Design Guide* and most states' own standards provide guidance for designs of breakaway supports that have been crash tested.

Costs for replacing noncompliant sign posts can be minimized by coordinating with the upgrading of the retroreflective sheeting of signs (FHWA 2014d).

The omnidirectional breakaway support system is commonly used for light poles (see Figure 25). The key component of the system is a high-strength, double-neck coupling, designed to break away quickly and cleanly upon the impact, behaving consistently and predictably regardless of impact angle.

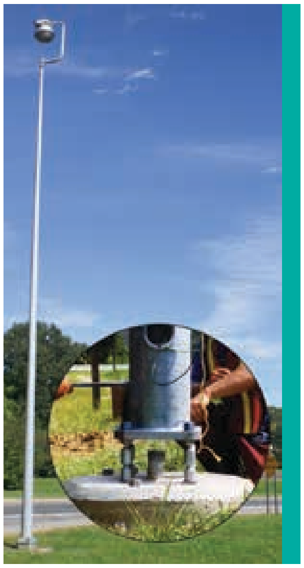


Figure 25. An Omnidirectional Breakaway Support System for Light Poles (Image: Transpo 2014)

Figure 26 illustrates a reusable breakaway support system for signs, mailboxes, etc. to make it possible to replace posts in minutes. This anchor can be installed in concrete, asphalt, and soil using a hand or power driver.

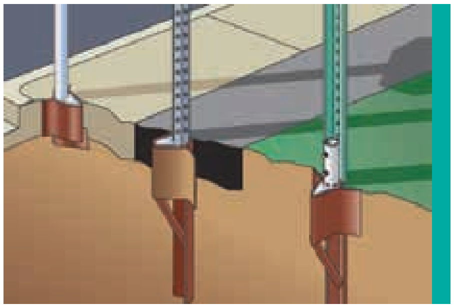


Figure 26. Sample of Breakaway Support System (Image: TAPCO)

Phone interviews were conducted with traffic and safety engineers from several state DOTs regarding the safety effects of breakaway supports. Most agencies reported that the countermeasure has been proven to be effective in reducing the severity of RwD crashes and that no evaluation is necessary. More detailed information regarding breakaway features for sign supports, utility poles, and other roadside features can be found on the FHWA website: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/ctrmeasures/breakaway/

**Agency Contact:**


**Nick Artimovich**
Roadway Departure Team
FHWA Office of Safety
202-366-1331
Nick.Artimovich@dot.gov

# CASE 13: Clear-Zone Improvements
# Dallas County, Iowa

A Clear zone is defined by the FHWA as *"An unobstructed, traversable roadside area that allows a driver to stop safely, or regain control of a vehicle that has left the roadway"* (AASHTO 2011a). The clear zone area, which starts at the edge of the traveled way, not only decreases the likelihood of a crash, but also reduces crash severity (see Figure 27). This area, which also includes a shoulder, a recoverable/nonrecoverable slope, and run-out area, can be achieved by removing/relocating roadside hazard objects or flattening slopes (FHWA 2014e).

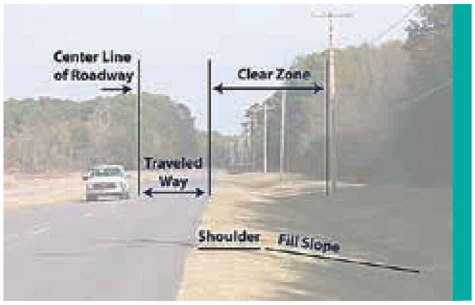



Figure 27. Clear-Zone Illustration (BMTE 2014)

Clear zone distances are most affected by the traffic volume, speed, roadside slope, and curvature. More specifically, as recommended by the AASHTO *Roadside Design Guide*, the suggested clear-zone distances for flat, level-terrain highways range between 7 and 34 feet, considering speed and average daily traffic (ADT) (AASHTO 2011a). See section 3-1 in the 2011 "Roadside Design Guide" for suggested clear-zone distances for different ADT and speed.

According to the Crash Modification Factor Clearinghouse website, changing clear zones from greater than or equal to 26.2 feet (8 meters) to less than or equal to 6.6 feet (2 meters), between 6.6 feet (2 meters) and 13.1 feet (4 meters), and between 13.1 feet (4 meters) and 26.2 feet (8 meters) results in increasing RwD fatal and injury crashes by 119, 60, and 27 percent, respectively (FHWA 2010).

In an attempt to reduce the RwD crash severity on their roads, in 2006, the Iowa Department of Transportation (Iowa DOT) started to develop standards and tools to be implemented by individual counties (Sperry et al. 2008). This program includes, but is not limited to, removal/relocation of hazards in the clear zone (e.g., trees, telephone poles, mailboxes) and the shielding or delineation of objects if achieving the first option is not feasible (see Figure 28). The safety evaluation results demonstrated that the number of total crashes dropped by up to 38 percent (Sperry et al. 2008).

Figure 28. Clear Zone (Image: Jack Latterell)

**Agency Contact:**

**Jim George**
Dallas County Engineer
Iowa Department of Transportation
515-993-4289
jgeorge@co.dallas.ia.us

# CASE 14: Shoulder Widening North Carolina

Roadway shoulders, as a safety feature, can improve road safety not only by allowing drivers to recover in a stable, clear recovery area, but also by providing drivers with more space to maneuver to avoid crashes. In addition, a wider shoulder improves stopping sight distance (SSD) at horizontal curves and provides better bicycle accommodations (see Figure 29).

Figure 29. Sample of Wider Shoulder (Image: Caltrans)

Shoulder width can vary between 2 feet for minor rural roads and 12 feet for major roads. It can also be widened on both inside and outside of curves (AASHTO 2011b). For low-volume roads (less than 1,000 vehicles per day) with narrow pavement width (less than 12 feet), it is more beneficial to consider narrower lanes with a wider shoulder (FHWA 2014b).

Based on current research on crash-related effectiveness of treatments, shoulder widening is considered a proven strategy that is compatible with other treatments for preventing RwD crashes (FHWA 2014b).

Shoulder widening can mitigate specific types of crashes, including single-vehicle RwD, multiple-vehicle head-on, and sideswipe crashes. Based on a recent study, in rural areas, upgrading a narrow unpaved shoulder (<5 feet) to a wider unpaved shoulder (>5 feet) can reduce these types of crashes up to 79 percent regardless of severity (Gayah and Donnell 2014).

The NCDOT completed many paved shoulder widening projects to mitigate RwD crashes on two-lane highways in 14 divisions throughout the state. Figures 30 to 32 illustrate three of many treatment sites on rural two-lane highways with an added 4-foot shoulder at Site 1 and an added 2-foot shoulder at Site 2 and Site 3 (NCDOT 2014).

Figure 30. Site 1: Driving North on U.S. 258 (NCDOT 2014)

Figure 31. Site 2: Driving West on State Route 1335 (NCDOT 2014)

Figure 32. Site 3: Driving East on State Route 2220 (NCDOT 2014)

*Continued on next page*

The NCDOT conducted a before-after analysis of these three treatment sites using three or more years before and after crash data. Table 12 lists study site characteristics and crash analysis results of the three projects. Considering weighting factors (76.8 PDO crashes for one "K" or "A Injury" crash, and 8.4 PDO crashes for one "B injury" or "C injury" crash), the crash severity index can be computed using the total equivalent PDO crashes divided by the total number of crashes.

The study found that the total number of RwD and all crashes decreased by up to 75.0 percent and 52.4 percent, respectively. Moreover, the analysis results demonstrated that the percent reduction in the total severity index and RwD severity index range from 43.7 percent to 69.2 percent at the three sites.

**Table 12. Before-After Analysis Results of Three Treatment Sites (NCDOT 2014)**

| | Crash Type/ Severity | Before Period (1999-2002) | After Period (2002-2005) | Percent Reduction/Increase (-/+) |
|---|---|---|---|---|
| Site 1:<br>Location: US 258<br>Added Shoulder Width: 4 ft.<br>Speed Limit: 55 mph | Total Crashes | 21 | 10 | -52.4 |
| | Total Severity Index | 7.43 | 3.96 | -46.7 |
| | Total RwD Crashes | 8 | 2 | -75.0 |
| | RwD Severity Index | 13.25 | 4.70 | -64.5 |
| | **Crash Type/ Severity** | **Before Period (2002-2006)** | **After Period (2006-2010)** | **Percent Reduction/Increase (-/+)** |
| Site 2:<br>Location: SR 1335-1318<br>Added Shoulder Width: 2 ft.<br>Speed Limit: 55 mph | Total Crashes | 16 | 10 | -37.5 |
| | Total Severity Index | 8.51 | 3.96 | -53.3 |
| | Total RwD Crashes | 9 | 7 | -22.2 |
| | RwD Severity Index | 13.53 | 4.17 | -69.2 |
| | **Crash Type/ Severity** | **Before Period (1997-2002)** | **After Period (2002-2006)** | **Percent Reduction/Increase (-/+)** |
| Site 3:<br>Location: SR 2220<br>Added Shoulder Width: 2 ft.<br>Speed Limit: 55 mph | Total Crashes | 23 | 11 | -52.2 |
| | Total Severity Index | 12.42 | 5.71 | -54.0 |
| | Total RwD Crashes | 19 | 10 | -47.4 |
| | RwD Severity Index | 9.66 | 5.44 | -43.7 |

**Agency Contact:**

**Shawn A. Troy**
Safety Evaluation Engineer
North Carolina Department of Transportation
919-773-2897
stroy@ncdot.gov

# Federal Highway Safety Improvement Program Funds

Several means of federal funding currently exist for local agencies to support highway safety projects for mitigating RwD crashes. The most popular program used is the Highway Safety Improvement Program (HSIP), a federal-aid safety program designed to reduce fatalities on all public roads.

HSIP is also known as Section 148, referring to the highway safety improvement program section of title 23 of the U.S. Code. This program is currently being funded by the Moving Ahead for Progress in the 21st Century Act (MAP-21). Projects funded by HSIP usually receive a federal share of 90 percent, with some projects being eligible for 100 percent funding (FHWA 2013e). The funding is set aside for each state, leaving it up to the states to decide how to spend the funds.

In order to receive funds, the state must develop and maintain a State Strategic Highway Safety Plan (SHSP) and fund projects in line with this plan (FHWA 2013f). For the fiscal year 2013, all 50 states as well as the District of Columbia were apportioned HSIP funds (FHWA 2013g). In 2013, 698 (21 percent) HSIP projects were classified under the SHSP emphasis area (EA), 15 (keeping vehicles on the road) and 815 (25 percent) projects were aimed at EA 16 (minimizing the consequences of leaving the roadway); both concern limiting the number and severity of RwD crashes (FHWA 2014i).

It should be noted that in two states, Minnesota and Washington, HSIP funds are proportionally distributed to local road systems based upon serious crashes (50 percent of the serious crashes occur on the local road system). This distribution results in approximately 50 percent of the HSIP funds being allocated to the local road systems to improve their safety (Preston et al. 2014).

**Pennsylvania**

Pennsylvania, along with many other states, makes use of these funds, distributing them through the Pennsylvania Department of Transportation (PennDOT). Some of the safety areas that Pennsylvania addresses using HSIP funding to reduce RwD collisions include: shoulder widening and rumble strip installation, safety edge installation, installation of chevrons or curve warning markings for horizontal curves, and clear-zone improvements (PennDOT 2012).

PennDOT distributes the funds amongst various planning regions according to several factors, including number of lane-miles, vehicle-miles traveled, fatalities, and crashes (Nelson et al. 2011). Furthermore, PennDOT has its own funding program to invest in safety improvements for preventing vehicle departure from roadways.

**Washington State**

In Washington State, federal funding is distributed through the County Safety Program, which, in 2010, funded more than 100 projects, totaling $45 million (WSDOT 2014). According to the County Safety Program, project costs range from $500,000 to $2.5 million (WSDOT 2014). Many RwD projects were funded including one in Douglas County where $750,000 was awarded to improve the clear zone; add guardrails, centerline rumble strips, and delineators; as well as upgrade signs, adding radar speed signs (WSDOT 2014).

**Minnesota**

Project selection in Minnesota starts with municipalities submitting funding applications to the state DOT, where they are then reviewed by a team comprising representatives from the state aid and safety offices as well as the FHWA (MnDOT 2014b). In order for a project to be funded, it must meet Minnesota's goals outlined in its SHSP (MnDOT 2014b). For state fiscal years 2015 and 2016, Minnesota has awarded more than $800,000 to go to installing chevrons; nearly $2.5 million in rumble strip and stripe installation; and more than $4 million in shoulder paving and safety edge installation, with nearly all those funds coming from HSIP (MnDOT 2014b).

### *Other Sources of Federal Aid*

In addition to HSIP, some states also make use of two other sections of Title 23 of the U.S. Code: Section 154 "Open Container Transfer Provision" and Section 164 "Repeat Offender Transfer Provision." Both provisions allow the federal share of eligible project costs to be funded at 100 percent (FHWA 2013h).

*Continued on next page*

#### Missouri

The state of Missouri is subject to both Section 154 and Section 164 transfer provisions (Nelson et al. 2011). Section 154 and Section 164 transfer some federal funds that have been withheld to be used for hazard elimination as part of HSIP Section 148, 23 U.S.C. §154. The funds used for HSIP-eligible projects are released back to the state DOT, which then funds eligible projects through the local Public Agency Program (MoDOT 2013). This program seeks to guide local governments in the process of applying for federal aid and coordinates processing the requirements for such aid (MoDOT 2013).

### Other Federal Funding Under MAP-21

MAP-21 provides several funding programs that local governments can take advantage of outside HSIP. Safety improvements can and often should be included during other federal-aid projects. For roads that are included in the National Highway System (NHS), federal funds can be obtained from the National Highway Performance Program (NHPP), which can then be used for highway safety improvements on the NHS, subject to the eligibility requirements of that program (FHWA 2013i). Similarly, the Surface Transportation Program (STP) provides funds for a number of eligible activities, including highway safety-infrastructure improvements and programs that can be used on any federal-aid highway (FHWA 2013j). Finally, the State Planning and Research (SP&R) fund provides for the development of various planning and research activities, including those related to highway safety (FHWA 2013k). This is important, as many aid programs and grants require some sort of improvement plan or safety evaluation before awarding funds. Local agencies need to work with metropolitan or regional planning organizations or State DOTs for federally funded projects.

### State Sources of Funding

However, funding programs are not limited to just the federal level. Various state programs were established to be included as part of the state DOT's budget or were derived from other forms of revenue.

#### Colorado

Colorado has made use of funds available for implementing countermeasures for RwD crashes from the Transportation Commission, revenue from charging tolls, grants, licensing fees, and partnerships between public and private interests (Nelson et al. 2011). Furthermore, the state of Colorado legislature passed a bill, known as the Funding Advancements for Surface Transportation and Economic Recovery Act of 2009 (FASTER), that provided funding for safety programs through the use of car rental fees as well as vehicle weight-based registration fees. Funds generated through FASTER are split among the Colorado DOT (60 percent), counties (22 percent), and municipalities (18 percent) in order to fund safety projects (CDOT 2014a). In 2010, FASTER provided more than $460,000 of funding to widen shoulders and install rumble strips, guardrail, roadway signs, and pavement markings in several counties throughout the state (CDOT 2014b).

### Nonfinancial Benefits Afforded to Local Transportation Agencies

Finally, state DOTs can help local agencies gain access to federal funding or grants, if the department is unable to provide them directly. In addition, various states have created organizations or programs to share funds among the different levels of highway administration in order to fund safety projects.

#### Georgia

The Georgia DOT (GDOT) is able to provide road safety audits along with other forms of assistance in order to help counties apply for safety funds (Nelson et al. 2011). Furthermore, GDOT has a Local Administered Project Certification program that is designed to help communities manage federal funding requirements so that they do not lose funding from noncompliance (GDOT 2012).

#### Iowa

Iowa shares its safety funds and has established the Iowa Traffic Safety Alliance to support local and multidisciplinary projects (Nelson et al. 2011). Similar to Georgia, Iowa has a Traffic Engineering Assistance Program that can provide experienced engineering assistance—up to 100 hours—to examine safety and to identify funding sources for the assisted projects (Iowa DOT 2014). One example of how this service can be used is to help perform traffic and safety analysis, B/C analysis, research to find funding sources, and preparation of reports. These services can help municipalities apply for funding that requires relevant safety data to be provided before funds are awarded, providing small transportation departments with the resources to pursue such funding.

# References


American Association of State Highway and Transportation Officials (AASHTO) (2011a). “Roadside Design Guide.” 4th Edition, Washington, D.C.

American Association of State Highway and Transportation Officials (AASHTO) (2011b). “A Policy on Geometric Design of Highways and Streets.” 6th Edition, Washington, D.C.

American Association of State Highway and Transportation Officials (AASHTO) (2008). “Driving Down Lane Departure Crashes: A national Priority.” Washington, D.C.

American Traffic Safety Services Association (ATSSA) (2014). “High Friction Surface Treatments.” Fredericksburg, Va. <http://www.atssa.com/Resources/HighFrictionSurfacing/Videos.aspx> (August 1, 2014).

American Traffic Safety Services Association (ATSSA) (2013). “Safety Opportunities in High Friction Surfacing.” Fredericksburg, Va. <https://s3.amazonaws.com/media.atssa.com/default-file/1480+ATSSA+High+Friction+LoRes.pdf>.

American Traffic Safety Services Association (ATSSA) (2011). “Cost Effective Local Road safety Planning and Implementation.” Fredericksburg, Va. <http://www.countyengineers.org/ResourcesEdu/PublishingImages/Local%20%20Roads%20NACE%20ATSSA.pdf>.

American Traffic Safety Services Association (ATSSA) (2008). “Low Cost Local Road Safety Solutions.” Fredericksburg, Va. <http://www.michigan.gov/documents/mdot/Low_Cost_Local_Road_447132_7.pdf>.

Bertini, R. L., Monsere, C., Nolan, C., Bosa, P., and El-Seoud, T. A. (2006). “Field 6 Evaluation of the Myrtle Creek Advance Curve Warning System.” Report No. FHWA-OR-RD-06-13. Oregon Department of Transportation (ODOT), Salem, Ore. <http://www.its.pdx.edu/upload_docs/1248894204FAoY3RFLqP.pdf>.

Better Military Traffic Engineering (BMTE) (2014). “The Clear Zone.” <http://www.tea.army.mil/DODProg/TE/BMTE/clearzone.htm> (August 1, 2014).

California Department of Transportation (Caltrans) (2012). “Traffic Manual, Chapter 7-Traffic Safety Systems.” Sacramento, Calif. <http://www.dot.ca.gov/hq/traffops/saferesr/Chapter-7-Traffic-Manual-1-2012.pdf>.

Carlson, P., Park, E., Anderson, C., Kuhn, B., Pike, A., Miles, J., Brydia, R., Ealding, W., Porter, R. J. (2010). “Pavement marking Demonstration Project: State of Alaska and State of Tennessee.” Report No. FHWA-HRT-09_039, Washington, D.C. <http://www.fhwa.dot.gov/publications/research/safety/09039/09039.pdf>.

Colorado Department of Transportation (CDOT) (2014a). “FASTER Safety.” <http://www.coloradodot.info/projects/faster/faster-safety> (August 1, 2014).

Colorado Department of Transportation (CDOT) (2014b). “FASTER Safety Projects – Statewide: February 2014.” <http://www.coloradodot.info/projects/faster/documents/faster-budget.pdf> (August 1, 2014).

Datta, T. K., Gates, T. J., and Savolainen, P. T. (2012). “Impact of Non-Freeway Rumble Strips-Phase I.” Report No. RC-1575, Michigan Department of Transportation (MDOT), Lansing, Mich. <http://www.michigan.gov/documents/mdot/MDOT_Research_Report_RC1575_Report_394019_7.pdf>.

DeVoe, E., and Monroe, L. (2012). “High Tension Cable Barrier in Median-Change in Fatal and Serious Injury Crashes, 2001-2011.” Minnesota Department of Transportation (MnDOT), Office of Traffic, Safety and Technology, St. Paul, Minn. <http://www.dot.state.mn.us/trafficeng/reports/BeforeAfterStudy11-2012.pdf>.

Edwards, C., Morris, N., and Manser, M. (2013). “A Pilot Study on Mitigating Run-Off-Road Crashes.” Center for Transportation Studies, University of Minnesota, Minneapolis. <http://www.its.umn.edu/Publications/ResearchReports/reportdetail.html?id=2296>.

Elkins, H. B. (2007). “Transportation Cabinet Installs New LED-Enhanced Curve Warning Sign on KY 82 in Estill County.” Kentucky Transportation Cabinet, Department of Highways, Frankfort, Ky. <http://migration.kentucky.gov/newsroom/kytc.d10/led_sign_estill.htm> (August 1, 2014).

Farber Law Group (FLG) (2014). “Rumble Strips Lower Car Accident on Washington Highway Says State Report.” <http://www.seattlecaraccidentlawyerblog.com/2009/09/rumble_strips_lower_car_accide.html> (August 1, 2014).

Federal Highway Administration (FHWA) (2014a). “Roadway Departure Safety.” Washington, D.C. <http://safety.fhwa.dot.gov/roadway_dept> (August 1, 2014).

Federal Highway Administration (FHWA) (2014b). “Manual for Selecting Safety Improvements on High Risk Rural Roads.” Washington, D.C. <http://safety.fhwa.dot.gov/hsip/hrrr/manual/hrrr_2014.pdf> (August 1, 2014)

Federal Highway Administration (FHWA) (2014c). “Crash Modification Factors Clearinghouse.” Washington, D.C. <http://www.cmfclearinghouse.org/study_detail.cfm?stid=358> (August 1, 2014).

Federal Highway Administration (FHWA) (2014d). “Safer Sign Supports: Are Yours Breakaway Yet?” Report No. FHWA-SA-06-14, Washington, D.C. <http://www.triplexgroup.com/products/FHWA%20Breakaway%20Sign%20Pamphlet.pdf>.

Federal Highway Administration (FHWA) (2014e). “Clear Zone and Horizontal Clearance.” Washington, D.C. <http://www.fhwa.dot.gov/programadmin/clearzone.cfm> (August 1, 2014).

# References


Federal Highway Administration (FHWA) (2014f). "Highway Safety Improvement Program 2013 National Summary Report." Report No. FHWA-SA-14-030, Washington, D.C. <http://safety.fhwa.dot.gov/hsip/reports/pdf/hsip_natlrptfinal072314.pdf>.

Federal Highway Administration (FHWA) (2013a). "Evaluation of the TAPCO Sequential Dynamic Curve Warning System." <http://www.fhwa.dot.gov/hfl/pubs/hif13040/chap02.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2013b). "Crash Modification Factors Clearinghouse." Washington, D.C. <http://www.cmfclearinghouse.org/study_detail.cfm?stid=350> (August 1, 2014).

Federal Highway Administration (FHWA) (2013c). "2013 National Roadway Safety Awards-Noteworthy Practices Guide." Washington, D.C. <http://safety.fhwa.dot.gov/roadwaysafetyawards/2013/npg2013.pdf>.

Federal Highway Administration (FHWA) (2013d). "Crash Modification Factors Clearinghouse." Washington, D.C. <http://www.cmfclearinghouse.org/study_detail.cfm?stid=345> (August 1, 2014).

Federal Highway Administration (FHWA) (2013e). "Highway Safety Improvement Program (HSIP) Enhanced Eligibility Questions & Answers." <http://www.fhwa.dot.gov/map21/qandas/qahsip.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2013f). "Highway Safety Improvement Program (HSIP)." <http://www.fhwa.dot.gov/map21/factsheets/hsip.cfm> (August 1, 2014).

Federal Highway Safety Administration (2013g). "Revised Apportionment of Federal-aid Highway Program Funds for Fiscal Year (FY) 2013." Report No. FHWA N 4510.765, Washington, D.C. <http://www.fhwa.dot.gov/legsregs/directives/notices/n4510765/n4510765_t1.cfm>.

Federal Highway Administration (FHWA) (2013h). "Penalty Transfer Provisions Interim Guidance - Open Container and Repeat Offender Laws (23 U.S.C. §§ 154 and 164)". <http://www.fhwa.dot.gov/map21/guidance/guidepentransprov.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2013i). "National Highway Performance Program (NHPP)." <http://www.fhwa.dot.gov/map21/factsheets/nhpp.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2013j). "Surface Transportation Program (STP)." <http://www.fhwa.dot.gov/map21/factsheets/stp.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2013k). "State Planning and Research (SP&R)." <http://www.fhwa.dot.gov/map21/factsheets/spr.cfm > (August 1, 2014).

Federal Highway Administration (FHWA) (2012a). "Every Day Counts (EDC)-High Friction Surface Treatment." Washington, D.C. <http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/pdfs/edc_hfst_21.pdf>.

Federal Highway Administration (FHWA) (2012b). "The Safety Edge-A Pavement Edge Drop-Off Treatment." Report No. FHWA-SA-10-034, Washington, D.C. <http://www.fhwa.dot.gov/everydaycounts/technology/safetyedge/brochure/brochure.pdf>.

Federal Highway Administration (FHWA) (2012c). "Safety Edge Brochure." <http://www.fhwa.dot.gov/everydaycounts/technology/safetyedge/intro.cfm>. (August 1, 2014).

Federal Highway Administration (FHWA) (2012d). "Safety Edge Design and Construction Guide." Washington, D.C. <http://www.fhwa.dot.gov/everydaycounts/technology/safetyedge/designconst/se_des_gde.pdf>.

Federal Highway Administration (FHWA) (2012e). "Proven Safety Countermeasures." Office of Safety, Washington, D.C. <http://safety.fhwa.dot.gov/provencountermeasures/> (August 1, 2014).

Federal Highway Administration (FHWA) (2012f). "Breakaway Features for Sign Supports, Utility Poles and Other Roadside Features." Washington, D.C. <http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/ctrmeasures/breakaway/breakaway.pdf>.

Federal Highway Administration (FHWA) (2011a). "Low-cost Treatments for Horizontal Curve Safety." Washington, D.C. <http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/ch2.cfm> (August 1, 2014).

Federal Highway Administration (FHWA) (2011b). "Safety Evaluation of the Safety Edge Treatment." Report No. FHWA-HRT-11-025, Washington, D.C. <http://www.fhwa.dot.gov/publications/research/safety/hsis/11025/11025.pdf>.

Federal Highway Administration (FHWA) (2011c). "Technical Advisory: Shoulder And Edge Line Rumble Strips." Report No. T 5040.39, Revision 1, Washington, D.C. <http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/t504039/t504039.pdf

Federal Highway Administration (FHWA) (2010). "Crash Modification Factors Clearinghouse." Washington, D.C. <http://www.cmfclearinghouse.org/study_detail.cfm?stid=237> (August 1, 2014).

Federal Highway Administration (FHWA) (2009a). "Manual on Uniform Traffic Control Devices (MUTCD)." Washington, D.C. <http://mutcd.fhwa.dot.gov/htm/2009/part3/part3b.htm>.

Federal Highway Administration (FHWA) (2009b). "Proven Safety Countermeasures-Enhanced Delineation and Friction for Horizontal Curves." Report No. FHWA-SA-12-009, Washington, D.C. <http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_009.pdf>.

Gayah, V. V., Donnell, E. T. (2014). "Establishing Crash Modification Factors and Their Use." Report No. FHWA-PA-2014-005-PSU WO 6, Pennsylvania Department of Transportation, Harrisburg, Pa. <http://ntl.bts.gov/lib/52000/52500/52591/PSU-2014-01.pdf>.

# References


Georgia Department of Transportation (GDOT) (2012). “LAP Manual.” <https://www.dot.ga.gov/localgovernment/FundingPrograms/Pages/LAPManual.aspx> (August 1, 2014).

Hallmark, S. L., Qui, Y., Hawkins, N., and Smadi, O. (2014). “Crash Modification Factors for Dynamic Speed Feedback Signs on Rural Curves.” Center for Transportation Research and Education, Iowa State University, Ames, Iowa.

Hallmark, S., Hawkins, N., and Smadi, O. (2013). “Toolbox of Countermeasures for Rural Two-Lane Curves.” Report No. IHRB Project TR-579, Center for Transportation Research and Education, Iowa State University, Ames, Iowa. <http://www.intrans.iastate.edu/research/documents/research-reports/rural_two-lane_curves_toolbox_w_cvr.pdf>.

Hallmark, S. L., Knickerbocker, S., and Hawkins, N. (2013a). “Dynamic Speed Feedback Signs for Rural Traffic Calming.” Iowa Department of Transportation (Iowa DOT), Ames, Iowa. <http://www.intrans.iastate.edu/publications/_documents/t2summaries/updated_dsfs_tech_brief.pdf>.

Hallmark, S., Hawkins, N., and Knickerbocker, S. (2013b). “Speed Management Toolbox for Rural Communities.” Iowa Department of Transportation (Iowa DOT), Ames, Iowa. <http://www.intrans.iastate.edu/research/documents/research-reports/rural_traffic_calming_toolbox_w_cvr.pdf>.

Hallmark, S. L., Hawkins, N., and Smadi, O. (2012). “Evaluation of Dynamic Speed Feedback Signs on Curves: A National Demonstration Project.” Report No. DTFH61-07-H-00022, Iowa Department of Transportation (Iowa DOT), Ames, Iowa.

Insurance Institute for Highway Safety (IIHS) (2012). “Collision with Fixed Objects and Animals.” <http://www.iihs.org/iihs/topics/t/roadway-and-environment/fatalityfacts/fixed-object-crashes> (August 1, 2014).

International Road Assessment Programme (iRAP) (2011). “iRAP Safety Assessment and Recommended Countermeasures.” <http://www.eurorap.org/media/134139/irap_mari_el_report_english_.pdf>.

Iowa Department of Transportation (Iowa DOT) (2014). “Guide to Transportation Funding Programs: of Interest to Local Governments and Others.” Ames, Iowa. <http://www.iowadot.gov/pol_leg_services/Funding-Guide.pdf> (August 1, 2014).

Iowa Department of Transportation (Iowa DOT) (2013). “Milled Rumble Strips.” Design Manual, Chapter 3, Section 3C-5, Ames, Iowa.

Jalayer, M., Gong, J., Zhou, H., and Grinter, M. (2015). “Evaluation of Remote Sensing Technologies for Collecting Roadside Feature Data to Support Highway Safety Manual Implementation.” Journal of Transportation Safety and Security. 7(3), DOI: 10.1080/19439962.2014.976691.

Knapp, K. K., and Robinson, F. (2012). “The Vehicle Speed Impacts of a Dynamic Horizontal Curve Warning Sign on Low-Volume Local Roadways.” Report No. CTS 12-12. Minnesota Department of Transportation (MnDOT), St. Paul, Minn. <http://www.its.umn.edu/Publications/ResearchReports/reportdetail.html?id=2284>.

Michigan Department of Transportation (MDOT) (2014). “Draft Technical Memo: Evaluation of Non-Freeway Rumble Strips-Phase II.” Lansing, Mich.

Midwest Transportation Consortium (MTC) (2009). “2008-2009 Annual Report.” Minnesota Department of Transportation, St. Paul, Minn. <http://www.intrans.iastate.edu/mtc/documents/annualReports/2009-mtc-annual-report.pdf>.

Milstead, R., Qin, X., Katz, B., Bonneson, J., Pratt, M., Miles, J., and Carlson, P. (2011). “Procedures for Setting Advisory Speeds on Curves.” Report No. FHWA-SA-11-22. Federal Highway Administration (FHWA), Washington, D.C. <http://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa1122/fhwasa1122.pdf>.

Minnesota Department of Transportation (MnDOT) (2014a). “Cable Median Barriers-How They Work.” <http://www.dot.state.mn.us/trafficeng/reports/cmbarrier.html> (August 1, 2014).

Minnesota Department of Transportation (MnDOT) (2014b). “Summary of Local HSIP Solicitation: State Fiscal Years (SFY) 2015 & 2016.” <http://www.dot.state.mn.us/stateaid/trafficsafety/hsip/2015-2016summary-hsip-solicitation.pdf> (August 1, 2014).

Minnesota Department of Transportation (MnDOT) (2008). “Traffic Safety Fundamentals Handbook,” St. Paul, Minn. <http://www.dot.state.mn.us/trafficeng/publ/fundamentals/MnDOT_Safety_Handbook_FINAL.pdf>.

Missouri Department of Transportation (MoDOT) (2013). “About US.” <http://contribute.modot.mo.gov/business/lpa/aboutus.htm> (August 1, 2014).

National Highway Traffic Safety Administration (NHTSA) (2012). “Traffic Safety Facts 2012.” Washington, D.C. <http://www-nrd.nhtsa.dot.gov/Pubs/812032.pdf>.

Nelson, M., Miller, J. P., Zisman, I., Helms, D., Albin, R. B., Focke, D. (2011). “Best Practices in Lane-Departure Avoidance and Traffic Calming.” National Cooperative Highway Research Program (NCHRP), Project 20-68A, Scan 09-03. Washington D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_09-03.pdf>.

Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Council, F., McGee, H., Prothe, L., and Eccles, K. (2003a). “A Guide for Addressing Run-Off-Road Collisions.” Publication. NCHRP Report 500, Vol. 6, Transportation Research Board, Washington, D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v6.pdf>.

# References


Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Council, F., McGee, H., Prothe, L., and Eccles, K. (2003b). "A Guide for Addressing Head-On Collisions." Publication. NCHRP Report 500, Vol. 4, Transportation Research Board, Washington, D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v4.pdf>.

Noyce, D. A., Martinez, C., and Chitturi, M. (2008). "The Operational and Safety Impacts of Run-Off-Road Crashes in Wisconsin: Tree, Fence, and Pole Hits." Wisconsin Department of Transportation (WisDOT), Madison, Wis. <http://www.topslab.wisc.edu/projects/documents/Final%20Report%209-8-08.pdf>.

North Carolina Department of Transportation (NCDOT) (2014). "Safety Evaluation Completed Projects-Safety Evaluation Group." <https://connect.ncdot.gov/resources/safety/Pages/Safety-Evaluation.aspx> (August 1, 2014).

Oklahoma Department of Transportation (2014). "Shoulder Treatments-Rumble Strips (Milled SRS, Rolled SRS)." <http://www.okladot.state.ok.us/oshsp/pdfs/ld-shouldertreatments.pdf> (August 1, 2014).

Olson, D., Sujka, M., and Manchas, B. (2013). "Performance Analysis of Centerline and Shoulder Rumble Strips Installed in Combination In Washington State." Report No. WA-RD 799.1, Washington State Department of Transportation, Olympia, Wash. <www.wsdot.wa.gov/research/reports/fullreports/799.1.pdf>.

Oregon Department of Transportation (ODOT) (2014). "Systemic Safety Measures-Updated Curve Warning Signs."<http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/UpdatedCurveWarningSigns.pdf> (August 1, 2014).

Pennsylvania Department of Transportation (PennDOT) (2012). "Pennsylvania Strategic Highway Safety Plan." Harrisburg, Pa. <http://www.justdrivepa.org/Resources/Strategic%20Highway%20Safety%20Plan.pdf>.

Preston, H., Storm, R., Cronin, B., and Hyland, J. (2014). "State DOT Administration of Local Road Safety Aid." NCHRP Project 20-24, Task 87. Washington, D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24%2887%29_FR.pdf>.

Ray, M. H., Weir, J., and Hopp, J. (2003). "In-Service Performance of Traffic Barriers." NCHRP Report 490, Transportation Research Board, National Research Council. Washington, D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_490.pdf>.

Road Safety Toolkit (RST) (2013). "High Friction Surfacing Treatment (HFST) Crash Reduction Program." Washington, D.C. <http://toolkit.irap.org/default.asp?page=casestudy&id=10> (August 1, 2014).

Satterfield, C., McGee, H. W., and Hanscom, F. R. (2009). "Low-Cost Safety Improvement for Horizontal Curves." Public Roads, 72(5), Washington, D.C. <https://www.fhwa.dot.gov/publications/publicroads/09mar/05.cfm>.

Sperry, R., Latterell, J., and McDonald, T. (2008). "Best Practices for Low-Cost Safety Improvements on Iowa's Local Roads." Iowa Department of Transportation (Iowa DOT), Ames, Iowa. <http://www.ctre.iastate.edu/reports/low-cost-safety-practices.pdf>.

Srinivasan, R., Baek, J., Carter, D., Persaud, B., Lyon, C., Eccles, K. A., and Lefler, N. X. (2009). "Safety Evaluation of Improved Curve Delineation." Report No. FHWA-HRT-09-045, Federal Highway Administration (FHWA), Washington, D.C. <http://www.fhwa.dot.gov/publications/research/safety/09045/09045.pdf>.

Torbic, D. J., Hutton, J. M., Bokenkroger, C. D., Bauer, K. M., Harwood, D. W., Gilmore, D. K., Dunn, J. M., Ronchetto, J. J., Donnell, E. T., Sommer III, H. J., and Garvey, P. (2009). "Guidance for the Design and Application of Shoulder and Centerline Rumble Strips." National Cooperative Highway Research Program (NCHRP), Report 641. Transportation Research Board, Washington, D.C. <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_641.pdf>.

Vest, A., Stamatiadis, N., Clayton, A., and Pigman, J. P. (2005). "Effect of Warning Devices on Curve Operating Speeds." Report No. KTC-05-20/SPR-259-03-1F, Kentucky Transportation Cabinet (KYTC), Frankfort, Ky. <http://www.ktc.uky.edu/files/2012/06/KTC_05_20_SPR_259_03_1F.pdf>.

Washington State Department of Transportation (WSDOT) (2014). "2010 County Safety Program: Selected Projects." <http://www.wsdot.wa.gov/LocalPrograms/Traffic/2010CountySafetyFunded.htm> (August 1, 2014).

SAFER ROADS SAVE LIVES

**American Traffic Safety Services Association**
15 Riverside Parkway, Suite 100
Fredericksburg, VA 22406
540-368-1701 ▮ www.atssa.com