IMPROVING DRIVER BEHAVIOR WITH INFRASTRUCTURE SAFETY COUNTERMEASURES

AMERICAN TRAFFIC SAFETY SERVICES ASSOCIATION

ATSSA

SAFER ROADS SAVE LIVES

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Overview and Acknowlegements

Roadway crashes are a result of three primary contributing factors: human behavior, the roadway itself, and the vehicle. A combination of any or all of these factors may lead to a crash or increase the severity of a crash.

However, research proves that the greatest potential to improve roadway safety is by a comprehensive approach that includes enforcement, education, emergency response, and engineering infrastructure safety countermeasures.

Engineering countermeasures are roadway and infrastructure improvements implemented directly to the roadway network. Countermeasures (also known as strategies) include rumble strips, highly reflective signs and pavement markings, roadside hardware devices (guardrail and cable median barrier), traffic control devices, and other geometric improvements. These strategies can actually mitigate against behavior-related crashes by alerting drivers of an upcoming change in the driving environment that requires action or by providing positive guidance to prevent a collision. Countermeasures can minimize the consequences of a driver action that causes a vehicle to depart the roadway or collide with another conflicting vehicle.

The following case studies illustrate how infrastructure safety countermeasures can impact driver behavior to improve roadway safety. They are grouped according to their ability to alert a driver, provide positive guidance that prevents a collision, or minimize the consequences once a vehicle has left the roadway. This document serves as a resource for understanding treatments and countermeasures that may reduce the number and severity of crashes due to driver error. ■

The American Traffic Safety Services Association (ATSSA) and CH2M Hill, a global leader in consulting, design, design-build, operations, and program management, developed this report. The team examined a synthesis of previously completed ATSSA roadway safety case studies and with CH2M Hill fine-tuned those studies and developed new material for additional case studies contained in this publication.

A wide variety of resources were used to develop this publication. A full list of references can be obtained upon request by emailing Communications@atssa.com with “References” in the subject line.

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Introduction

As stated in the overview, roadway crashes are a result of three primary contributing factors: human behavior, the roadway itself, and the vehicle. Frequently there is an overlap between these factors.

As shown in Figure 1, human factors or driver behavior is a factor in 95 percent of crashes; however, the roadway environment and vehicle condition also influence crashes. A combination of any or all of these factors may lead to a crash or increase the severity of a crash.

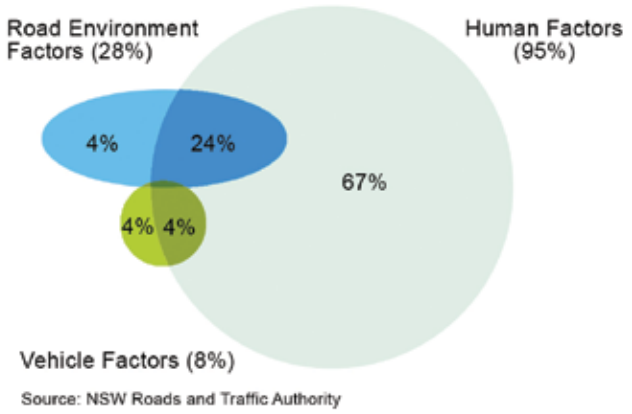

Figure 1. Crash contributing factors (Image: New South Wales Roads and Traffic Authority)

Example. A young driver in a small vehicle may leave a travel lane due to a distraction; the edge of the pavement may drop off a sufficient depth that results in "scrubbing" of the tire. The driver then overcorrects the situation due to inexperience, and a crash results.

Because human behavior (such as distraction, fatigue, speed, alcohol) is the primary contributor to crashes, a typical reaction is that behavior-related crashes can only be addressed by enforcement or educational programs.

Research proves—and national best practices endorse—the greatest potential to improve roadway safety is with a comprehensive approach that includes enforcement, education, emergency response, and engineering infrastructure countermeasures.

Although infrastructure safety improvements cannot change the initial driver behavior, they can effect change in the sequence of crash events and reduce the severity of crashes. Median-crossover crashes often result when a motorist is speeding, fatigued, distracted, or driving under the influence of drugs, alcohol, or a combination of both.

Cable median barrier eliminates median-crossover crashes and reduces the severity of the crash.

The following case studies discuss how infrastructure safety countermeasures directly impact driver behavior to improve roadway safety. The studies are grouped according to their ability to alert a driver, provide positive guidance that prevents a collision, or minimize the consequences once a vehicle has left the roadway. This document serves as a resource for better understanding and defining treatments and countermeasures that may reduce crashes or the severity of crashes due to driver behavior. ■

Part I: Alerting Drivers by Providing Information

Many features of the roadway's infrastructure can prevent driver errors and help reduce the potential for crashes. These features can warn drivers of an upcoming change in the driving environment that requires action or alerts drivers to an error before the event results in a crash. Most of these elements are low-cost, are easy to install, and can be implemented systemically throughout the jurisdiction's roadway network.

The following five case studies provide examples of safer infrastructure used to alert drivers so they may bring the vehicle back on course, reducing the likelihood of a crash.

CASE 1: Centerline, Shoulder, and Transverse Rumble Strips

Roadway departure is one of the more severe types of crashes, compared with other crash types.

Roadway departure occurs when a vehicle departs from the roadway by either crossing an edge line or a centerline. The latter may result in a head-on collision.

The reasons for roadway-departure events are varied but do include the driver attempting to avoid a vehicle, an object, or an animal in the travel lane; inattentive driving due to distraction, fatigue, medical conditions, or the use of alcohol or drugs; wet or slippery pavement conditions; driver inexperience; or traveling too fast through curves or downhill. In difficult situations, many drivers do not have the knowledge or the skills to maintain or regain control of the vehicle in a safe manner.

Although features of the roadway infrastructure cannot affect the initial driver behavior that leads to the roadway departure, they can change the sequence of crash events and prevent or reduce the severity of those crashes. To effectively address roadway-departure crashes, it is critical to select the appropriate set of roadway safety features and install them correctly in the locations with the greatest potential to prevent or reduce the severity of crashes. Many of the roadway safety features that can prevent crashes are low-cost, are easy to install, and can be implemented systemically throughout the jurisdiction's roadway network.

One example of a low-cost infrastructure treatment is centerline or shoulder rumble strips. The vibration and noise caused by these grooves in the pavement can greatly influence drivers' reactions to crossing the edge or centerline by prompting a corrective action when alerted that they are leaving the roadway. The vibration and noise can also awaken a drowsy driver. Additionally, rumble strips can serve as an effective guide, alerting drivers as to the location of the travel lane when fog, snow, driving rain, or darkness obscures pavement markings.

The results of an evaluation of shoulder rumble strips, which included more than 200 sites in 19 states, indicate a reduction in single-vehicle roadway-departure collisions of 11 percent to 18 percent for urban and rural freeways and 15 percent for two-lane rural roads. Furthermore,

Figure 2. Shoulder rumble strip on Interstate 95 (North), Stafford County, Va. (Image: James Scott Baron, ATSSA)

Figure 3. A sample of milled centerline rumble strips (Image: Neal Hawkins, Center for Transportation Research)

fatal and injury single-vehicle roadway-departure collisions were reduced 13 percent to 16 percent for urban and rural freeways and 29 percent for two-lane rural roads.

The Michigan Department of Transportation (MDOT) installed centerline rumble strips along approximately 5,400 miles of highways and expressways between 2008 and 2010. During an evaluation of their effectiveness, MDOT found that the centerline rumble strips reduced opposite-direction sideswipe collisions, multivehicle head-on collisions and single-vehicle roadway-departure crashes by 46 percent, 35 percent, and 31 percent, respectively.

Transverse rumble strips (also called in-lane rumble strips) are used to warn drivers in rural areas that they are approaching an intersection. The strips are grooves crossing the roadway surface to provide a tactile and audible warning for drivers. Effectiveness evaluations for this treatment applied to approaches at 154 stop-controlled intersections in Iowa and Minnesota indicate they may be effective in reducing severe-injury crashes, which could be related to a reduction in speed approaching the intersection that occurs once the driver is alerted by the noise and vibration of the rumble strip. ■

CASE 2: Roadway Signs

Roadway signs visually communicate regulations, warnings, directions, locations, and points of interest to drivers.

These signs convey information to help drivers make better, quicker decisions while operating their vehicle. These decisions may relate to judging vehicle gaps through which to cross or turn at intersections, clearly identifying a particular street they are looking for, stopping for crossing vehicles or pedestrians, or safely navigating curves.

Signs that are positioned correctly and not obstructed by vegetation or other roadside objects will clearly convey the appropriate message to the motorist. At night, some signs are brilliantly bright, and the message is clear and crisp due to “retroreflective” sheeting that is highly effective even in adverse weather conditions—day or night. Ultimately, drivers who make intelligent, informed decisions not only improve their own driving experience but often help improve driving conditions for all motorists.

Today’s retroreflective sheeting technology provides for advance detection of roadway signs to notify the motorist of an upcoming change in the roadway or a warning for the motorist to make a decision soon.

Advance warning signs give notice to drivers about an upcoming change in condition (such as an upcoming intersection, a reduction in speed, or the possibility of pedestrians in a school zone or a crosswalk) or the roadway environment itself.

When installed correctly, these signs convey the warning message with sufficient time and distance for drivers to prepare for a change. An advance intersection warning sign provides the driver with the opportunity to make a safe lane change and adjust speed prior to turning at the intersection, reducing the potential for a rear-end crash. Additionally, roadway signs appropriately set for the speed limit of the roadway permit the driver to continue at speed without slowing down at each intersection to read a street name sign. Advance warning signs at intersections can help prevent crashes by alerting drivers that there may be traffic in their path.

Prior to a curve, advance warning signs (post-mounted chevrons) notify drivers that the alignment is about to change and they should lower their current speed. Once in a curve, chevrons provide increased visibility of and delineation along a curve to help guide motorists. Retroreflective

Figure 4. Faded, ineffective signs like this should be replaced to immediately improve roadway safety for motorists (Image: James Scott Baron, ATSSA)

Figure 5. Retroreflective signage effectively guides motorists safely at night in a residential Virginia neighborhood (Image: James Scott Baron, ATSSA)

Figure 6. Post-mounted chevrons in a curve, Route 218, King George County, Va. The school-area sign (right) warns of pedestrians in the area (Image: James Scott Baron, ATSSA)

Figure 7. A Wrong Way sign with LED enhancement (Image: Traffic & Parking Control Co. Inc. (TAPCO))

chevron signs also provide illumination in low-light driving conditions for curves that do not have roadway lighting. This guidance encourages a speed reduction that will assist the driver to keep the vehicle in the lane and not depart the roadway.

Regulatory signs convey requirements to which drivers must adhere. Stop and Yield signs, for example, help drivers to understand where they must share the same roadway space with other road users. Orderly movement of drivers through intersections reduces the potential for crashes. Speed limit signs eliminate the need for drivers to make decisions about an appropriate speed for the given roadway geometry and volume conditions. These signs promote uniformity in driving speeds and can prevent drivers from responding inappropriately to the given conditions. Additionally, One-Way and Wrong Way signs provide positive guidance about the correct direction of travel along a roadway or a particular segment of the roadway.

To improve driver behavior and help mitigate wrong-way-driving incidents, some of the general principles for sizing and installing signs must be modified to be most effective.

Mounting regulatory signs (such as Wrong Way and Do Not Enter) at a height of 3 feet, rather than the typical 5 feet in rural areas and 7 feet in urban areas, makes them more visible at night, because they are more directly in the path of a vehicle's headlights. This lower height also makes the signs more visible to impaired and older drivers, who tend to look for visual cues from the pavement area.

In using this signage modification, the California Department of Transportation noted that wrong-way-driving incidents decreased from 50 to 60 per month to two to six per month at some ramps that were notable for these incidents. Also, angling these signs toward the direction that the wrong-way driver is entering the ramp or roadway and installing signs on both sides of the roadway further increase the opportunity to positively affect driver behavior and prevent crashes.

Other means to increase the visibility of these signs at night are red retroreflective strips on the signposts and light-emitting diodes (LEDs) around the sign edges. These two features alone make the sign more visible from a greater distance, before the vehicle headlights illuminate the sign's retroreflective message.

When the Texas Department of Transportation implemented flashing LED signs at 29 exit ramps along a 15-mile highway corridor in 2012, wrong-way-driving incidents decreased by approximately 30 percent.

Figure 8. Another use of a Wrong Way sign at the foot of a freeway ramp (Image: TAPCO)

LEDs are another technology used to improve and enhance driver guidance and help prevent or correct driver error. To enhance the visibility of static roadway signs, LEDs can be inserted along the outline of chevrons or around the circumference of other signs. LEDs can also be used in dynamic-signing applications to provide feedback or to convey a message to drivers only when a certain condition is in effect.

For example, flashing speed indicator boards provide instant feedback to motorists about their operating speed, as compared to the regulatory or warning speed at that location. This feedback can improve driver behavior by prompting a reduction to a more appropriate speed for the condition.

Similarly, variable speed limit systems use traffic speed and volume, weather, and road surface conditions to determine appropriate speeds at which drivers should be traveling, given current conditions. These advisory or regulatory speeds are conveyed to drivers through overhead or roadside LED variable-message signs.

Gap acceptance signs are another LED-based method that enhances safety by providing guidance to drivers at unsignalized intersections. These signs provide red or yellow warning lights that indicate the presence of oncoming vehicles, thereby informing drivers they should wait before attempting a turning maneuver.

The Institute of Transportation Engineers (ITE) has published data that indicate a reduction of certain crash types as a result of signs that were installed to address the specific crash types. By providing appropriate guidance, these signs essentially correct previous driver errors by preventing current drivers from making errors.

These sign types include curve warning arrows (20 percent crash reduction), advance curve warning signs and speed plaques (20 percent crash reduction), advisory speed signs (36 percent crash reduction) and a special curve warning arrow sign with the stated speed (75 percent crash reduction).

Further information from ITE indicates that roadway signs in general could be expected to reduce fatal crash rates (29 percent), injury crash rates (14 percent), and combined fatal and injury crash rates (14 percent), while producing a cost-benefit ratio of 7.3.

Information from the Federal Highway Administration (FHWA) indicates that the installation of double stop signs reduces total crashes by 11 percent and right-angle crashes by 55 percent, while advance warning signs reduced total crashes by 40 percent at rural locations. The low cost of signs (for materials, maintenance, and installation) make them the ideal approach to improving roadway safety along roadways and at intersections, particularly if crash history indicates correctable problems do in fact exist. ■

Figure 9. A speed indicator board provides instant feedback to the driver (Image: TAPCO)

CASE 3: Pedestrians and Bicycles

The roadway infrastructure should ideally provide safe travel for all modes of transportation.

One of the causal factors to collisions between vehicles and pedestrians or bicyclists is the driver's inattention or inability to see the pedestrian or bicyclist. The driver may be inattentive to the possibility of a pedestrian in the travel lane or a bicyclist riding alongside the travel lane. Also, pedestrians or bicyclists can be obscured by other vehicles in the traffic stream or less visible in nighttime driving conditions.

Several infrastructure treatments and safety solutions can be systemically deployed to alert drivers of the presence of pedestrians and bicyclists.

Figure 10. A highly visible, clearly marked pedestrian crosswalk (Image: Neal Hawkins, Center for Transportation Research)

Well-maintained crosswalk markings that are retroreflective increase the visibility of pedestrian crossing locations. The markings alert drivers of the possibility that pedestrians or bicyclists may be crossing the roadway and help reduce the potential for pedestrian-vehicle collisions. Static warning signs used in combination with the markings further alert drivers to the potential for a conflict with pedestrians or bicyclists crossing the roadway. Pavement markings alone may not encourage drivers to reduce their speed as they approach the crosswalk; therefore, the use of lights in the form of high-intensity activated crosswalk (HAWK) beacons, in-pavement flashing warning lights, or rectangular rapid flashing beacons (RRFB) can further enhance the conspicuity of crosswalks by alerting drivers to the presence of pedestrians or bicyclists.

HAWK beacons are installed over the roadway and activated by pedestrians or bicyclists. The beacons first display a yellow signal to alert drivers of a change and then display a red signal to alert drivers to the presence of pedestrians or bicyclists and to indicate a required stop while pedestrians are using the crosswalk.

The red signal tends to achieve a higher compliance rate for drivers stopping than the other lighting treatments, which are amber-colored. An evaluation that compared 21 HAWK sites with 102 unsignalized intersections used as a reference group concluded the HAWK effected a 29 percent reduction in total crashes, a 15 percent reduction in severe crashes and a 69 percent reduction in pedestrian crashes.

Figure 11. In-pavement lighting improves the visibility of the crosswalk at night (Image: LightGuard Systems Inc.)

Evaluations have also shown that in-pavement warning lights reduce the speed of drivers approaching the crosswalk and reduce the number of drivers who drive over the crosswalk while pedestrians or bicyclists wait to start crossing. This treatment can be installed so the in-pavement warning lights can be triggered manually or automatically and then shut off after a set period of time. The lights are focused toward the approaching vehicles.

RRFB units are mounted on signposts in conjunction with crosswalk warning signs. The units have two rectangular yellow LED indicators, which flash rapidly in an alternating sequence. The flashing lights alert drivers of the presence of pedestrians or bicyclists crossing or waiting to cross the roadway. An evaluation of this safety treatment at a trail crossing in Florida indicates that occurrence of drivers yielding increased from 2 percent to 35 percent after the RRFBs were installed. The driver yield compliance increased to 54 percent when the lights were flashing. Prior to installation, 82 percent of pedestrians or bicyclists were

Figure 12. Example of a rectangular rapid flashing beacon (Image: TAPCO)

Figure 13. A green-colored travel lane for bicyclists (Image: blog.sfgate.com)

able to cross the entire intersection, while 18 percent had to stop in the middle and yield to oncoming drivers. After installation, 94 percent were able to cross all the way while only 6 percent had to stop in the middle.

Bike lanes are created to provide a portion of the roadway for the preferential or exclusive use of bicyclists. The lanes are designated by pavement markings and signing to alert drivers to this area of the roadway and the potential for bicyclists to be present adjacent to travel lanes. Evaluations indicate that this defined area helps drivers and bicyclists stay in more central positions in their respective lanes. This has the effect of maintaining an appropriate separation between the travel modes and reducing the collisions caused by drivers swerving into an adjacent lane to pass bicyclists.

To enhance the ability to alert drivers to the potential presence of bicyclists, green-colored pavement is an infrastructure treatment that indicates a portion of the roadway is designated for exclusive or preferential use by bicyclists. To maximize the ability to alert drivers, the colored pavement is only used where bike lanes cross the path of drivers and where drivers should yield to bicyclists. Examples of these conflict areas include where a bike lane extends through an intersection, where a bike lane crosses a right-turn lane, where a channelized right-turn lane crosses a bike lane, or where a bike lane is adjacent to a dedicated bus bay. The colored pavement supplements traditional bike lane pavement markings. ■

CASE 4: In Work Zones

Not only do the driving conditions of work zones differ from normal driving conditions, but the complexity of roadway work zones differs between locations based on the construction or maintenance activity (short-term, long-term, lane closures, shoulder closures).

Advance warning signs alert drivers of an upcoming work zone. Arrow boards identify lane closures and inform drivers of required merging maneuvers. Traffic control devices such as signs, pavement markings, barriers, drums, and tubular markers guide drivers along the correct path and assist them to maintain their vehicles in the appropriate lane through the entire work zone.

Well-maintained devices that are clean, retroreflective, positioned appropriately, and free from damage and wear and tear provide better guidance to drivers, particularly during nighttime or adverse weather conditions. Unquestionably, the better guidance afforded drivers helps reduce the potential for collisions before, within, and after work zones.

Speed-feedback display signs immediately alert drivers if they are driving too fast. These signs typically light up if the vehicle speed is 5 miles per hour (or a set speed) over the posted speed limit. Furthermore, pavement markings define the area of travel through a work zone for drivers, thereby separating vehicles between lanes and from nonmotorized users. Longitudinal guidance is also provided with drums and delineators, the spacing of which can be increased or decreased depending upon the degree of driver guidance required. ■

Figure 14. Longitudinal channelizers in Washington, D.C. (Image: Plastic Safety Systems Inc.)

CASE 5: Brighter, Wider, High-Visibility Pavement Markings

Roadway-departure crashes represent a significant safety concern, particularly in rural locations and at night.

Although many of these crashes are single-vehicle run-off-the-road crashes, they also include vehicles that leave their lane and crossover into oncoming traffic. During reduced visibility, nighttime, and in wet weather, drivers require additional assistance in identifying and maintaining their travel lane to drive confidently and safely. Effective pavement markings significantly assist the driver in making important driving decisions, which contributes significantly to roadway safety for all motorists.

Figure 15. Yellow spray thermoplastic edge lines being applied to an interstate highway near Raleigh, N.C. (Image: ATSSA Pavement Marking Division)

Highly visible, retroreflective pavement markings address traffic crashes by providing a more clearly marked roadway to enable drivers to identify and maintain their lane.

Options in pavement markings include higher-contrast markings, higher-profiled markings in wet environments, wider, more visible markings, the use of higher-retroreflective materials (glass bead and larger reflective elements) and raised pavement markers. Each of these strategies offers significant improvements over standard markings, particularly at locations that may require enhanced delineation, such as curves.

Additional details on pavement markings can be found in the Manual on Uniform Traffic Control and in the Roadway Delineation Practices Handbook.

Wider pavement markings are effective in improving safety. Data from New York state revealed a 10 percent decrease in total crashes and a 33 percent decrease in fixed-object crashes. This was observed when 8-inch-wide pavement markings were used as opposed to standard 4-inch-wide markings.

Similarly, the Texas Transportation Institute (TTI) found that in Michigan, wider markings produced reductions for all crash types, including a 24.6 percent reduction in fatal and injury crashes, a 39.5 percent reduction for crashes at night and a 33.2 percent reduction in wet crashes at night.

Figure 16. Glass beads being applied during a double-yellow-centerline plural-component epoxy application (Image: ATSSA Pavement Marking Division)

The dimensions of wider markings can vary, ranging from 5 inches to 8 inches, with 6 inches being the most commonly used according to a TTI study. The cost of a wider pavement marking is generally 20 percent to 50 percent higher than standard markings, which can cost between 10 cents and $2.35 per foot, depending on the location and materials, which may include paint, thermoplastic plural-component epoxies and polyureas, and preformed tape.

Raised pavement markers are reflective markers that are used on longitudinal lines to provide additional visibility and delineation and can also provide an auditory warning when driven over. These markers can be installed in a raised position on the pavement or in a recessed groove within the pavement to allow for snowplowing in winter months. Positioning longitudinal pavement markings in recessed grooves also protects the reflective glass beads or other reflective media from snowplow damage and excessive tire wear, thereby enhancing the service life of the marking.

Even where standard, nonreflective pavement markings may be used, they have been shown to have a positive effect on safety. Using data from a number of different states, it was found that an average crash reduction of 21 percent can be attributed to pavement markings.

The addition of an edge line, where one is not already present, has also been shown to be a low-cost solution that improves safety and should be considered by local jurisdictions — especially those with numerous rural roads.

Figure 17. Fresh pavement markings safely guide motorists on a rural Virginia road (Image: James Scott Baron, ATSSA)

All pavement markings can be beneficial, but by their nature, they will wear out, fade, and lose their effectiveness over time. It is critical that agencies have a plan in place to maintain pavement markings and upgrade them when necessary to maintain the greatest roadway safety impact. The plan should consider traffic conditions, environmental conditions, and potential safety needs.

Whenever pavement markings are installed or rehabilitated, they should incorporate retroreflectivity performance to the greatest extent possible for the safety of all motorists. For some types of markings, such as liquid pavement markings (paint, plural-component epoxies, polyureas, and thermoplastic), this is achieved by adding highly reflective glass beads onto the liquid binder. For other types of markings, such as preformed tape, the pavement marking material already contains retroreflective beads that are built into the product. ■

Part II: Providing Positive Guidance and Enhancing the Infrastructure to Prevent Collisions

CASE 6: Skid-Resistant Surfaces and the Safety Edge$_{SM}$

Skid-resistant roadway surfaces help a vehicle's tires maintain contact with the road through horizontal curves and in curves at inappropriately high speeds. High-friction surface treatments (HFST) can also help prevent the vehicle from departing the roadway.

Figure 18. HFST in Placer County, Calif. (Image: Richard J. Baker, DBi Services)

HFST is a thin layer of durable aggregates (typically calcined bauxite) that is highly resistant to "polishing" or wear. The aggregate is bonded to the asphalt, concrete, or other pavement surfaces using polymer binders.

When this treatment was applied to 75 Kentucky locations in 2010, roadway-departure crashes decreased by 91 percent in wet weather and 78 percent in dry weather conditions.

Another low-cost roadway safety improvement that helps prevent crashes is the Safety Edge$_{SM}$, which provides an opportunity for a driver who has drifted off the pavement near a vertical edge drop-off to return to the pavement safely before a crash occurs. This feature is extremely effective on rural roads with unpaved shoulders.

This treatment mitigates the vertical elevation difference by sloping the edge of the pavement to 30 degrees during paving or resurfacing projects.

An evaluation conducted at 261 treated sites (685 miles) in Georgia and 148 sites (514 miles) in Indiana showed a 5.7 percent reduction in total crashes, based on crash data of six years before and three years after resurfacing the study sites in Georgia and those of two years before and three years after in Indiana. This low-cost roadway safety treatment also resulted in high benefit-cost ratios, based on crash reductions. ■

Figure 19. Federal Highway Administration's (FHWA's) Andy Mergenmeier and Chris Wagner gathering data on a new Safety Edge$_{SM}$ project (Image: Frank Julian, FHWA)

Figure 20. Note the tire tracks on the shoulder and onto the roadway. The edge of the Safety Edge$_{SM}$ remained unharmed after being crossed by a fully loaded asphalt truck during road construction (Image: Frank Julian, FHWA)

CASE 7: Flexible Channelizing Devices

Drivers can become overwhelmed with the number of choices and decisions when navigating through the roadway environment. The likelihood of crashes increases for all drivers—especially inexperienced and older drivers—as that number of choices increases. There are several low-cost, easy-to-install safety improvements that can help ease the driving task by eliminating some choices at specific locations or by spreading the decisions into multiple locations within a short period of time.

Flexible channelizing devices aid drivers by providing positive guidance, restricting movements, or discouraging illegal or unsafe maneuvers. While delineators indicate roadway alignment, channelization devices supplement pavement markings and delineation.

Flexible channelizing devices were initially installed at highway-railroad crossings to discourage motorists from driving around lowered gate arms. State departments of transportation, such as North Carolina, Florida, Arkansas, and Michigan, have implemented and documented their experiences with these devices at highway-railroad crossings and have found that violations (drivers driving in the opposite lane to maneuver around lowered gate arms) decreased approximately 80 percent.

Flexible channelizing devices can also be installed to close median openings, thus managing access. This application further enhances roadway safety by eliminating more complicated left turns that require drivers to determine appropriate turning gaps in oncoming traffic.

When installed to minimize median crossings at traffic islands, channeling devices enhance safety by discouraging drivers from attempting illegal turns. For example, the Florida Department of Transportation installed flexible channelizing devices at 16 full median openings between March and September 2007. This resulted in eight fewer crashes per year per location, with an associated net construction cost savings of approximately $125,000 per location.

Another use of flexible channelizing devices to promote drivers to stay in their lane is along the pavement markings that designate high-occupancy vehicle lanes. This vertical barrier encourages driver compliance more effectively than pavement markings alone. The device spacing can be increased or decreased, depending upon the violation rate. An added benefit is that the flexibility of the devices enables easier access for emergency vehicles into the lane.

An additional application for these devices is along right-turn lanes and in merge areas. The vertical markers cue drivers to stay in the lane for the distance required to decelerate or accelerate to the appropriate speed. This reduces the number of decisions that drivers need to make, helping them to focus on turning after decelerating or merging into traffic after accelerating. When used in this manner, the devices are also known as lane separators. ■

Figure 21. Flexible channelizing posts at a railroad crossing, Washougal, Wash. (Image: Pexco LLC)

Figure 22. Flexible channelizing devices (Image: Pexco LLC)

Figure 23. Flexible channelizing devices (Image: Pexco LLC)

CASE 8: Offset Right and Left Turns

Another roadway safety improvement that provides guidance to drivers is offset right- and left-turn lanes.

To create an offset, the turn lane is moved laterally, so vehicles in opposing traffic lanes do not obstruct the view of the turning driver.

A clear line of sight assists left-turning drivers by identifying an appropriate gap in oncoming traffic in which to turn, thereby reducing the potential for a collision between a turning vehicle and an oncoming vehicle.

This safety improvement is appropriate for both unsignalized and signalized intersections.

The benefit of reconfiguring 12 intersections in Wisconsin proved to be twice the construction cost of offsetting the left-turn lanes. A reduction in total, injury, left-turn and rear-end crashes was achieved at these locations through the use of this roadway safety improvement.

An offset right-turn lane is an infrastructure treatment that assists drivers on the stop-controlled, minor-road approach to an expressway intersection.

The right-turn lane on the expressway is offset laterally to provide the driver stopped on the minor road with a clear line of sight to oncoming vehicles on the expressway. By eliminating the view obstruction caused by the presence of right-turning vehicles in a conventional right-turn lane that is adjacent to the expressway through lanes, this infrastructure treatment assists drivers with identifying an appropriate gap through which to enter the nearside expressway intersection. This guidance also reduces the potential for a nearside right-angle collision between vehicles turning or crossing from the minor road and through vehicles on the divided highway.

An evaluation of this treatment using a brief period of post-installation data at two locations in Iowa and one in Nebraska indicates that this can be an effective roadway safety treatment for reducing nearside right-angle collisions.

One Iowa site achieved a 44 percent reduction in these types of crashes, while a Nebraska site had a total reduction of right-angle collisions. A reduction was not achieved at an Iowa site; however, this result could be attributable to a narrow median and alignment issue. ■

Figure 24. An offset turn (Image: Sean Coyle, Illinois Department of Transportation)

CASE 9: Pedestrian Refuge Islands and Bump-Outs

Pedestrian refuge Islands located in roadway medians provide positive guidance to both pedestrians and drivers and reduce the potential for pedestrian-vehicle collisions. In addition to identifying an appropriate crossing location, these islands reduce the complexity of the task and decision-making effort required by pedestrians to allow them to cross one direction of traffic at a time.

The refuge island and the associated crosswalk markings provide guidance to drivers and enhance the visibility of and expectation for a pedestrian in the roadway. Flexible channelizing devices and RRFBs can also enhance the visibility of pedestrian refuge islands and provide further guidance to drivers regarding the presence of pedestrians.

After installation of refuge islands and flashing beacons along State Route 92 in Florida, 85 percent of drivers yielded to pedestrians present in the crosswalks. National experience suggests refuge islands may reduce pedestrian crashes by 46 percent and motor vehicle crashes by up to 39 percent.

Curb extensions are another infrastructure treatment that provides positive guidance to both pedestrians and drivers and reduces the potential for pedestrian-vehicle collisions. By extending the sidewalk into the parking lane at corner and mid-block pedestrian crossing locations, this treatment enhances the visibility of pedestrians for drivers and encourages drivers to decrease speed. Like the refuge islands, curb extensions help to channel pedestrians to appropriate, safe crossing locations. ■

Figure 25. An Asheville, N.C., mid-block pedestrian crossing with a pedestrian refuge island (Image: Lyubov Zuyeva)

Figure 26. Reflective material on the concrete curb below the sign and its post alerts motorists there is a curb on the roadway (Image: Professional Pavement Products)

CASE 10: Wrong-Way-Driving Incident Detection

Wrong-way driving may be caused by a variety of factors including distraction, confusion, and impaired driving.

Wrong-way driving incidents are more likely to occur at night by younger drivers that are speeding or by motorists impaired by drugs, alcohol, or a combination of both. Occasionally, older drivers may be confused by lack of signing or pavement markings and inadvertently proceed on a roadway in the wrong direction.

Wrong-way driving may be reduced or eliminated—or the frequency and severity of associated crashes may be minimized—through the installation of infrastructure treatments aimed at preventing driver error or correcting an error once it has occurred.

Intelligent transportation system (ITS) technologies can effectively detect a wrong-way driver and warn both the wrong-way driver and other motorists about the presence of an errant vehicle.

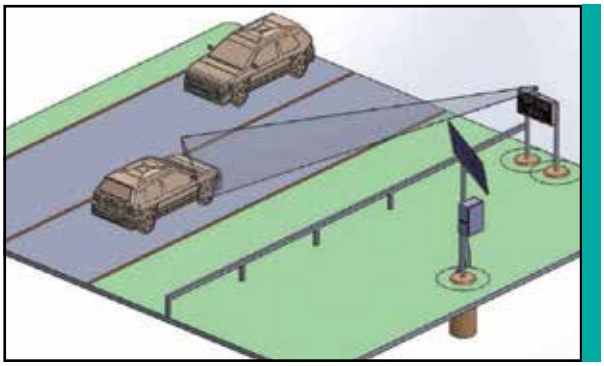

Figure 27. Conceptual rendering of the New York Thruway Wrong-Way Entry ITS Warning System (Image: Fiberdyne Labs Inc. and Herkimer Industries)

These detection systems provide the ability to determine exactly where vehicles are entering the roadway in the wrong direction. Once detected, drivers are alerted through the use of in-pavement warning lights, flashing Wrong Way signs, vertically mounted warning lights, and dynamic message signs displaying messages such as “Wrong Way Driver Ahead” or “All Traffic Move to Shoulder and Stop.”

The Harris County Toll Road Authority (HCTRA) in Texas also dispatches law enforcement personnel to intercept errant drivers. Law enforcement officers there have successfully intervened in 19 of the 30 wrong-way-driving incidents detected by HCTRA in 2012, preventing collisions. ■

Figure 28. Wrong-Way Entry ITS Warning System on the New York Thruway (Images: New York State Media Services Center)

CASE 11: In Work Zones

The safety of all motorists and roadway workers must be considered while roadways are under construction.

Infrastructure safety improvements can help minimize worker exposure to vehicles outside of the work zone, and other improvements can also be applied inside the work zone to enhance worker visibility for drivers.

To minimize worker exposure, longitudinal barriers provide a continual separation area between the travel lanes and the work zone.

An errant vehicle that strikes the barrier is safely redirected back into the travel lane, thereby preventing an intrusion into the work zone. These temporary barriers are also movable, so they can be deployed as necessary in response to changing traffic patterns or conditions throughout the work zone. They are made of concrete or plastic, capable of being filled with water to add weight and stability.

Positive guidance can also be provided to motorists when work-zone personnel wear light-colored clothing, hard hats, and—most importantly—retroreflective garments to improve visibility in both day and nighttime conditions.

Construction and maintenance equipment can be made more visible with bright paint colors, conspicuity tape, lights, or retroreflective materials. In addition, backup alarms increase both road-user and worker awareness of work-zone vehicles. ■

Figure 29. Longitudinal channelizers in Adair Village, Ore. (Image: Plastic Safety Systems Inc.)

Figure 30. A road worker in a retroreflective vest and hard hat, Manassas, Va. (Image: James Scott Baron, ATSSA)

Part III: Minimizing Consequences When a Vehicle Leaves the Road

According to the FHWA and as reported in the Fatality Analysis Reporting System (FARS) database, approximately 57 percent of motor vehicle traffic fatalities that have occurred annually in the United States in recent years are due to roadway departure.

The probability for roadway-departure crashes to have severe outcomes depends on side slopes, fixed-object density, offset to fixed objects, and shoulder width. Collision with a fixed object is usually identified as the first harmful event in run-off-road crashes.

After a vehicle leaves the roadway, roadway safety improvements, such as those defined in this booklet, can help prevent or reduce the severity of a collision. Several options provide the ability to enhance safety by minimizing the consequences of a driver action that causes a vehicle to depart the roadway.

CASE 12: Cable Median Barriers, Guardrails, and Crash Cushions

Figure 31. Installed cable median barrier (Image: Gibraltar)

Figure 32. A low-speed crash into a cable barrier system yielded a textbook vehicle capture (Image: Gibraltar)

A Safety countermeasure that significantly reduces crash severity is cable median barrier.

When installed correctly in between opposing directions of traffic, the cable median barrier can redirect a vehicle back toward the intended travel lane to help prevent deadly head-on collisions. A collision still occurs between the errant vehicle and the cable barrier, but the outcome is likely to result in property damage only and not an injury or fatality as a result of a head-on collision. Also, cable median barrier can prevent a vehicle from traveling across the oncoming lanes and striking fixed objects alongside the roadway.

Several state departments of transportation (including Illinois, Minnesota, and Missouri) determined there was an elimination of cross-median crashes and a reduction in the severity of roadway-departure crashes due to the installation of cable median barrier along several of their state highways.

Cable barriers are often times used in the median where there is space to accommodate these devices. Often times, site conditions will require a semi-rigid post and beam guardrail system such as the MASH tested W-Beam. W-Beam barriers have been successfully used since the Interstate System was built in the 1950's. With slight modifications, modern-day W-Beam is versatile enough to remain crashworthy with the higher center-of-gravity passenger vehicles seen on America's roadways today.

Another safety countermeasure that can help reduce crash severity once a vehicle has left the roadway is an impact attenuator, or crash cushion.

Crash cushions are protective systems that prevent errant vehicles from impacting objects or individuals (work-zone workers). These devices also reduce damage to structures, equipment, and vehicles by absorbing the colliding vehicle's energy and smoothly decelerating the vehicle to a safe stop when it impacts the crash cushion. ■

Figure 33. Note the skid marks of the vehicle that struck this guardrail. Crashes such as this are often unreported, especially if the vehicle operator can drive away. A dedicated, stable source of federal funding is important to ensure that these life-saving safety devices are repaired in a timely manner (Image: Karen Boodlal, KLS Engineering)

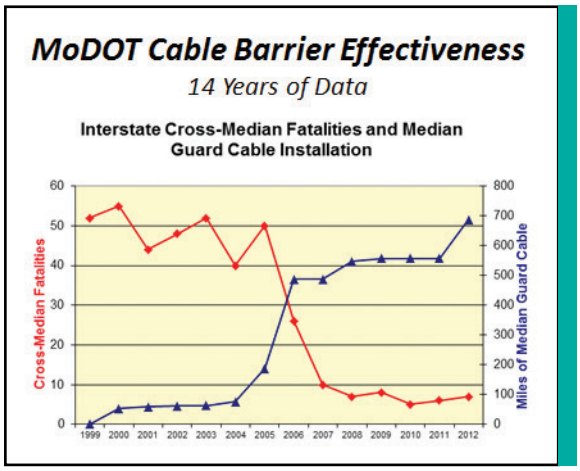

Figure 34. MoDOT cable barrier effectiveness (Image: John P. Miller, Missouri Department of Transportation)

Figure 35. Newly installed crash cushion (Image: Trinity Highway Products)

CASE 13: Alarms, Platforms, and Temporary Attenuators in Work Zones

The complexity of the driving conditions in a work zone can lead to driver errors that result in potential risk to work-zone workers themselves. Roadway safety infrastructure improvements can help increase the visibility and the overall safety within the work zone to help minimize driver error.

Intrusion alarms, for example, notify work-zone workers when an errant vehicle has left the travel lane and has entered the work area. This audible notification provides an additional window of time for workers to safely move to a protected location. Some alarms can also sound when impacted or when a detector is triggered.

Figure 36. This portable worker alert system provides a warning to road workers in the event a vehicle enters the work zone (Image: Astro Optics LLC – a TAPCO company)

Protection for work-zone workers who install and remove signs, drums, and other devices can sometimes be provided via an appropriate, safe truck platform. This worker-protection method of placing or retrieving traffic control devices on roadways helps reduce worker exposure to traveling vehicles and thereby reduces the potential for work-zone incidents and crashes.

Temporary attenuators can be used for road construction projects to protect motorists and work-zone workers. One example is a truck-mounted attenuator (TMA).

TMAs are energy-absorbing safety devices that attach to the rear of a work truck to help prevent rear-end collisions between slow-moving or stopped work vehicles and traveling vehicles. As a protective shield, TMAs benefit workers and the motoring public when construction or maintenance activities occur adjacent to active traffic lanes.

An analysis of potential rear-end crashes in mobile and short-duration operations found TMAs to be highly effective in reducing the severity of rear-end crashes and the associated crash costs.

In California recently, both a California Department of Transportation (Caltrans) employee and a motorist were spared a severe outcome when a passenger vehicle traveling at a high rate of speed departed its travel lane and struck a Caltrans truck involved in snow removal operations in the left shoulder of Interstate 80. The photos in Figure 37 show the results of that crash. ■

Figure 37. A TMA following impact by an automobile (Image: TrafFix Devices Inc.)

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