US DEPARTMENT OF TRANSPORTATION - FEDERAL HIGHWAY ADMINISTRATION
PROVEN SAFETY COUNTERMEASURES

U.S. Department of Transportation
Federal Highway Administration

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Proven Safety Countermeasures

Enhanced Delineation for Horizontal Curves

Enhanced delineation at horizontal curves includes a variety of potential strategies that can be implemented in advance of or within curves, in combination, or individually.

Potential Strategies	In Advance of Curve	Within Curve
Pavement markings (standard width or wider)	✓	✓
In-lane curve warning pavement markings	✓	✓
Retroreflective strips on sign posts	✓	✓
Delineators		✓
Chevron signs		✓
Enhanced Conspicuity (larger, fluorescent, and/or retroreflective signs)	✓	✓
Dynamic curve warning signs (including speed radar feedback signs)	✓	
Sequential dynamic chevrons		✓

Enhanced delineation treatments can alert drivers to upcoming curves, the direction and sharpness of the curve, and appropriate operating speed.

Agencies can take the following steps to implement enhanced delineation strategies:

1. Review signing practices and policies to ensure they comply with the Manual on Uniform Traffic Control Devices (MUTCD) principles of traffic control devices. Consistent practice for similar curves sets the appropriate driver expectancy.
2. Use the systemic approach to identify and treat problem curves. For example, Minnesota uses risk factors that include curve radii between 500 and 1,200 ft, traffic volumes between 500 and 1,000 vehicles per day, intersection in the curve, and presence of a visual trap.[1]
3. Match the appropriate strategy to the identified problem(s), considering the full range of enhanced delineation treatments. Once the MUTCD requirements and recommendations have been met, an incremental approach is often beneficial to avoid excessive cost.

Chevron signs with retroreflective strips on sign posts installed along a curve. Source: FHWA

Safety Benefits:

Chevron Signs

25% reduction in nighttime crashes.[1]

16% reduction in non-intersection fatal and injury crashes.[2]

Oversized Chevron Signs

15% reduction in fatal and injury crashes.[3]

Sequential Dynamic Chevrons

60% reduction in fatal and injury crashes.[4]

In-Lane Curve Warning Pavement Markings

35 - 38% reduction in all crashes.[5]

New Fluorescent Curve Signs or Upgrade Existing Curve Signs to Fluorescent Sheeting

18% reduction in non-intersection, head-on, run-off-road, and sideswipe in rural areas.[1]

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/rwd/keep-vehicles-road/horizontal-curve-safety.

FHWA-SA-21-035

1 (CMF ID: 2492,2493,2482) Albin et al. Low-Cost Treatments for Horizontal Curve Safety 2016. FHWA-SA-15-084. (2016).
2 (CMF ID: 2483) Srinivasan et al. Safety Evaluation of Improved Curve Delineation. FHWA-HRT-09-046. (2009).
3 (CMF ID: 8073) Lyon et al. Safety Evaluation of Two Curve Warning Treatments: In-Lane Curve Warning Pavement Markings and Oversized Chevron Signs. Presented at the 96th TRB Annual Meeting, Paper No. 17-00492. (2017).
4 (CMF ID: 10302) Hallmark, S. Evaluation of Sequential Dynamic Chevrons on Rural Two-lane Highways. FHWA. (2017).
5 (CMF ID: 10312,4142) Donnell et al. Reducing Roadway Departure Crashes at Horizontal Curve Sections on Two-lane Rural Highways. FHWA-SA-19-005. (2019).

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Safety Benefits:

Center Line Rumble Strips

44-64%
reduction in head-on fatal and injury crashes on two-lane rural roads.[4]

Shoulder Rumble Strips

13-51%
reduction in single vehicle, run-off-road fatal and injury crashes on two-lane rural roads.[4]

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/rwd/keep-vehicles-road/rumble-strips.

FHWA-SA-21-036

Longitudinal Rumble Strips and Stripes

Longitudinal rumble strips are milled or raised elements on the pavement intended to alert drivers through vibration and sound that their vehicle has left the travel lane. They can be installed on the shoulder, edge line, or at or near the center line of an undivided roadway.

Rumble stripes are edge line or center line rumble strips where the pavement marking is placed over the rumble strip. This can increase the visibility and durability of the pavement marking during wet, nighttime conditions, and can improve the durability of the marking on roads with snowplowing operations.

With roadway departure crashes accounting for more than half of the fatal roadway crashes annually in the United States, rumble strips and stripes are designed to address these crashes by alerting distracted, drowsy, or otherwise inattentive drivers who drift from their lane. They are most effective when deployed systemically.

Transportation agencies should consider milled center line rumble strips (including in passing zone areas) and milled edge line or shoulder rumble strips with bicycle gaps for systemic safety projects, location-specific corridor safety improvements, as well as reconstruction or resurfacing projects.

Considerations

- Rumble strips are relatively low-cost, and economic analyses have indicated benefit/cost ratios that exceed 100.[1]
- Where rumble strips cannot be placed due to noise concerns, agencies may consider a design using an oscillating sine wave pattern (also known as "mumble stripes") that reduces noise outside of the vehicle. However, the safety benefits of this design need more study.[2]
- Maintenance concerns:
  - Where rumble strips are placed along a pavement joint, there are typically no issues with joint stability if the pavement structure and joint was already in good condition.
  - Studies have shown no evidence of issues related to snow, ice, or rain build-up in the rumble strip.[3]

Shoulder rumble strips and center line rumble stripes are installed on this roadway. Source: FHWA

Example of an edge line rumble stripe. Source: Missouri DOT

1 Himes, S., and McGee, H. Decision Support Guide for the Installation of Shoulder and Center Line Rumble Strips on Non-Freeways. Federal Highway Administration Report No. FHWA-SA-16-115. (August 2016).
2 Bedoka et al. ***Did You Hear That?*** Public Roads Magazine, Volume 80, No. 4. FHWA Publication No. FHWA-HRT-17-002. (2017).
3 NCHRP Synthesis 339: Centerline Rumble Strips – A Synthesis of Highway Practices. (2005
4 (CMF ID: 3388, 3389, 3435, 3680) NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. (2009).

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Safety Benefits:

HFST can reduce crashes up to:

63%
for injury crashes at ramps.[2]

48%
for injury crashes at horizontal curves.[2]

20%
for fatal crashes at intersections.[3]

Automated application of HFST. Source: FHWA

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/rwd/keep-vehicles-road/pavement-friction/hfst.

FHWA-SA-21-052

Pavement Friction Management

Friction is a critical characteristic of a pavement that affects how vehicles interact with the roadway, including the frequency of crashes. Measuring, monitoring, and maintaining pavement friction—especially at locations where vehicles are frequently turning, slowing, and stopping—can prevent many roadway departure, intersection, and pedestrian-related crashes.

Pavement friction treatments, such as High Friction Surface Treatment (HFST), can be better targeted and result in more efficient and effective installations when using continuous pavement friction data along with crash and roadway data.

Continuous Pavement Friction Measurement

Friction data for safety performance is best measured with Continuous Pavement Friction Measurement (CPFM) equipment. Spot friction measurement devices, like locked-wheel skid trailers, cannot safely and accurately collect friction data in curves or intersections, where the pavement polishes more quickly and adequate friction is so much more critical. Without CPFM equipment, agencies will assume the same friction over a mile or more.

CPFM technology measures friction continuously at highway speeds and provides both network and segment level data. Practitioners can analyze the friction, crash, and roadway data to better understand and predict where friction-related crashes will occur to better target locations and more effectively install treatments.[1]

High Friction Surface Treatment

HFST consists of a layer of durable, anti-abrasion, and polish-resistant aggregate over a thermosetting polymer resin binder that locks the aggregate in place to restore or enhance friction and skid resistance. Calcined bauxite is the aggregate shown to yield the best results and should be used with HFST applications.

Applications

HFST should be applied in locations with increased friction demand, including:

- Horizontal curves.
- Interchange ramps.
- Intersection approaches.
  - Higher-speed signalized and stop-controlled intersections.
  - Steep downward grades.
- Locations with a history of rear-end, failure to yield, wet-weather, or red-light-running crashes.
- Crosswalk approaches.

Considerations

- HFST is applied on existing pavement, so no new pavement is added.
- If the underlying pavement structure is unstable, then the HFST life cycle may be shortened, resulting in pre-mature failure.
- The automated installation method is preferred as it minimizes issues often associated with manual installation: human error due to fatigue, inadequate binder mixing, improper and uneven binder thickness, delayed aggregate placement, and inadequate aggregate coverage.
- The cost can be reduced when bundling installations at multiple locations.

1 Izzopl et al. Continuous Friction Measurement Equipment as a Tool for Improving Crash Rate Prediction: A Pilot Study. Virginia Department of Transportation. (2016).
2 (CMF ID: 10582,10333) Merritt et al. Development of Crash Modification Factors for High Friction Surface Treatments. FHWA. (2020).
3 (CMF ID: 2269) NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements. (2008).

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Federal Highway Administration

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Proven Safety Countermeasures

Safety Benefits:

Flatten sideslope from 1V:3H to 1V:4H:

8%
reduction for single-vehicle crashes.[2]

Flatten sideslope from 1V:4H to 1V:6H:

12%
reduction for single-vehicle crashes.[2]

Increase the distance to roadside features from 3.3 ft to 16.7 ft:

22%
reduction for all crashes.[3]

Increase the distance to roadside features from 16.7 ft to 30 ft:

44%
reduction for all crashes.[3]

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/rwd/provide-safe-recovery/clear-zones/clear-zones.

FHWA-SA-21-029

Roadside Design Improvements at Curves

Horizontal curves account for 27 percent of all fatal crashes and 80 percent of all fatal crashes at curves are roadway departure crashes.[1] Roadside design improvements at curves is a strategy encompassing several treatments that target the high-risk roadside environment along the outside of horizontal curves. These treatments can reduce roadway departure fatalities and serious injuries by giving vehicles the opportunity to recover safely and by reducing crash severity.

Roadside design improvements can be implemented alone or in combination, and are particularly recommended at horizontal curves—where data indicates a higher risk for roadway departure fatalities and serious injuries.

Roadside Design Improvements to Provide for a Safe Recovery

In cases where a vehicle leaves the roadway, having strategic roadside design elements, including an added or widened shoulder, flattened sideslopes, or a widened clear zone can provide drivers with an opportunity to regain control and re-enter the roadway in their lane or come to a safe stop before rolling over or encountering a fixed object.

- 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. Agencies should avoid adding new fixed objects such as trees and utility cabinets or poles in the clear zone. AASHTO's *Roadside Design Guide* details the clear zone width adjustment factors to be applied at horizontal curves.
- **Slope flattening** reduces the steepness of the sideslope to increase drivers' ability to keep the vehicle stable, regain control of the vehicle, and avoid obstacles. Slopes of 1V:4H or flatter are considered traversable (i.e., drivers can retain control of a vehicle by slowing or stopping). Slopes between 1V:3H and 1V:4H are generally considered traversable, but non-recoverable (i.e., errant vehicle will continue to the bottom of the slope).
- **Adding or widening shoulders** gives drivers more recovery area to regain control in the event of a roadway departure.

Roadside Design Improvements to Reduce Crash Severity

Since not all roadside hazards can be removed, relocated, or redesigned at curves, installing roadside barriers to shield unmovable objects or steep embankments may be an appropriate treatment. Three common types of roadside barriers are:

- **Cable barrier** is a flexible barrier made from steel cables mounted on weak steel posts. Flexible barriers are more forgiving and have the most deflection.
- **Metal-beam guardrail** is a semi-rigid barrier where a W-beam or box-beam is mounted on steel or timber posts. These deflect less than cable barriers, so they can be located closer to objects where space is limited.
- **Concrete barrier** is a rigid barrier that has little to no deflection.

Clear zone provided on the outside of the curve. Source: FHWA.

1 Fatality Analysis Reporting System.
2 (CMF ID: 4622,4632) NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements. (2008).
3 (CMF ID: 35,36) Elvik, R., and Vaa, T. Handbook of Road Safety Measures. (2004).

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Federal Highway Administration

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Proven Safety Countermeasures

Safety Benefits:

Two-Way Stop-Controlled Intersection to a Roundabout

82%
reduction in fatal and injury crashes.[1]

Signalized Intersection to a Roundabout

78%
reduction in fatal and injury crashes.[1]

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/intersection-safety/intersection-types/roundabouts.

FHWA-SA-21-042

Roundabouts

The modern roundabout is an intersection with a circular configuration that safely and efficiently moves traffic. Roundabouts feature channelized, curved approaches that reduce vehicle speed, entry yield control that gives right-of-way to circulating traffic, and counterclockwise flow around a central island that minimizes conflict points. The net result of lower speeds and reduced conflicts at roundabouts is an environment where crashes that cause injury or fatality are substantially reduced.

Roundabouts are not only a safer type of intersection; they are also efficient in terms of keeping people moving. Even while calming traffic, they can reduce delay and queuing when compared to other intersection alternatives. Furthermore, the lower vehicular speeds and reduced conflict environment can create a more suitable environment for walking and bicycling.

Roundabouts can be implemented in both urban and rural areas under a wide range of traffic conditions. They can replace signals, two-way stop controls, and all-way stop controls. Roundabouts are an effective option for managing speed and transitioning traffic from high-speed to low-speed environments, such as freeway interchange ramp terminals, and rural intersections along high-speed roads.

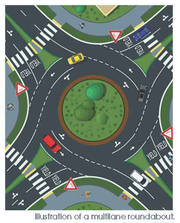

Illustration of a multilane roundabout. Source: FHWA

Example of a single-lane roundabout. Source: FHWA

1 (CMF ID: 2411,2281) AASHTO. The Highway Safety Manual. American Association of State Highway Transportation Professionals. Washington, D.C., (2010).

U.S. Department of Transportation
Federal Highway Administration

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Safety Benefits:

11%
reduction in fatal and injury crashes.[2]

21%
reduction in run-off-road crashes.[2]

19%
reduction in head-on crashes.[2]

Benefit-Cost Ratio Range[3]

700:1 to 1,500:1

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/rwd/provide-safe-recovery/safetyedge.

FHWA-SA-21-038

SafetyEdge^{SM}

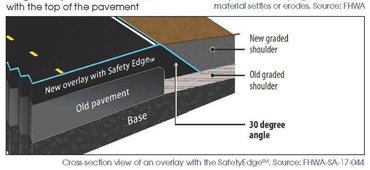
The SafetyEdge^{SM} technology shapes the edge of the pavement at approximately 30 degrees from the pavement cross slope during the paving process. This safety practice eliminates the potential for vertical drop-off at the pavement edge, has minimal effect on project cost, and can improve pavement durability by reducing edge raveling of asphalt.

Rural road crashes involving edge drop-offs are 2-4 times more likely to include a fatality than other crashes on similar roads.[1] Vehicles may leave the roadway for various reasons ranging from distracted driver errors to low visibility, or to the presence of an animal on the road. Exposed vertical pavement edges can cause vehicles to become unstable and prevent their safe return to the roadway. The SafetyEdge^{SM} gives drivers the opportunity to return to their travel lane while maintaining control of their vehicle.

The SafetyEdge^{SM} technology only requires adding one of several commercially available devices to the screed or endgate when placing hot-mix asphalt. Forms for shaping the edge of concrete pavement are simpler and can be made on site by the contractor. Some agencies allow the SafetyEdge^{SM} to remain exposed while a segment is under construction, unlike conventional pavement edges. However, before construction ends, agencies should bring the adjacent roadside flush with the top of the pavement for both the SafetyEdge^{SM} and traditional pavement edge. Over time, regardless of the edge type, the edge may become exposed due to settling, erosion, and tire wear. When this occurs, the gentle slope provided by the SafetyEdge^{SM} is preferred versus the traditional vertical pavement edge.

Transportation agencies should develop standards for implementing the SafetyEdge^{SM} systemwide on all new asphalt paving and resurfacing projects where curbs and/or guardrail are not present, while also encouraging standard application for concrete pavements.

Example of the SafetyEdge^{SM} after backfill material settles or erodes. Source: FHWA



Cross-section view of an overlay with the SafetyEdge^{SM}. Source: FHWA-SA-17-044

1 Hallmark et al. Safety Impacts of Pavement Edge Drop-offs. (Washington, DC: AAA Foundation for Traffic Safety: 2006), p. 93.
2 (CMF ID: 9208, 9211, 9217) Donnell et al. Development of Crash Modification Factors for the Application of the SafetyEdge℠ on Two-Lane Rural Roads. FHWA-HRT-17-081. (2017).
3 Safety Effects of the SafetyEdge℠. FHWA-SA-17-044. (2017).

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Proven Safety Countermeasures

Safety Benefits:

Wider edge lines can reduce crashes up to:

37%
for non-intersection, fatal and injury crashes on rural, two-lane roads.[2]

22%
for fatal and injury crashes on rural freeways.[3]

Benefit Cost Ratio

25:1
for fatal and serious injury crashes on two-lane rural roads.[4]

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/other/visibility/pavement-markings.

FHWA-SA-21-055

Wider Edge Lines

Roadway departures account for over half of all traffic fatalities in the United States. If drivers cannot clearly identify the edge of the travel lanes and see the road alignment ahead, the risk of roadway departure may be greater. Wider edge lines enhance the visibility of travel lane boundaries compared to traditional edge lines. Edge lines are considered "wider" when the marking width is increased from the minimum normal line width of 4 inches to the maximum normal line width of 6 inches.[1]

Applications

Wider edge lines increase drivers' perception of the edge of the travel lane and can provide a safety benefit to all facility types (e.g., freeways, multilane divided and undivided highways, two-lane highways) in both urban and rural areas.[2] Wider edge lines are most effective in reducing crashes on rural two-lane highways, especially for single-vehicle crashes.[3] Agencies should also consider implementing a systemic approach to wider edge line installation based roadway departure crash risk factors. Potential risk factors for two-lane rural roads include:

- Pavement and shoulder widths.
- Presence of curves.
- Traffic volumes.
- History of nighttime crashes.

Considerations

- Wider edge lines are relatively low cost.
- Wider edge lines can be implemented using existing equipment during maintenance procedures like re-striping and resurfacing, with the only cost increase being the additional material.
- Paint may have a lower initial cost, but more durable materials (e.g., thermoplastic) may result in a lower life cycle cost based on their longer service life.
- As the number of automated vehicles increases on roadways, wider edge lines may provide better guidance for these vehicles' sensors.

Source: Texas Transportation Institute

1 Manual on Uniform Traffic Control Devices, Section 3A.06. FHWA. (2009).
2 (CMF ID: 4737) Park et al. "Safety effects of wider edge lines on rural, two-lane highways. " Accident Analysis and Prevention Vol. 48, pp.317-325, (2012).
3 Potts et al. Benefit/Cost Evaluation of MoDOT's Total Striping and Delineation Program: Phase II. Missouri Department of Transportation. (2011)
4 Abdel-Rahim et al. Safety Impacts of Using Wider Pavement Markings on Two-Lane Rural Highways in Idaho. Idaho Transportation Department. (2018).

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Safety Benefits:

Lighting can reduce crashes up to:

42%
for nighttime injury pedestrian crashes at intersections.[1]

33-38%
for nighttime crashes at rural and urban intersections.[2,1]

28%
for nighttime injury crashes on rural and urban highways.[1]

Source: WSDOT

For more information on this and other FHWA Proven Safety Countermeasures, please visit https://highways.dot.gov/safety/proven-safety-countermeasures and https://highways.dot.gov/safety/other/visibility/roadway-lighting-resources.

FHWA-SA-21-050

Lighting

The number of fatal crashes occurring in daylight is about the same as those that occur in darkness. However, the nighttime fatality rate is three times the daytime rate because only 25 percent of vehicle miles traveled (VMT) occur at night. At nighttime, vehicles traveling at higher speeds may not have the ability to stop once a hazard or change in the road ahead becomes visible by the headlights. Therefore, lighting can be applied continuously along segments and at spot locations such as intersections and pedestrian crossings in order to reduce the chances of a crash.

Adequate lighting (i.e., at or above minimum acceptable standards) is based on research recommending horizontal and vertical illuminance levels to provide safety benefits to all users of the roadway environment. Adequate lighting can also provide benefits in terms of personal security for pedestrians, wheelchair and other mobility device users, bicyclists, and transit users as they travel along and across roadways.

Applications

Roadway Segments

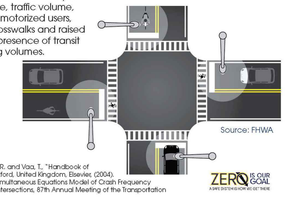
Research indicates that continuous lighting on both rural and urban highways (including freeways) has an established safety benefit for motorized vehicles.[1] Agencies can provide adequate visibility of the roadway and its users through the uniform application of lighting that provides full coverage along the roadway and the strategic placement of lighting where it is needed the most.

Intersections and Pedestrian Crossings

Increased visibility at intersections at nighttime is important since various modes of travel cross paths at these locations. Agencies should consider providing lighting to intersections based on factors such as a history of crashes at nighttime, traffic volume, the volume of non-motorized users, the presence of crosswalks and raised medians, and the presence of transit stops and boarding volumes.

Considerations

Most new lighting installations are made with breakaway features, shielded, or placed far enough from the roadway to reduce the probability and/or severity of fixed-object crashes. Modern lighting technology gives precise control with minimal excessive light affecting the nighttime sky or spilling over to adjacent properties. Agencies can equitably engage with underserved communities to determine where and how new and improved lighting can most benefit the community by considering their priorities, including eliminating crash disparities, connecting to essential neighborhood services, improving active transportation routes, and promoting personal safety.



Source: FHWA

1 (CMF ID: 436,453,1192) Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004).
2 (CMF ID: 2376) Ye et al. A Simultaneous Equations Model of Crash Frequency By Collision Type for Rural Intersections. 87th Annual Meeting of the Transportation Research Board. (2008).