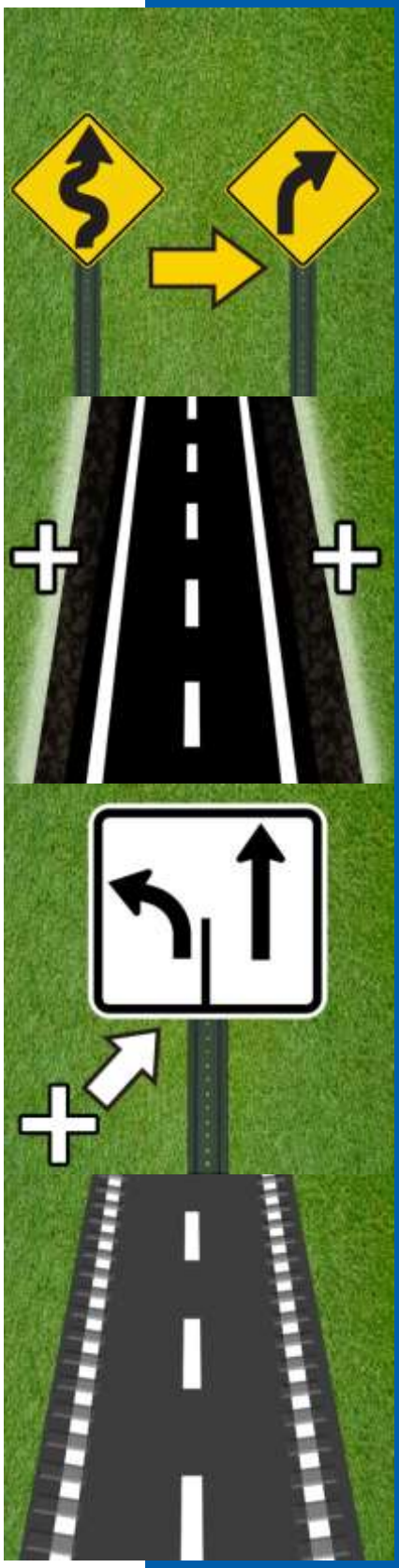


COUNTERMEASURES TO IMPROVE LOW-VOLUME ROAD SAFETY IN THE SOUTHEAST

Table of Contents

INTRODUCTION

Of the four million miles of public roadways in the United States, almost three million miles are rural roads [1]. In 2016, 50 percent of all fatal crashes occurred along rural roads, but only 30 percent of the total vehicle miles traveled were in rural areas [2]. Low-volume roads (LVRs) carry an annual average daily traffic (AADT) volume of fewer than 2,000 vehicles per day (vpd); they account for approximately 20 percent of the rural National Highway System and over 50 percent of the Federal-Aid System [1]. Despite these roadways carrying low traffic volumes, historical crash data indicate their crash rates are higher than other highways, accounting for half of all fatalities [2]. Typically, LVRs are classified as local roads, and most are located in rural areas. In 2016, the fatality rate on rural roads was 1.96 fatalities per 100 million vehicles miles of travel (MVMT); conversely, for all roads the fatality rate was 1.18 fatalities per 100 MVMT [2].

In 2016, most of the Southeast Transportation Consortium's (STC) member states saw higher fatality rates than the rest of the nation. For example, 834 fatal crashes occurred in Kentucky; 607 took place on rural roads (approximately 73 percent). In Mississippi, 98 percent of the 690 fatal crashes occurred on rural roads [2]. Because traffic data are lacking for local roads, it is exceptionally difficult to estimate crash rates and exposure, which are needed to prioritize roads for safety interventions. The high number of LVR miles in these states may contribute to their high fatal crash rates.

To identify effective countermeasures for improving LVR safety in the Southeast, a literature review and web-based survey were conducted [3]. This document summarizes the main features of each countermeasure identified. However, this document does not cover all aspects of installing countermeasures. Rather, its goal is to provide readers with a basic understanding of their application and potential effectiveness. Entries for each countermeasure contain the following information:

- Description: General description of the countermeasure
- Implementation: Description of possible applications
- Crashes Affected: Identification of potentially affected crash types
- Effectiveness: Documentation of crash reduction through Crash Modification Factors (CMF)
- Cost: Estimates of cost for installation and maintenance
- Sources: Documentation of references used for the summary sheet.

Table 1 summarizes key features of the countermeasures addressed in this document and sorts them according to cost.

Table 1. Summary of countermeasure attributes

Countermeasure	Affected Crashes	Cost	Maintenance		Effectiveness	
			Cost	Frequency	CMF	Benefit/Cost
Install safety edge	Run-off-road Drop off	Low	-	20 years	0.85-0.92	40.9
Add centerline rumble strips	Run-off-road Head on Sideswipe Adverse weather condition crashes	Low	-	10 years	0.75 to 0.85	26.1
Add edge line rumble strips	Run-off-road Adverse weather crashes	Low	-	10 years	0.78 to 0.90	71.8
Install advanced intersection warning signs	Right angle Rear end Head on	Low	-	-	0.73; 0.425 (rear end)	-
Install horizontal alignment signs	Run-off-road	Low	$1,280	5 years	0.70	43.5
Install retroreflective strips on sign posts	Run-off-road Right angle Rear end Head on	Low	-	-	-	-
Install rumble strips for intersection/ curve approaches	Run-off-road Right angle Rear end Head on	Low	-	-	0.76 to 0.91	-
Add pavement markers	Run-off-road wet or night conditions	Low-Medium	-	-	CMF ≤ 0.76	-
Add pavement markings	Run-off-road Head on Sideswipe Night crashes	Medium	-	5 years	0.56 -062 (edge line); 0.67 (centerline)	20.2 (centerline and edge line)
Add high-friction pavement surface	Run-off-road wet conditions	High	-	10 years	0.25 to 0.60	4.1
Remove/shield fixed objects	Run-off-road fixed object	High	$7,000	5 years	CMF ≤ 0.71	4.6
Widen shoulders	Run-off-road Sideswipe Head on	High-Very High	N/A	N/A	0.90 - 0.97	-
Add left-turn lane	Head on Rear end Left-turn	Very High	$20,000	10 years	-	6.0 (4-leg); 3.7 (3-leg)
Increase clear zone	Run-off-road fixed object	Very High	-	-	0.78 (3.3 ft to 16.7 ft)	-

Countermeasure	Affected Crashes	Cost	Maintenance		Effectiveness	
			Cost	Frequency	CMF	Benefit/Cost
Re-align roadway segments	Head on Sideswipe Rear end Run-off-road	Very High	-	-	Reduce crashes by 28 percent	-

Sources

1. Federal Highway Administration (2016). *Highway Statistics 2016*. United States Department of Transportation.
2. National Highway Safety Administration (2018). *Traffic Safety Facts 2016 Data: Rural/Urban Comparison*. United States Department of Transportation, National Highway Traffic Administration.
3. Stamatiadis, N., Weast, J. and Green, E. (2019). *Synthesis on the Contributing Factors and Effective Countermeasures for Low-Volume Roadway Fatality Rates in the Southeast*. FHWA/LA17.624, Louisiana Department of Transportation and Development, Baton Rouge, LA.

INSTALL SAFETY EDGE

DESCRIPTION

"A safety edge is a treatment intended to minimize drop-off-related crashes. With this treatment, the pavement edge is sloped at an angle (30-35 degrees) to make it easier for a driver to safely reenter the roadway after inadvertently driving onto the shoulder. This treatment is designed to be a standard policy for any overlay project." [1]

IMPLEMENTATION

This treatment frequently aims to allow for safe correction of vehicles that have left the traveled way and encounter a pavement-shoulder drop-off [1]. The safety edge is typically implemented on the entire length of a project where frequent edge drop-offs occur, particularly on rural roads with unpaved shoulders [1]. Iowa first used the safety edge in 2008 along a county road in Clinton County. In 2010, Iowa DOT adopted the safety edge as a Standard Practice for construction and rehabilitation projects [2].

CRASHES AFFECTED

Run-off-road and drop-off related crashes

EFFECTIVENESS

The benefit-cost ratio for installing a safety edge on a road with lower volume narrower conditions is 40.9 [1]. Safety edge treatments appear to have a small positive crash reduction effect with the best effectiveness measure for rural two-lane highways having a CRF of 5.7 [3].

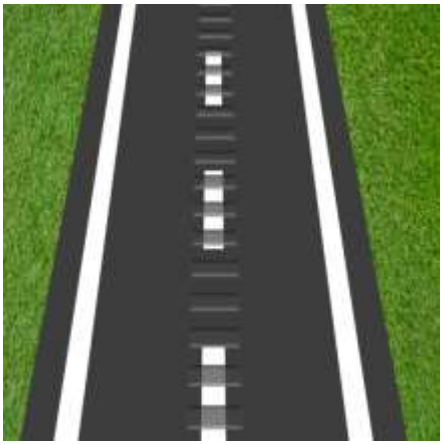
COST

Low; Initial investment: $2,145 per mile; Cost of maintenance: N/A; Frequency of maintenance: 20 years

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Hallmark, Shauna. (2017). "Safety Benefits of the Safety Edge". TRB First International Roadside Safety Conference. Iowa State University, Institute for Transportation.
3. Graham, J. L., Richard, K. R., O'Laughlin, M. K. and Harwood, D. W. (2011). *Safety Evaluation of the Safety Edge Treatment*. U.S. Departmnt of Transportation, Federal Highway Administration.

ADD CENTER LINE RUMBLE STRIPS



DESCRIPTION

"Rumble strips are raised or grooved patterns on the roadway that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips)." [1]

IMPLEMENTATION

Centerline rumble strips are used to prevent multi-vehicle cross-centerline and roadway departure crashes [2]. The noise and vibration alert a distracted or drowsy driver that a steering correction is required. When visibility is poor due to rain, fog, snow, and darkness, centerline rumble strips can help keep drivers in their lane. Rumble strips should be installed on all new rural two-lane highways with posted speeds of 50 mph or greater [1]. Centerline rumble strips are a strong countermeasure for improving safety along rural, undivided, two-lane roads [3].

CRASHES AFFECTED

Run-off-road; head on; sideswipe; adverse weather conditions

EFFECTIVENESS

Installing centerline rumble strips has a crash reduction factor of 15 to 25 percent [2]. The CMF for installing centerline rumble strips in lower volume, narrower conditions is 0.75 to 0.85 with a benefit-cost ratio of 26.1 [1]. A 25 percent reduction in frontal and opposing-direction sideswipe crashes and an overall 12 percent drop in all crashes has been observed following their installation along rural, two-lane roads.

COST

Low; Initial investment: $5,000 per lane-mile; Cost of maintenance: N/A; Frequency of maintenance: 10 years (two applications)

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. American Traffic Safety Services Association. (2015). *Preventing Vehicle Departures from Roadways*. Fredericksburg, VA, USA.
3. Persaud, B. N., Retting, R. A. and Lyon, C. A. (2004). Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads. *Accident Analysis and Prevention,* 36(6): 1073-1079.

ADD EDGE LINE RUMBLE STRIPS

DESCRIPTION

"Rumble strips are raised or grooved patterns on the roadway that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips)". [1]

IMPLEMENTATION

Edge line rumble strips are installed to prevent run-off-road crashes [2]. The noise and vibration alert a distracted or drowsy driver that a steering correction is required. When visibility is poor due to rain, fog, snow, and darkness, edge line rumble strips can help keep drivers in their lane. Rumble strips should be installed on all new rural two-lane highways with posted speeds of 50 mph or greater [1]. Installing edge line rumble strips is a strong countermeasure for improving safety along rural, undivided, two-lane roads [3].

CRASHES AFFECTED

Run-off-road; adverse weather conditions

EFFECTIVENESS

Installing edge line rumble strips in lower volume, narrower conditions has a CMF of 0.78 to 0.90 with a benefit-cost ratio of 71.8 [1]. Installing edge line strips following installation of centerline rumble strips can lower crash rates 47 percent and produce a 15.3 percent decline in fatal or injury crash rates [4].

COST

Low; Initial investment: $3,000 per lane-mile; Cost of maintenance: N/A; Frequency of maintenance: 10 years (two applications)

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. American Traffic Safety Services Association. (2015). Preventing Vehicle Departures from Roadways. Fredericksburg, VA, USA.
3. Golembiewski, G.A., Chandler, B. and Anderson, R., 2011. *Roadway Departure Safety: A Manual for Local Rural Road Owners*. U.S. Department of Transportation. Federal Highway Administration.
4. Olson, D., Sujka, M., and Manchas, B. (2013). *Performance Analysis of Centerline and Shoulder Rumble Strips Installed in Combination in Washington State*. Washington State Department of Transportation.

INSTALL ADVANCED INTERSECTION WARNING SIGNS

DESCRIPTION

"Advanced intersection warning signs can help alert drivers to the upcoming presence of an intersection. Signs can be placed with sufficient distance prior to the intersection to allow drivers to perceive and react and can be installed on both sides of the roadway to solicit greater awareness." [1]

IMPLEMENTATION

Installing advanced warning signs for intersections warns drivers of approaching intersections and can help reduce crash rates. These signs are highly recommended for high-crash, stop-controlled intersections in rural areas [1]. One type of advanced warning sign that has been used in Iowa is a sign and beacon combination [2].

CRASHES AFFECTED

Right angle; rear end; head on

EFFECTIVENESS

Installing advanced intersection warning signs resulted in a CMF of 0.733 for total, 0.803 for right angle, and 0.425 for rear end crashes [3].

COST

Low; Initial investment: $5,000 per location; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Hallmark, S., James, J., Knickerbocker, S., Hawkins, N., Thapa, R., and Litteral, T. (2018). *Evaluation of Rural Intersection Treatments*. Iowa State University. Center for Transportation Research and Education.
3. Himes, S., Gross, F.B., Persaud, B. and Eccles, K.A. 2016. *Safety Evaluation of Intersection Conflict Warning System*. University of North Carolina. Highway Safety Research Center.

INSTALL HORIZONTAL ALIGNMENT SIGNS

DESCRIPTION

"Horizontal alignment signs, informally called curve warning signs, can improve safety by alerting drivers to changes in roadway geometry that may not be apparent or expected. These signs provide visual information for the driver about the nature of the curve they are approaching, letting them know whether it's a gradual curve, a sharp turn, a hairpin turn, or some combination. Different types of curve warning signs are identified in The *Manual on Uniform Traffic Control Devices* (MUTCD)." [1]

IMPLEMENTATION

Advanced curve warning signs have a demonstrated track record of improving the safety of horizontal curves [2]. Installations take a variety of forms, including LED-enhanced curve warning signs [3], larger signs, and repeated signs for greater emphasis [4]. These signs should be used on any curve with a run-off-road crash history.

CRASHES AFFECTED

Run-off-road

EFFECTIVENESS

Installing enhanced curve warning signs can reduce all crashes by 10 percent and decrease serious crashes by 35 percent [4]. They can reduce fatalities as well [3].

COST

Low; Initial investment: $2,400 per sign; Cost of maintenance: $1,280 (life-cycle cost); Frequency of maintenance: 5 years

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. American Traffic Safety Services Association. (2015). Preventing Vehicle Departures from Roadways. Fredericksburg, VA, USA.
3. 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.
4. Beale, V. F., Troyer, D., Chock, A., Hopwood, C. and McNeill, M. (2018). Getting to Zero Deaths on Ohio's Low-Volume Roads. *Transportation Research Record: Journal of the Transportation Research Board,* 2672(32): 40-48.

INSTALL RETRO-REFLECTIVE STRIPS ON SIGN POSTS

DESCRIPTION

"The use of retroreflective strips on sign posts may be beneficial when there is a need to draw additional attention to the signs, especially at night. Reflective strips may be added to stop signs, curve or intersection warning signs, and other regulatory or guidance signs, etc." [1]

IMPLEMENTATION

Retroreflective strips must cover the entire post; their color should match the color of the sign. The MUTCD provides guidance on placing and locating this auxiliary signing [2].

CRASHES AFFECTED

Run-off-road; right angle; rear end; head on

EFFECTIVENESS

In one study, installing retroreflective strips on chevron curve warning signs did not significantly affect vehicle speed or lateral lane position [3]. No safety evaluation of these installations has been performed.

COST

Low; Initial investment: $5,000 per location; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Federal Highway Administration (2009). *Manual of Uniform traffic Control Devices* U.S. Department of Transportation, Federal Highway Administration.
3. Re, J.M., Hawkins Jr, H.G. and Chrysler, S.T., 2010. Assessing Benefits of Chevrons with Full Retroreflective Signposts on Rural Horizontal Curves. Transportation Research Record, 2149(1), pp.30-36.

INSTALL RUMBLE STRIPS FOR INTERSECTION/CURVE APPROACHES

DESCRIPTION

"Rumble strips are raised or grooved patterns on the roadway that provide both an audible warning (rumbling sound) and physical vibration to alert drivers of an upcoming intersection, curve, or other geometry change. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips)." [1]

IMPLEMENTATION

This countermeasure has not been used extensively in the US. Agencies have installed them in rural areas to warn drivers of approaching intersections or curves and sometimes to warn about reduced speed zone.

CRASHES AFFECTED

Run-off-road (for curves); right angle; rear end; head on

EFFECTIVENESS

Installing rumble strips at intersections can reduce fatal, incapacitating, and non-impacting injury crashes by 21 percent and lower fatal and incapacitating injuries by 39 percent [2]. Speed reductions of approximately 5 percent have been noted for a curve installation [3].

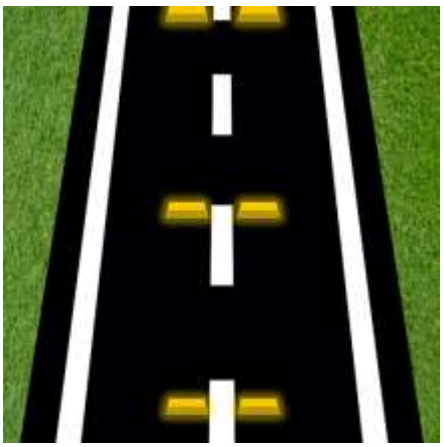
COST

Low; Initial investment: $5,000 per location; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Srinivasan, R., Baek, J. and Council, F. (2010). Safety evaluation of transverse rumble strips on approaches to stop-controlled intersections in rural areas. *Journal of Transportation Safety & Security*. 2(3), pp.261-278.
3. Vest, A., Stamatiadis, N., Clayton, A., and Pigman, J. (2005). *Effect of Warning Signs on Curve Operating Speeds*. KTC-05-20, Kentucky Transportation Center.

ADD PAVEMENT MARKERS



DESCRIPTION

"Raised pavement markers are designed to supplement the delineation provided by pavement markings. During certain conditions, particularly on wet roads in the dark, motorists may have difficulty determining the location of the center line and edge line pavement markings, increasing the likelihood of roadway departure. By installing raised pavement markers, the pavement markings are much more prominent in adverse weather conditions, providing important information to the driver." [1]

IMPLEMENTATION

Raised pavement markers are used to improve nighttime visibility (especially in wet conditions) and increase sight distance. The pavement markers must conform to the color of the line in which they are used. Installation can improve curve delineation and provide an auditory signal to drivers warning them for required steering actions. Markers require proper installation to prevent their failure, including removal by snowplows [3].

CRASHES AFFECTED

Run-off-road in wet or night conditions

EFFECTIVENESS

Installing raised pavement markers can result in a CMF less than or equal to 0.76 [1] and reduce roadway departure crashes by up to 85.6 percent while lowering injury numbers [2].

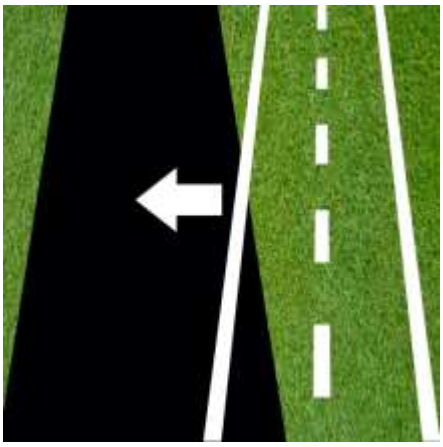
COST

Low to medium; Initial investment: $20,000 Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Federal Highway Administration. (2013). "2013 National Roadway Safety Awards-Noteworthy Practices Guide." Washington, D.C.
3. Agent, K. and Green, E. (2009). *Evaluation of the Use of Snowplowable Raised Pavement Markers*, KTC-09-09, Kentucky Transportation Center.

ADD PAVEMENT MARKINGS



DESCRIPTION

"Edge line markings separate the travel lane from the shoulder and communicate the intended roadway alignment and travel path to the driver. Centerline markings separate two opposing traffic streams on a roadway, guide the road user, and delineate travel lanes." [1]

IMPLEMENTATION

Agency guidelines must be followed when installing edge line and centerline markings on LVRs. Various combinations of edge and center line markings may be used depending on roadway width. Installing centerline and edge line pavement markings can enhance the visibility of road curves. Locations with a history of night crashes may benefit from such installations.

CRASHES AFFECTED

Run-off-road; head on; sideswipe; night crashes

EFFECTIVENESS

For lower volume, narrower conditions, installing edge line pavement markings can yield CMF between 0.56 and 0.62. Using centerline pavement markings can result in a CMF of 0.67 [1]. Installing these features may reduce crashes by up to 24 percent [2] and have a benefit-cost ratio of 20.2 [1]. Improving marking reflectivity can result in a CMF of 0.85 [3].

COST

Medium; Initial investment: $16,000 per lane-mile; Cost of maintenance: N/A; Frequency of maintenance: 5 years (two applications)

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Elvik, R. and Vaa, T. (2004). *Handbook of Road Safety Measures*. Oxford, United Kingdom, Elsevier.
3. Carlson, P., Avelar, R., Park, D., and Kang, D. (2015). Nighttime Safetya nd Pavement Marking Retroreflectivity on Two-Lane Highways: Revisited with North Carolina Data. Proceedings 94th Annula Meeting of the Transportaion Research Board, Washington, D.C.

ADD HIGH-FRICTION PAVEMENT SURFACE

DESCRIPTION

"Vehicles often leave the road due to lack of friction—especially in wet conditions when water between the tires and pavement could cause hydroplaning. Pavement friction treatments can reduce the number of wet-road crashes by improving friction at specific locations." [1]

IMPLEMENTATION

High friction surface treatments are layers of durable aggregate that resist polishing [2]. This treatment is cost-effective because it lasts for a pavement's entire service life. This treatment is applied most frequently to horizontal curves to reduce run-off-road crashes in wet and dry conditions [3].

CRASHES AFFECTED

Run-off-road in wet conditions

EFFECTIVENESS

For lower volume, narrower conditions, the benefit-cost ratio for improving pavement friction is 4.1; the CMF ranges from 0.25 to 0.60 [1]. Installing high friction surface treatments can reduce wet-weather crashes between 40 percent and 75 percent [4]. In wet conditions, run-off-road crash rates can fall by 91 percent; for dry conditions these treatments can lower crash rates by 78 percent [3].

COST

High; Initial investment: $25 per square yard; Cost of maintenance: N/A; Frequency of maintenance: 10 years (two applications)

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. American Traffic Safety Services Association. (2015). Preventing Vehicle Departures from Roadways. Fredericksburg, VA, USA.
3. Road Safety Toolkit (RST) (2013). High Friction Surfacing Treatment (HFST) Crash Reduction Program. Washington, D.C.
4. Golembiewski, G.A., Chandler, B. and Anderson, R., 2011. *Roadway Departure Safety: A Manual for Local Rural Road Owners*. U.S. Department of Transportation. Federal Highway Administration.

REMOVE/SHIELD FIXED OBJECTS

DESCRIPTION

"Removing, redesigning, marking, or relocating fixed objects within the clear zone reduces the likelihood of a crash. If a crash occurs, adding breakaway features, crash cushions, or redirection devices reduces crash severity." [1]

IMPLEMENTATION

Fixed objects that can pose threats include culverts, bridges, driveways, trees, ditches, slopes, utility poles, and public broadcast service routing stations. LVRs may not have adequate clear zones to let errant vehicles avoid these fixed objects. Guardrail systems may be used to shield fixed objects; however, for small objects their installation may not be cost-effective. Removing, redesigning, relocating, reducing, and shielding are steps that can be taken to reduce fixed object crashes. However, some of these treatments are not practical (e.g., relocating trees or removing utility poles).

CRASHES AFFECTED

Run-off-road; fixed object

EFFECTIVENESS

Removing fixed objects on two-lane rural roads has the potential to reduce crashes by up to 16 percent [2]. Relocating select hazardous utility poles has a CMF of less than 0.71 [1]. For lower volume, narrower conditions, removing or shielding fixed objects in the clear zone has a benefit-cost ratio of 4.6 and a CMF of less than 0.71.

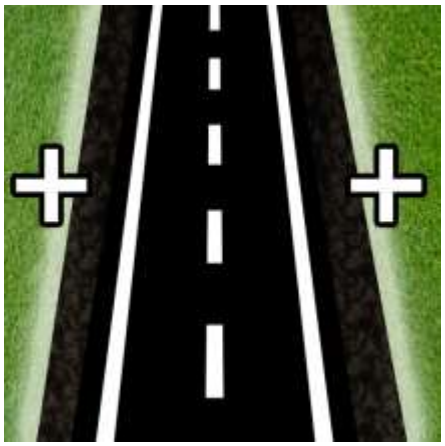
COST

High; Initial investment: $10,000 per acre; Cost of maintenance: $7,000 per location; Frequency of maintenance: 5 years

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Lacy, J. (2002). *Southeast Regional Fatal Study: A Causal Chain Analysis in North Carolina*. University of North Carolina. Highway Safety Research Center.

WIDEN SHOULDERS



DESCRIPTION

"Increasing shoulder widths may offer several benefits such as providing an area for drivers to maneuver to avoid crashes, increasing safety by providing a stable, clear recovery area for divers who have left the travel lane, improving stopping sight distance at horizontal curves by providing an offset to objects such as barrier and bridge piers, providing a shelf for snow in northern climates, improving bicycle accommodations and providing space for emergency storage of disabled vehicles." [1]

IMPLEMENTATION

Shoulder widening can address run-off-road crashes by providing additional space in which errant vehicles may recover. Shoulder widening can help reduce run-off-road (fixed object, rollover, and other run-off-road crashes); head on; and opposite- and same-direction sideswipe crashes on rural, two-lane roads [2].

CRASHES AFFECTED

Run-off-road; sideswipe; head on

EFFECTIVENESS

Compared to having no shoulder, the presence of a 10-foot shoulder reduces the probability of a fatal crash from 8.2 percent to 5.7 percent [3]. Crashes were 83 percent more likely when no shoulder was present compared to when a 4-foot shoulder had been installed [2]. The *Highway Safety Manual* provides CMFs based on shoulder width [5].

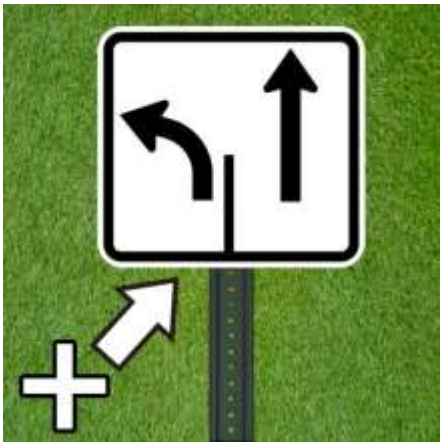
COST

High to very high; Initial investment: $50,000-100,000 per mile for 2-foot paved shoulder; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Fitzpatrick, K., Parham, A., Brewer, M. and Miaou, S. (2001). *Characteristics of and Potential Treatments for Crashes on Low-Volume, Rural Two-Lane Highways in Texas*. Texas Transportation Institute.
3. Peng, Y., Geedipally, S. R. and Lord, D. (2012). *Effect of Roadside Features on Single-Vehicle Roadway Departure Crashes on Rural Two-Lane Roads*. *Transportation Research Record: Journal of the Transportation Research Board,* 2309(1): 21-29.
4. Ewan, L., Al-Kaisy, A. and Hossain, F. (2016). Safety Effects of Road Geometry and Roadside Features on Low-Volume Roads in Oregon. *Transportation Research Record: Journal of the Transportation Research Board,* 2580(1): 47-55.
5. American Association of State Highway and Transportaion Officials (2010). *Highway Safety Manual*, Washington, D.C.

ADD LEFT TURN LANE



DESCRIPTION

"Left turn lanes are used as auxiliary lanes for storage or to accommodate left turning vehicles with decreasing speed as they approach the intersection. Installing left turn lanes can reduce rear-end crashes by allowing vehicles to proceed through the intersection without having to stop or slow down for vehicles waiting to make a left turn." [1]

IMPLEMENTATION

A left-turn lane helps prevent rear-end crashes between a stopped or slowing vehicle attempting to turn left. Installations in rural areas were proven more effective in reducing crashes than in urban areas.

CRASHES AFFECTED

Head on; rear end; left-turn crashes

EFFECTIVENESS

The benefit-cost ratio for installing a left-turn lane on a lower volume four-way intersection is 6.0; for a three-leg intersection it is 3.7 [1]. Installing a two-way left-turn lane (TWLTL) can result in 36 percent reduction in total crashes and lower rear end crashes by 47 percent [2].

COST

Very high; Initial investment: $400,000 per intersection; Cost of maintenance: $20,000 per location; Frequency of maintenance: 10 years

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Persaud, B., Lyon, C., Lefler, N., Carter, D. and Eccles, K.A. (2008). *Safety Evaluation of Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads*. U.S. Department of Transportation. Federal Highway Administration.

INCREASE CLEAR ZONE

DESCRIPTION

"A clear zone is an unobstructed, traversable roadside area that allows a driver to stop safely or regain control of a vehicle that has left the roadway. Clear roadsides consider both fixed objects and terrain that may cause vehicles to rollover. Creating or increasing clear zones within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs, as opposed to providing a clear zone throughout an entire corridor." [1]

IMPLEMENTATION

Clear zones can be expanded by removing or relocating fixed objects near the roadway and using breakaway posts [2]. Flattening slopes and eliminating pavement edge drops can also help drivers recover an errant vehicle.

CRASHES AFFECTED

Run-off-road; fixed object

EFFECTIVENESS

The CMF for increasing the clear zone from 3.3 feet to 16.7 feet on rural two-lane roads is 0.78 [3]. Increasing the clear zone by 5 feet can reduce fixed-object and run-off-road crashes by 13 percent, while a 20-foot increase can reduce the same type of crashes by 44 percent [4].

COST

Very high; Initial investment: $300,000 per mile; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Al-Kaisy, A., Ewan, L., Veneziano, D. and Hossain, F. (2015). *Risk Factors Associated with High Potential for Serious Crashes*. Western Transportation Institute, Oregon Deptartment of Transportation.
3. Boodlal, L., Donnell, E.T., Porter, R.J., Garimella, D., Le, T., Croshaw, K., Himes, S., Kulis, P.N. and Wood, J. (2015). *Factors Influencing Operating Speeds and Safety on Rural and Suburban Roads*. Turner-Fairbank Highway Research Center.
4. Gan A., Shen J., and Rodriguez A. (2005). *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects*. Lehman Center for Transportation Research.

RE-ALIGN ROADWAY SEGMENTS

DESCRIPTION

"Horizontal and vertical geometry may be reconstructed in a variety of ways. For example, horizontal and vertical curves may benefit from increased radii, thereby increasing sight distance. Modifying road geometry may also include eliminating horizontal or vertical curves and providing a more direct alignment. Although changing alignment is a high-cost treatment, in some cases sight distance is restricted by horizontal and vertical curvature. Straightening a roadway will increase sight distance and allow for better visibility of other vehicles." [1]

IMPLEMENTATION

This treatment frequently aims to correct reduced or limited sight distance. It can also help lower high crash rates attributable to reduced or limited sight distance. Realignment can address intersection deficiencies, including sight distance and approach alignment. Realigning intersections may be more critical when horizontal or vertical geometry restricts sight distance and less expensive countermeasures cannot lower crashes rates. Despite the potential expense of realignment, it can help to significantly reduce crash rates [2].

CRASHES AFFECTED

Head on; sideswipe; rear end; run-off-road

EFFECTIVENESS

Geometric realignment can reduce crashes by 28 percent [2]. This countermeasure has not yet been fully evaluated due to its high costs and the changes in geometry following installation.

COST

Very high; Initial investment: $300,000 per mile; Cost of maintenance: N/A; Frequency of maintenance: N/A

SOURCES

1. Atkinson, J. E., Chandler, B. E., Betkey, V., Weiss, K., Dixon, K., Giragosian, A., Donoughe, K., and O'Donnell, C. (2014). *Manual for Selecting Safety Improvements on High Risk Rural Roads*. U.S. Department of Transportation, Federal Highway Administration.
2. Lacy, J. (2002). *Southeast Regional Fatal Study: A Causal Chain Analysis in North Carolina*. University of North Carolina. Highway Safety Research Center.